UNIVERSITY OF EAST SARAJEVO

FACULTY OF MECHANICAL ENGINEERING

4th INTERNATIONAL SCIENTIFIC CONFERENCE



COMETa2018

„Conference on Mechanical Engineering Technologies and Applications“

PROCEEDINGS

27th-30th November

East Sarajevo-Jahorina, RS, B&H

COMETa 2018
4th INTERNATIONAL SCIENTIFIC CONFERENCE
27th - 30th November 2018
Jahorina, Republic of Srpska, B&H
University of East Sarajevo
Faculty of Mechanical Engineering
Conference on Mechanical Engineering Technologies and Applications

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PREFACE

Faculty of Mechanical Engineering East Sarajevo is organizing the 4th International Scientific Conference COMETa 2018 - "Conference on Mechanical Engineering Technologies and Applications". The aim of the conference is to contribute to the implementation of new technologies in production processes by achieving better cooperation between scientific research institutions and companies, and to enable practical application of research results presented in the proceedings.

The main objective of the conference is to bring together eminent domestic and international experts in the field of engineering and the application of new technologies and the development of mechanical systems, and to contribute increasing the competitiveness of the domestic economy through the exchange of experience and knowledge, public presentations of current research and new construction solutions.

The organization of previous conferences COMETa2012, COMETa2014 and COMETa2016, according to the assessments of participants, especially foreign colleagues, were successful.

The efforts were recognized by the Ministry of Science and Technology of the Republic of Srpska, since in May 2018 the COMETa conference was ranked among international scientific conferences of the first category.

The COMETa 2018 conference program consists of the following thematic areas:

- *Manufacturing technologies and advanced materials,*
- *Applied mechanics and mechatronics,*
- *Machine design and product development,*
- *Energy and environmental protection,*
- *Maintenance and technical diagnostic,*
- *Quality, management and organization.*

At this year's COMETa2018 conference, a record number of papers from the country and abroad have been submitted. In total 277 authors from 13 countries participates in the international conference COMETa2018, 112 papers were accepted, including 4 plenary papers. Within the COMETa2018 conference, it is planned to organize two working meetings that will focus on the current topics of the Conference.

With the desire to improve the organizational as well as the scientific effect of the Conferences, and appreciating the contributions made by the scientific community in this way, we want to emphasize that each of your suggestions is more than welcome and will be appreciated in connection with the above.

On behalf of the Organizing and Scientific Committee of the COMETa2018 conference, we would like to express our gratitude to all authors, reviewers, institutions, companies and individuals who contributed to the Conference.

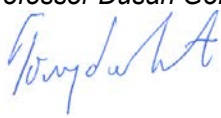
Hoping that the results of our joint work will meet expectations, the organizer of the Conference, Faculty of Mechanical Engineering East Sarajevo, wants you active participation that will contribute to the development of modern ideas and solutions, in the spirit of technical and technological development of the modern world.

We wish you a pleasant stay in Jahorina. Welcome to the COMETa2018 conference.

East Sarajevo, November 21st, 2018.

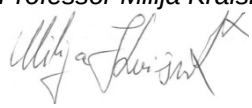
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MACHINE TOOLS AND INDUSTRY 4.0 - TRENDS OF DEVELOPMENT

Saša Živanović[1], Slobodan Tabaković[2], Milan Zeljković[3]

Abstract:Primary goals of trends of digitalization in the Industry are increasing of efficiency, productivity and quality of product. As a basic unit of modern manufacturing industry, numerical controlled machine tools have important role in industrial digitalization. Their improvement trough implementation of digitally connected components and subsystems enables a creation of an adaptive mechatronic system which can be a part of connected production system. This paper describes some of the key and desired characteristics of Machine Tool 4.0 such as Cyber-physical Machine Tools, vertically and horizontally integrated machine tools and more intelligent, autonomous and safer machine tools.

Key words: Cyber-physical systems (CPS), Cyber-physical machine tools (CPMT), Industry 4.0, Machine tools

1 INTRODUCTION

The continuous development of technologies and society is enabled by intensive developments improvement of production technologies. This applies in particular to the development of machine tools as a basis of industrial technological systems of today [1].

Intensive development of technology with integration of information systems into all elements of society at the beginning of the twenty-first century has significantly influence in development of the society, globalization and market demands.It could be seen basis on changing the product life cycle of on market, intensive using the new materials and with an increasing trend towards the personalization of products. That caused intensive structural and functional changes in whole industry. As a good example for mentioned above could be taken a time reducing trends between significant conceptual changes in industrial production, popularly called industrial revolutions (Fig. 1). As well evolution of machine tools follows this trend, but it does not match completely with time period and time intervals until the occurrence of significant changes in development of machine tools, are shorter.

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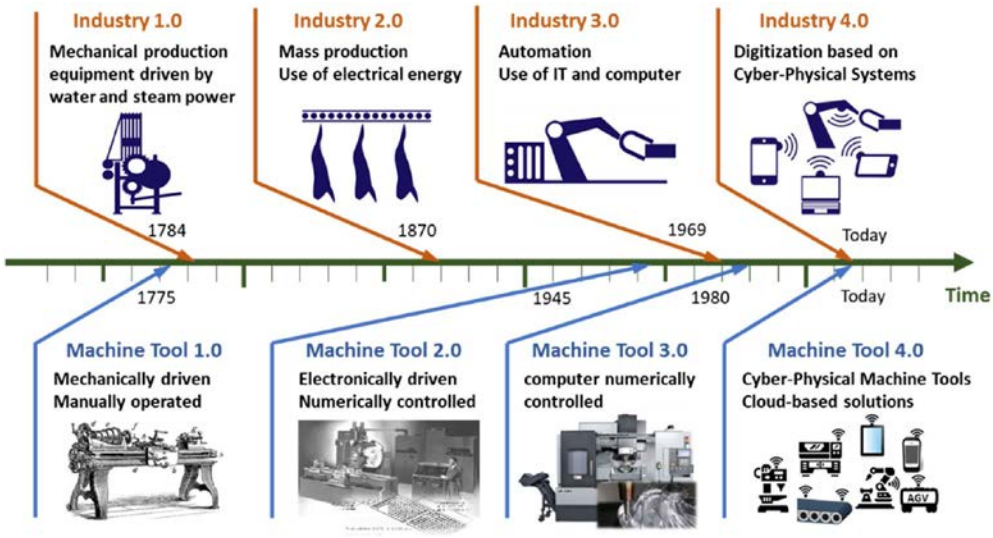


Figure 1. *Evolutionary history of industrialization and machine tools [3]*

In the past five years, several industrial initiatives such as “Industry 4.0”, “Industrial Internet of Things”, “Factories of the Future” and “Made in China 2025”, have been announced by different governments and industrial leaders [2]. This initiative is stimulus for improvement of production systems and machine tools with high degree of intelligence and autonomy. The evolutionary history of machine tools has significantly affected the history of industrialization. As shown in Fig. 1, while industrialization can be briefly divided into four industrial revolutions, i.e. Industry 1.0 (mechanization, end of 18th century), Industry 2.0 (mass production, start of 20th century), Industry 3.0 (automation and IT, start of 1970s) and Industry 4.0 (Cyber-Physical Systems-based digitization, present time) [3].

History of evolution of machine tools is presented in Fig. 1. They can be presented trough four phases: (i) Machine Tool 1.0 (mechanically driven but manually operated, end of 18th century), (ii) Machine Tool 2.0 (electronically driven and numerically controlled, middle of 20th century), (iii) Machine Tool 3.0 (computer numerically controlled, late 20th century) and (iv) Machine Tool 4.0 (Cyber-Physical Machine Tools and cloud-based solutions, present time) [3].

As is stated in [2] it is predicted that current CNC machine tools are not intelligent and autonomous enough to support the smart manufacturing systems envisioned by the aforementioned initiatives. Inspired by recent advances in Information and Communication Technology (ICT) such as Cyber-Physical Systems (CPS) and Internet of Things (IoT), a new generation of machine tools, i.e. Machine Tool 4.0, represents a future development trend of machine tools for Industry 4.0. The Industry 4.0 as the new industrial revolution we are experiencing is predicted to be based on the advances of ICT such as CPS, IoT and cloud computing [2, 4].

2 EVOLUTION OF MACHINE TOOLS FROM MT1.0 TO MT4.0

Much like the different stages of industrialization, machine tools have also gone through different stages of technological advancements, from Machine Tool 1.0 (MT1.0)

to Machine 4.0 (MT4.0). Industrie 4.0 pleads for a new generation of machines—Machine Tool 4.0. Figure 2 shows the evolution of machine tools from MT 1.0 to MT 4.0.

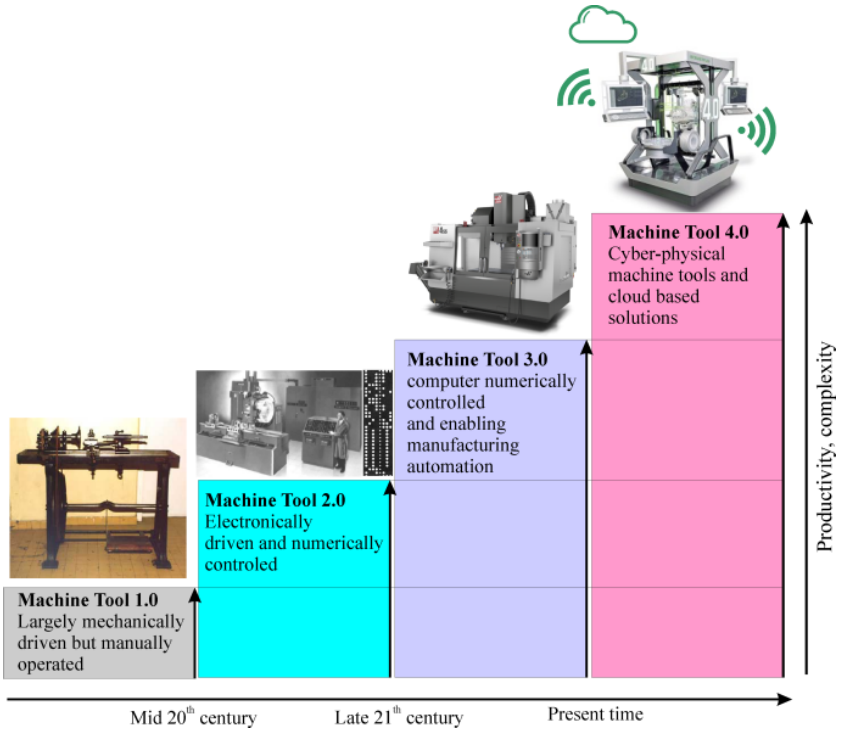


Figure 2. *From MT1.0 to MT 4.0*

2.1 Machine Tool 1.0 (1775-1945)

Machine tools besides the steam engine are the driving force of the industrial revolution. They had been existed before industrial revolution, but development of steam energy made possible to building the machine tool in today's form. Therefore, 1800 years is considered as the year of development modern machine tools.

The first machine tools offered for sale (i.e. commercially available) were constructed in England around 1800. During this time, both Henry Maudslay and Joseph Whitworth were responsible for dramatically advancing the accuracy of the machine tools [5].

In the early twentieth century, automobile industry dominantly influenced in further machine tool development in terms of rapid progress of standardization and the advances of machine tool design and construction. The machine tools up till this time were mostly manually operated with some form of mechanical assistance for high precision machining. These machine tools still required a great deal of skills and experiences to operate [2, 6].

2.2 Machine Tool 2.0 (1945-1980)

Since the late 1940s, machine tools had experienced a significant advancement in motion actuation and control, i.e. the development and deployment of numerical control (NC), and the gradual shift from mechanical to electronic actuations in general [2,6].

The first NC machines were designed for manual or fixed cycle operations at the Massachusetts Institute of Technology in the late 1940s [7]. These machines had electronically driven and numerically controlled, though only for positioning the workpiece relative to the tool. Considerable time was saved, but yet the operator had to select the tools, speeds and feeds. Later, the enhanced NC machines enabled material removal to occur at the same time as the control of the workpiece/tool movements [2, 6].

These NC machines were also termed tape-controlled machines, because the information was stored on either punched card/tape or magnetic tape [2, 6, 8]. It was difficulty to edit and change the programs at the machine, the machines had only very limited memory capacity. In any case, in comparison with the conventional manually-operated machine tools (MT1.0), the advantages of NC machine tools (MT2.0) are multiple.

2.3 Machine Tool 3.0 (1980-)

The accelerated advancement of computers, around the 1970s, has resulted them being used in assisting NC machines, which led to the birth of Computer Numerical Control (CNC) machine tools. Around 1980th for controlling the machine tools computers was successfully used, thereby forming a CNC machine tool. CNC machine tool is part of machining system which is guided with alphanumeric geometrical and technological data's of part which should be produced on the machine [9].

Controller is configured for every machine itself, by adjusting the specific operating system parameters of the computer which running the machine. Contour machining was begun to be common and servosystem were used. In programming were used programming languages, and then the first CAD/CAM version of systems.

Using of CNC machines has radically improved industrial production. Curves are as easy to cut as straight lines; complex 3-D structures are relatively easy to produce; and the number of machining steps that require human action is dramatically reduced. CNC automation also allows for more flexibility in the way that part programs for different components are quickly produced and executed on a single machine tool [2, 6]. The significance of CNC machines in fact goes much further beyond machines themselves. Several CNC machines can be tied together and/or controlled via a central computer to perform coordinated machining processes. This gives rise to Direct Numerical Control (DNC) and Flexible Manufacturing System (FMS) [10].

2.4 Machine Tool 4.0

Machine Tool 4.0 (MT4.0) defines a new generation of machine tools that are smarter, well connected, widely accessible, more adaptive and more autonomous [2,6]. MT 4.0 can be better used for predictive maintenance, increasing efficiency and process optimization.

Machine Tool 4.0, otherwise known as Cyber-Physical Machine Tool (CPMT), is the integration of machine tool, machining processes, computation and networking, where embedded computers and networks can monitor and control the machining processes, with feedback loops in which machining processes can affect computations and vice versa [2].

3 MACHINE TOOLS AND INDUSTRY 4.0

Industry 4.0 is the term given to the factory of the future and the shift toward using advanced technologies that are heavy on automation, data collection and

connectivity. In this new industrial world, everything will be connected through the internet and the cloud, enabling factories to function as a system rather than individual parts [11]. Machine tools will become a part of Industry 4.0 which will affect changes in them. These changes primarily relate to: (i) preventative maintenance, (ii) improved utilization, (iii) energy savings, (iv) avoiding improper use, (v) improved quality assurance and (vi) change in the role of humans.

One of the main characteristic of Industry 4.0 is data collection. Machine tools will have sensors that will collect many different kinds of data, including data on how much the machine has operated the conditions it has operated in and the condition of the components of the machine tool. By collecting and analyzing these data, machines could estimate when a component needs replacement. Predictive maintenance could keep machines running more efficiently and prevent downtime [11].

Research carried out over in the last few years has shown the fact that in industrial plants machine tools are used inefficiently. In the total time of machine tools using, machining takes less than 40% (in some cases less than 25%) of the time [11]. Improved utilization of machine tools is possible by collecting and analyzing data about things like tool changes, program stops and feed holds. Energy savings is important characteristic for smart new machine tools, which can also collect data on energy use to help save companies money.

Industry 4.0 will also help identify when machines are being used improperly. Machine can send out an alert if it detects conditions outside of norm of normal work. This could help prevent serious mistakes caused by human error or malfunction, which could avoid downtime as well as worker injury. One of the most important goals of Industry 4.0 in the area of machine tools is improvement of quality. In new machine tool is very important use of automation which also improves quality by reducing the natural variation that comes with human action.

Concept of Industry 4.0 will change basic role of human operators in Shopfloor. Many jobs will shift from physically operating to operating them via computers, monitoring data and providing oversight to automated operations. This will require some substantial retraining of human workers [11]. One of advantages of Industry 4.0 for workers is improved safety. Automatization allows to workers a surveillance job thereby decreasing a risk of human error.

Getting started with IoT, automatization and other benefits Industry 4.0, on the beginning looks frightening, but it should be started where is possible, so as not to be left behind for competition. Basic aims which should be achieved using Industry 4.0 principles are better information – better making decision and better achieved results.

4 CYBER-PHYSICAL MACHINE TOOL

In the era of Industry 4.0, inspired by advances in Information and Communication Technology (ICT), such as CPS (Cyber-Physical Systems), Internet of Things (IoT) and cloud computing, in [2] propose a new generation of machine tools – Cyber-Physical Machine Tools (CPMT) – as a promising development trend of machine tools. The definition of CPMT is given in section 2.4, while the four main components shown in Fig.3, from [1].

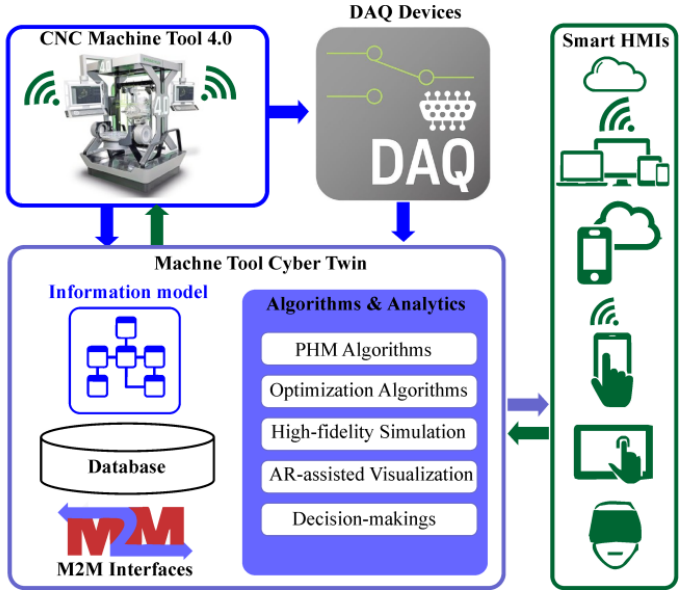


Figure 3. *Components and functions of Cyber-Physical Machine Tool*

Proposed CPMT [2] consists of four main components: (1) CNC Machine Tool, (2) Data Acquisition Devices, (3) Machine Tool Cyber Twin (MTCT), and (4) Smart Human- Machine Interfaces (HMIs).

(1) The CNC machine tool here it represents physical CNC machine tool including all components and subsystems, as well as the machining processes, with possibility of the integration of machine tool, machining processes, computation, networking, monitoring and control the machining processes, with feedback loops. Aiming to advance current CNC machine tools into a higher level of intelligence and autonomy, in researches [2, 3, 6, 12] proposes a new generation of machine tools, i.e. Cyber-Physical Machine Tools (CPMT).

(2) Data acquisition devices include various types of sensors, and are responsible for collecting real-time field-level manufacturing data from the critical components and machining processes such that important real-time manufacturing data generated during machining processes can be recorded and analyzed in the next stages [4].

(3) The Machine Tool Cyber Twin (MTCT), is the most significant difference between a CPMT and a traditional CNC machine tool. The MTCT, as a digital abstraction of the machine tool, has built-in computations that monitor and control the physical processes on the one hand, and provide the data to the cloud for further analysis on the other [12].

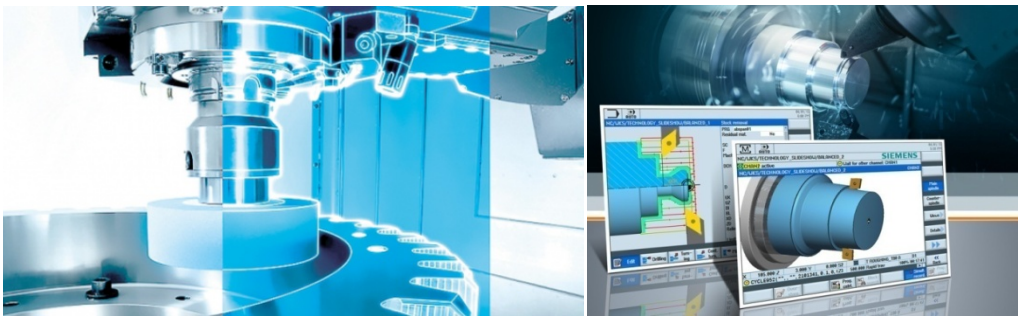
(4) Smart Human-Machine Interfaces should provide information's from machines with Internet based storage in form of a cloud. Commercial solutions of IIoT applications use two type of Cloud storage: private (with acquisitions software installed on premise) and public (where the software manufacturer is owner of the cloud).Smart HMIs allow users to intuitively interact with the system and make efficient decisions with the implementations of various network and interaction technologies [2].

5 TRENDS OF DEVELOPMENT

For the further development of machine tools in era of Industry 4.0 is crucially to using open platforms, standards and interfaces. Trends or fields of action for machine tool manufacturers are [13-19]:

- digitalization of CNC machines,
- MT integration-vertical and horizontal,
- Real-time manufacturing data acquisition,
- Data integration and communication,
- Intelligent algorithms and analytics,
- M2M communication,
- Advanced Human-Machine Interactions.

The digitalization of CNC machines, mills, and other factory production equipment is the future that the Internet of Things has been promising us [15]. Digitalization is a growing trend in the industrial space, and the process finding its way into every corner of the factory floor. The digitalization of machines can help engineers predict real world results and failures [15]. An example of real and digital machine tools (milling and turning) is shown in Fig.4.



a) real and digital milling Machine Tool [14]b) real and digital turning machine tool [15]

Figure 4. *The digitalization of machines can help engineers predict real world results and failures*

5.1 MT integration-vertical and horizontal

CPMT presents the class of machines with new level of integration, which can be horizontal or vertical.

Vertically integrated machine tools support the end-to-end digital integration throughout the engineering process which encompassing design, process planning, manufacturing, assembly etc. [6].

Typical model of the preparation machining process starts with CAD model of workpiece with an information about geometry, tolerance, material. Based on this model in CAM is chosen machine tool, tool, fixture and toolpath is generated, simulation of toolpath and/or removing material and postprocessing for translating into G code all information except axis movement is lost.

Today a new standard, known as STEP-NC (Standard for Product Model Data Exchange for Numerical Control), is being used as the basis for development of the next generation of CNC controller. These standards are ISO 14649 [20] and ISO 10303 AP 238 [21].

The STEP-NC AP238 standard is the result of a more than decade international effort to replace G code (ISO 6983 standard) with a modern associative language that connects the CAD design data used to determine the machining requirements for an operation with the CAM process data [22,23]. Classical programming is still the most commonly used way of programming and object oriented programming has not been introduced to the full extent. However, these two methods are simultaneously used as illustrated in Fig.5 [38].

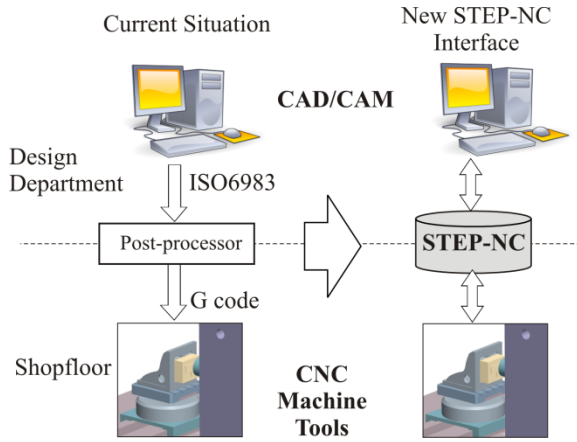


Figure 5. *Current G code and new STEP-NC interface for programming CNC machine tools [38]*

Unlike G-code, STEP-NC describes tasks which to be carried out (what-to-do information) instead of methods to do the job (how-to-do information) for a machine tool [6]. The STEP-NC provides new opportunities to support high level information from design to CNC controller. It allows bi-directional data flow between CAD/CAM and CNC without any information loose [23]. Therefore, STEP-NC is not machine-dependent. STEP-NC is fully compliant with STEP [24], which makes it possible to bring complete design data to the machine tool, hence enabling machine tools to be vertically integrated.

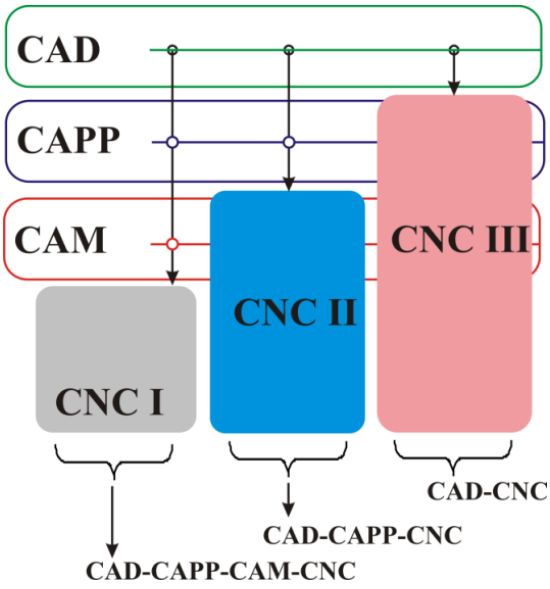


Figure 6. *Evolution of CNCs for vertical integration*

The illustration of the evolution of the CNC system is shown in Fig. 6, where CNC III represents the ultimate scenario for CNCs that are vertically integrated in such a way that they will act using STEP-NC standards as an interface between CAD and CNC.Such a move, or any other similar approach, effectively calls upon CNC controllers to embrace a brand new control language, and controller manufacturers to develop more robust, interoperable and intelligent CNC controllers [6].

Horizontally integrated machine tools are those interconnected among themselves as well as with other manufacturing facilities and resources (e.g. robots, conveyors, in situ measurement equipment and even MES (Manufacturing Execution System) and ERP (Enterprise Resource Planning) systems) to establish a cooperative production system [6].

There are some preliminary attempts by some controller manufacturers. CNC developer Siemens and robotic supplier KUKA teamed up to integrate KUKA's mxAutomation with the Sinumerik CNC platform [27], Fig 7. With such integration, the operator of the machine can run both the machine tool and robot from a single control panel [6].

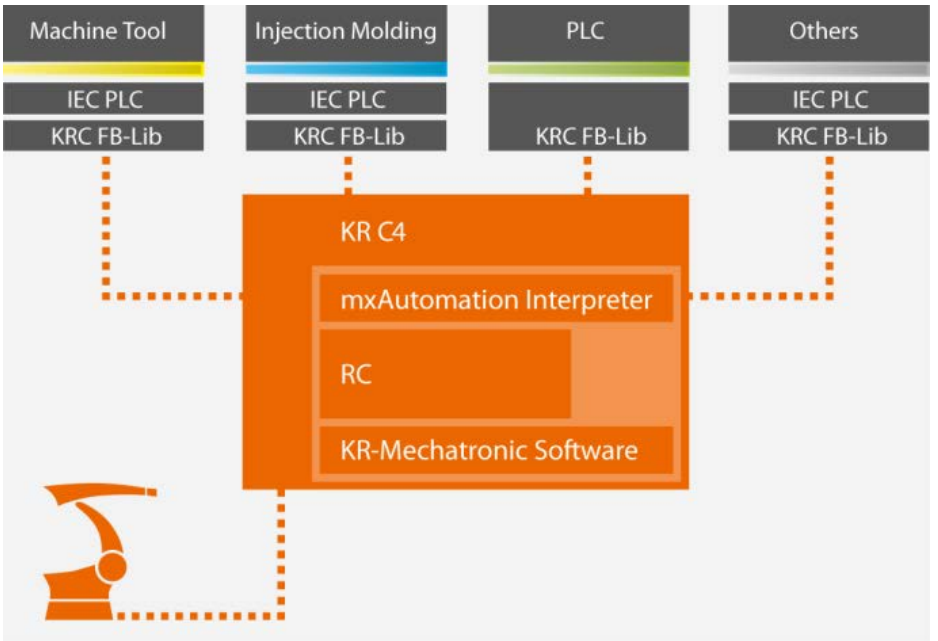


Figure 7. *Integration of Kuka robots in machine environment [25]*

The mxAutomation function package, KUKA.PLC mxA, makes it possible for external controllers with an embedded PLC to command KUKA robots on the basis of elementary motion instructions. This provides an easy route to implementing a central operator control concept for robot-automated production machines that is highly convenient for end customers [25].

A key requirement of CPMT is the ability to acquire accurate and reliable data from the machines and/or their components. The data might be directly measured by sensors or obtained from the controller. Considering various types of data, a seamless and tether free method to manage data acquisition procedure and transferring data to the central server is required where specific protocols such as MTConnect [6, 26].

Integration of machine tools with other industrial equipment is also a focus of the Industrial Internet Consortium (IIC) [27], which is formed in 2014 with an aim to accelerate the development, adoption and widespread use of interconnected machines and devices, and intelligent analytics [6].

5.2 Real-time manufacturing data acquisition

During the machining process every component or/and subsystem of machine tool generates huge amount data's in real time. Collecting this data's is precondition for achieving advanced functionality of new machine tools (CPMT) because thesedata's could have big influence on product quality, productivity and costs [2].

Although modern CNC controllers could directly provide some useful feedback data (e.g. spindle speed, axes position, etc.), some critical data that severely affect the manufacturing processes such as tool/workpiece/machine vibration, temperature, cutting force, etc. can only be acquired by deploying additional sensors [2,28].

With the rapid development of sensing technology, various sensors (e.g. force/torque, accelerometers, acoustic emission, motor power and current sensors, etc.) are available for extracting different data from the machine tool. A summary of real-time data acquisition technologies regarding process monitoring can be found in [28, 29].

5.3 Data integration and communication

Complexity of data's which are collected from different sources make integration this data's for the purpose of managing a serious challenge. There is an urgent need for a unified data exchange standard for the field-level manufacturing devices.

Currently, MTConnect and OPC-UA are both striving to solve this problem. MTConnect is a lightweight, open, and extensible protocol designed for the exchange of data between shop floor equipment and software applications [30]. OPC-UA is an open and royalty free set of standards designed as a universal factory floor communication protocol developed by the OPC Foundation [31]. MTConnect provides a bottom-up strategy which makes it easy to be implemented, but it is currently a read-only standard, which means it is only able to be used in reading data from the devices, but not writing to them. On the other hand, OPC-UA is a bidirectional standard which is able to be used for both monitoring and controlling [2].

5.4 Intelligent algorithms and analytics

To be apossible to use extensive data collected from the machine and machining process, it is necessary to have developed intelligent algorithms and methods for data analysis, which should be implemented in MTCT, whit what CPMT can get advanced autonomous functionality and possibility for making decision. Research in this area has always been current and active. To shorten machining time and increase product quality developed a Fuzzy logic algorithm that allows in-process feed-rate optimization [32]. Developed a System Manager algorithm to achieve high-fidelity machining simulation was realized by the utilization of STEP, STEP-NC and real-time monitoring data [33].

Although the research is very intensive in this field of study, much effort is still needed in developing efficient, accurate and reliable algorithms and data analysis methods in order to provide to a new machine a real intelligence.

5.5 M2M communication

Generally, M2M refers to the communications among computers, embedded processors, sensors, actuators, and mobile terminal devices without or with limited human intervention [34]. In the proposed CPMT, M2M communications include the communications between the machine tool and other field-level devices, for example robots, AGVs, workpieces, and so forth. M2M interfaces should allow the machine tool to exchange information with other devices so that they can actively monitor and control each other.

Research on M2M communication is still at the preliminary stage. Developing M2M interfaces for the proposed CPMT is a crucial and challenging task [6].

5.6 Advanced Human-Machine Interactions (HMI)

CPMT allows advanced human-machine interactions. Smart, mobile, networked and context-sensitive HMIs need to be developed to provide users with: (i) comprehensive and intuitive perception of the CPMT, (ii) ubiquitous access to the real-time information and applications, as well as (iii) instant and distributed decision making support [2].

6 CHALLENGES FOR MACHINE TOOL

Machine tools producers follow the machine tools development trends according to Industry 4.0,and in this chapter some of actual example will be shown. Mazak is presented challenges in development of large machine tools [19], which can be listed: (i) thermal compensation, (ii) volumetric compensation, (iii) additive manufacturing AM, (iv) hybrid manufacturing, (v) multi-tasking machine, etc.

In the **thermal compensation** of the errors in machine tools include sensors are positioned on the machine structure and the spindle and feedback data to the CNC, which then compensates for axis positions accordingly (Intelligent Thermal Shield), Fig.8.

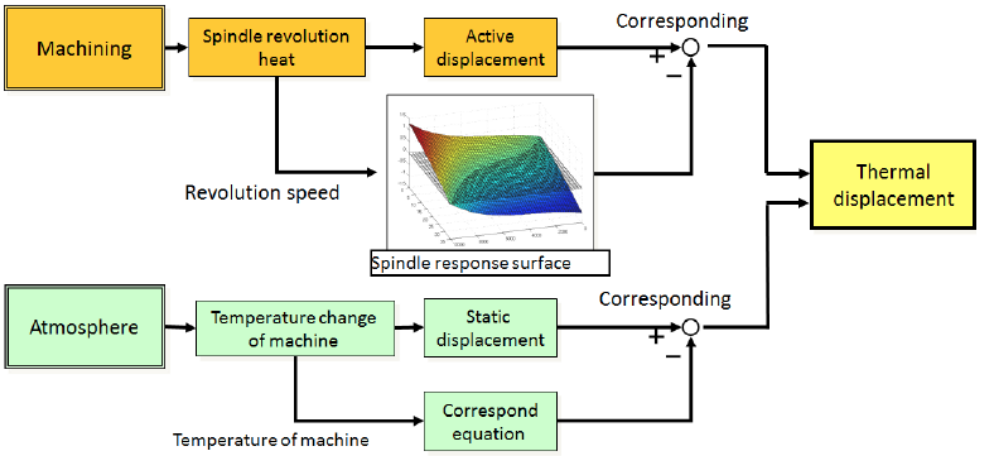


Figure 8. *Thermal compensation [19]*

Volumetric error compensation is a method of compensating the axes of a machine tool to remove geometric errors in positioning. This type of compensation produces a machine geometric performance, which is consistent throughout the whole volume of the machine tool. Major manufacturers of CNC control units as are: Siemens, Fanuc, Heidenhain and Mazak have optional function for volumetric error compensation. Calibration is carried out with an Etalon laser tracker system but it is a time consuming & costly activity, Fig.9. Technique & customer understanding is still in the early stages of acceptance [19].

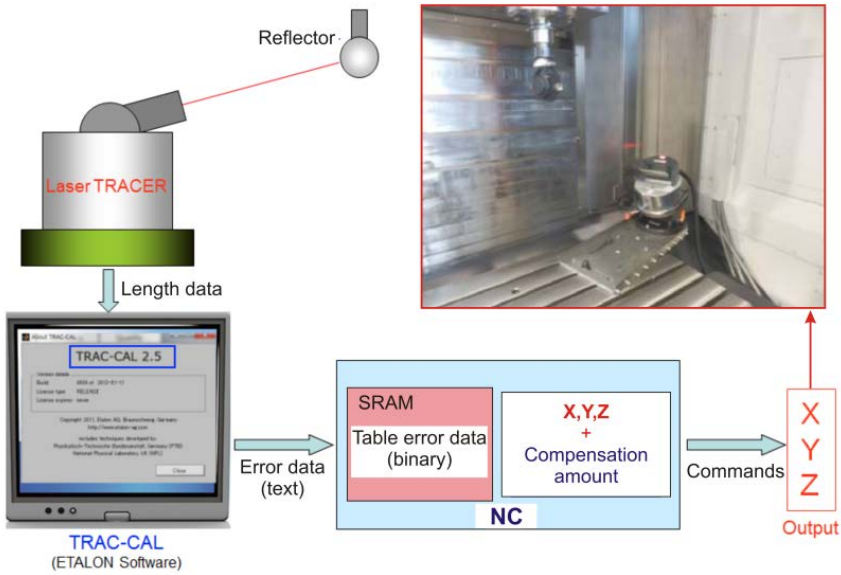


Figure 9. *Volumetric compensation [19]*

Additive manufacturing and Machine tool 4.0 have the goal is to develop laser metal deposition welding so that it can be used for the flexible manufacture of components for prototypes and for small batch sizes. Two main types of AM technology being developed: Selective Laser Melting and Laser Metal Deposition. In laser metal deposition welding, a material is simultaneously melted and applied to a surface. In this case, the material is metal powder. The heat source is a high-performance laser. This additive manufacturing process is combined with conventional machining in the hybrid machine tools.

As a samples of development this hybrid type of machine tools can be mentioned manufactures MAZAK [19], and DMG MORI in cooperation with Schaeffler Technologies AG & Co [35], whose concept will be described below.

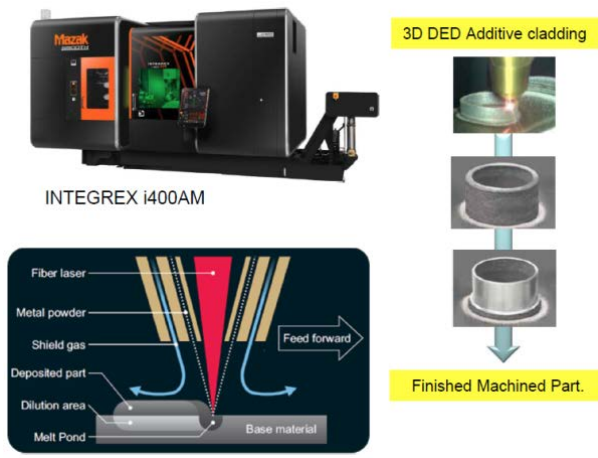


Figure 10. *Integrex i400AM [19]*

Hybrid manufacturing is a synergistic combination of 3-D printing and advanced 3 or 5-axis machining that should allow the user to design and make parts that are uneconomic or simply impossible to produce any other way. Hybrid manufacturing technologies will deliver the benefits of both subtractive and additive technologies, such as: reduced material usage, high accuracy surface finish, mixed material properties, greater geometrical freedom, and enhanced productivity. Figure 10 shows machine of the company MAZAK Integrex i400 AM which

can accomplish hybrid technology of manufacturing. As can be seen on the Fig.11, machine tools that combine both, subtractive and additive technologies, have AM head and milling spindle in the same machine.

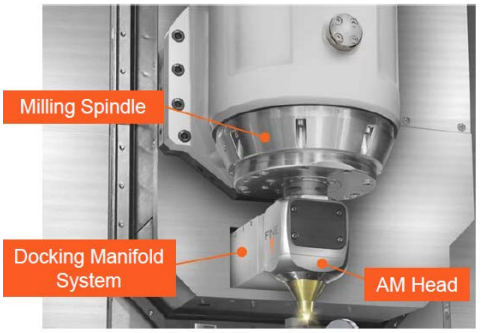


Figure 11. *AM head and milling spindle in same machine [19,37]*

Figure 12 shows another example of the DMG Mori machine tool, which can achieved 3D printing and 5-axis machining combined in one machine.

Reducing of the cost of production and time in the process of machining of complex parts is the very important for progress of industry in countries which is leader of industry. In order to meet these requirements by creating a new possibility for machine tools, a Hybrid Multi-tasking machine tool has been developed by equipping Laser Metal Deposition functionality in addition to existing integrated turning and milling capabilities [37].



Figure 12. *3D printing and 5-Axis machining combined in one machine [35]*

Another example of good cooperation between the two companies Schaeffler and DMG MORI's are developing a partnership, and as a result of this collaboration, the developed functional prototype of Machine tool 4.0.The "Machine tool 4.0" concept, one

of four finalists nominated for the German Industry Innovation Award, is a joint development from Schaeffler and DMG MORI [16, 17, 36], one of the world's leading manufacturers of chip-forming machine tools, Fig.13.



Figure 13. *Schaeffler and DMG Mori's collaborative "Machine Tool 4.0", at EMO 2017 in Hanover [36]*

At EMO 2017 in Hanover, Schaeffler presented a functional prototype of a multi-channel CMS (Condition monitoring systems) for machine tools. In-house systems and sensors such as piezoelectric vibration sensors can be connected to the CMS. Piezoelectric vibration, force and pressure sensors from other manufacturers can also be integrated into the CMS via an IEPE (Integrated Electronics Piezo-Electric) interface. This offers a major advantage in those operators can use the sensors that are available and suitable for the individual measuring point and measurement task. The current prototype has six measurement channels. The system is designed so that, for example, the electronic monitoring of the lubrication conditions in linear recirculating roller bearing and guideway assemblies can also be integrated in the future [17].

The new multi-channel system for monitoring machine tool condition is specially designed for CNC machine tools. Schaeffler thus achieved two goals: (i) monitoring the condition of key components and predicting their behavior using a single CMS and (ii) the flexible integration of sensors, different manufacturers in one CMS. This prototype is tested in initial pilot projects on various CNC machine tools, Fig.14, as well as on the developed functional prototype Machine Tool 4.0 at Schaeffler's manufacturing location in Höchstadt. This machining center serves as a technology platform and development project for digitalized products in the machine tool sector. Machine Tool 4.0 is used to develop and test the algorithms for the multi-channel CMS for monitoring and diagnosing the condition of rolling bearings and components in machine tools under real conditions [17].

The software for the prototype is very sophisticated, as most functions, algorithms and the optional connection to the Schaeffler Cloud from other projects can be ported with only minimal outlay. Due to the connection to the Schaeffler Cloud, all digital services offered by Schaeffler for monitoring and detecting damage to rolling bearings are already available in the prototype CMS. As a local solution, the multi-channel CMS facilitates the monitoring of FAG rolling bearings based on the integrated bearing catalogue, as well as bearings from other manufacturers [17].

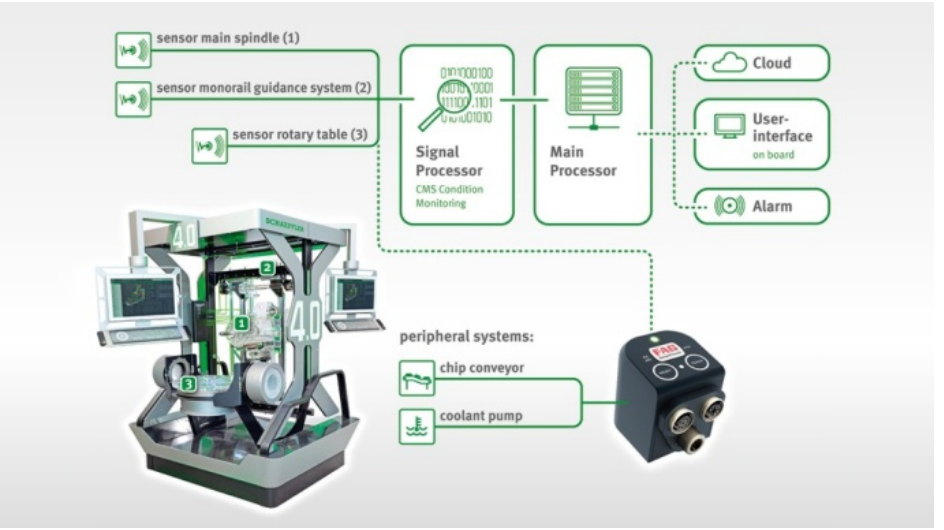


Figure 14. *Machine tool 4.0 and condition analyses [16, 17]*

Digital revolution with monitoring of all important subsystems of machine tools increases their reliability, quality and efficiency. Technical solutions like these have a goal to control of the processes, maximize availability, and optimize of the product quality.

7 CONCLUSION

At the dawn of the new industrial revolution, known as the Industry 4.0, some of industrial initiatives clearly indicate needs for improving production systems which will have high level of intelligence and autonomy.

As the key element of any production system, machine tools are expected to make step-changes to the new generation of machine tools, known as Machine tool 4.0, or Cyber-Physical Machine Tool (CPMT).

This paper examines the relation between Industry 4.0 and machine tools as well as development trends, which are a challenge for a new machine tools generation. From such new machine tools, they are expected to be smarter, well connected, widely available, adaptable and autonomous. Machine tool producers follow the trends in the development of machine tools according Industry 4.0 and some of the very current challenges are: (i) thermal compensation, (ii) volumetric compensation, (iii) additive manufacturing AM, (iv) hybrid manufacturing, etc.

Inspired by recent advances in ICT such as CPS, IoT and cloud computing, a new generation of machine tools, is proposed as a promising development trend of machine tools in the era of MT 4.0. In summary, the Industry 4.0 is paving the way for efficient and smart manufacturing systems.

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THIRD MISSION OF UNIVERSITY - STATE, CHALLENGES, PERSPECTIVE

Vojislav Miltenović[1], Biljana Marković[2]

Abstract:The role of the university in society is very significant, primarily related to activities in the fields: scientific research (knowledge creation), education (knowledge dissemination) and transfer of technology, innovations and product development (knowledge application). From the aspect of company survival in the market and regional economic development, the most important activities related to the transfer of technology, innovation and product development are recognized as the third mission of the university. Over the past few decades, universities have become key players in regional economic development and knowledge transfer, which should lead to significant changes in higher education institutions. The purpose of this paper is to assess the state, challenges, and perspective of higher education institutions in fulfilling the third mission of regional economic development, and the changes that need to be implemented to fulfill this new mission.

Key words: Innovation, Mission of the university, Ranking of universities, Transfer of technology

1 INTRODUCTION

The products are not created in one, big step, but in a larger number of small steps, whose content must be precisely defined. The resulting sequence of steps is called the "process", while the set of all steps of this process is called the "process of product creation". Therefore, it can be said that the process of product creation is a key process in the company, where ideas and innovations are identified, which leads to quality, innovative and commercially competitive products. In order to come from the idea to the finished product, it is necessary to successfully carry out a number of steps. In this respect, the structure of the product creation process plays a very important role. One of the demands of a successful realization of the product creation process is project management, especially in terms of costs, deadlines, technical requirements and product quality.

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During its life cycle, the product passes through different phases (Fig. 1). At the beginning of the life cycle is the process of product creation. The basis of product creation consists of methods and procedures, scientific research, innovations as well as the ideas and creativity of development engineers. The development of the product itself must be carried out systematically and in a clearly structured series of processes.
The process of product creation takes place in 3 phases (Fig. 1):

- Product planning;
- Product development;
- Product manufacturing.

In the product planning phase, intensive analysis of trends in technique and technology development, market demands, customer requirements, and product placement opportunities on the market are carried out. This results in a precise definition of the product profile or the requirements that must be met during product creation. Before the products are released into the market, their prototype testing is carried out. Based on the experience gained in the production and the market, the products are constantly improving, enhancing and innovating throughout the life cycle.

Innovation can help companies to increase competitive ability by: developing new high-quality products, introducing new technologies into production, introducing new organizations into production, conquering new markets, establishing new market relations, etc. It should be borne in mind that the path from invention to innovation is difficult and time-consuming, with a high risk of being unsuccessful. Every successful innovation requires a lot of time, discipline and analysis from development engineers.

Innovations can arise as a result of the work of individuals, as a result of work in the company itself and as a result of scientific research. The best innovations are based on the results of scientific research work. So the key preconditions for successful creation of new products are scientific research, educated personnel with appropriate competences and innovations.

It is not difficult to conclude that from the aspect of the survival of enterprises on the market and economic development, activities at universities are very important, both in the field of scientific research and education of highly skilled personnel, as well as in the field of transformation of research potential into market competitively priced products.

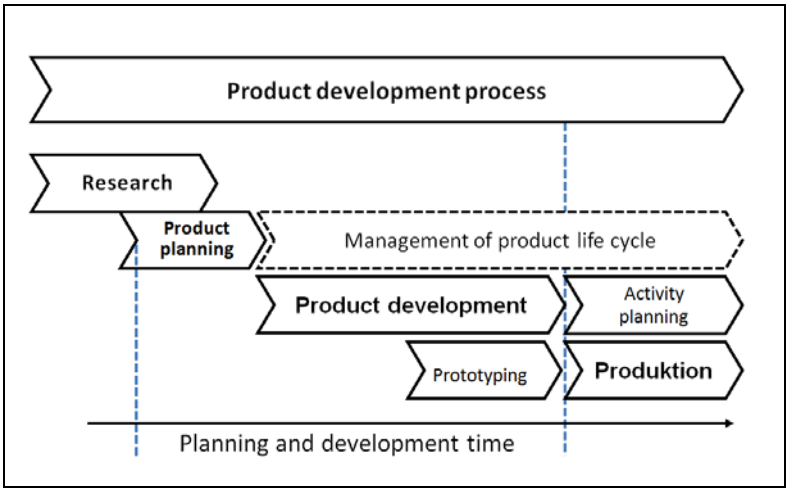


Figure 1. *Phases of the product development process*

2 UNIVERSITY MISSIONS

2.1 The trigger for the mission

The word *university* is of Latin origin - *universitas magistrorum et scholarium,* which implies a community of teachers and scholars. Universities represent autonomous higher education institutions which award diplomas and degrees and comprise multifarious faculties.

Higher education has long been in the process of transition and multiple reforms followed by a very long discussion. One of the important issues in these discussions is the mission of the university. The first mission of the university is education and it was realized in 1150 at the University of Paris (College of Sorbonne since 1257). The University was internationally highly reputed for its academic performance in the humanities – notably in theology and philosophy. It introduced several academic standards and traditions that have endured ever since and spread internationally.

The trigger for the second mission of research was Humboldt who led to the establishment of the University of Berlin in 1810. Humboldt was the first to call of the independence of academia, worked on the integration of natural, social sciences and humanities and to demand the unity of research and teaching.

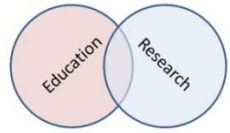
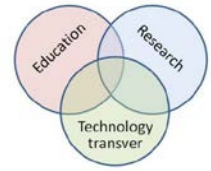
Mission	1st	2nd	3rd
Representation			
Time - Years	1150	1810	1980
Trigger	College of Sorbonne	University of Berlin -Humboldt	Silicon Valley and Stanford, UNI from Japan and EU

Figure 2*. Mission of University [9]*

The major catalyst of the third mission university - technology transfer and innovations - was the emergence of an independent relationship between science, industrial innovation and government policy leading to the so-called ‘knowledge-based’ economy. To push toward research and commercialization, the governments are trimming their contribution to university budgets and requiring them to supplement their earnings from the fruits of their research, whether through knowledge transfer, spin-offs, or equity stakes in start-ups.

It is considered that the third mission for universities has emerged since 1980s as a result of global pressure on universities to take a more important role in knowledge economy. An important contribution to the promotion of the third mission of the university was given by the Organization for Economic Cooperation and Development (OECD), primarily related to technology transfer and innovation activities, including patenting,

licensing and creation of spin-off firms and technology parks. In such an approach, the entrepreneurial university is seen as an engine of economic growth of a country.

2.2 The role of education

The task of education is to acquire scientific knowledge in the function of development of work skills and abilities. If one is to observe scientific research as a process of knowledge creation, then the function of education is knowledge dissemination. An innovative approach in product development is mostly based on the application of the results of scientific work for the purpose of solving numerous tasks and issues. Considering the scope of knowledge and information necessary in such circumstances, team work may be considered purposeful. However, when one co-operates in interdisciplinary project teams, team work can be rather complex and it requires a new approach to work, as well as engineers who have acquired suitable competences in the course of their education.

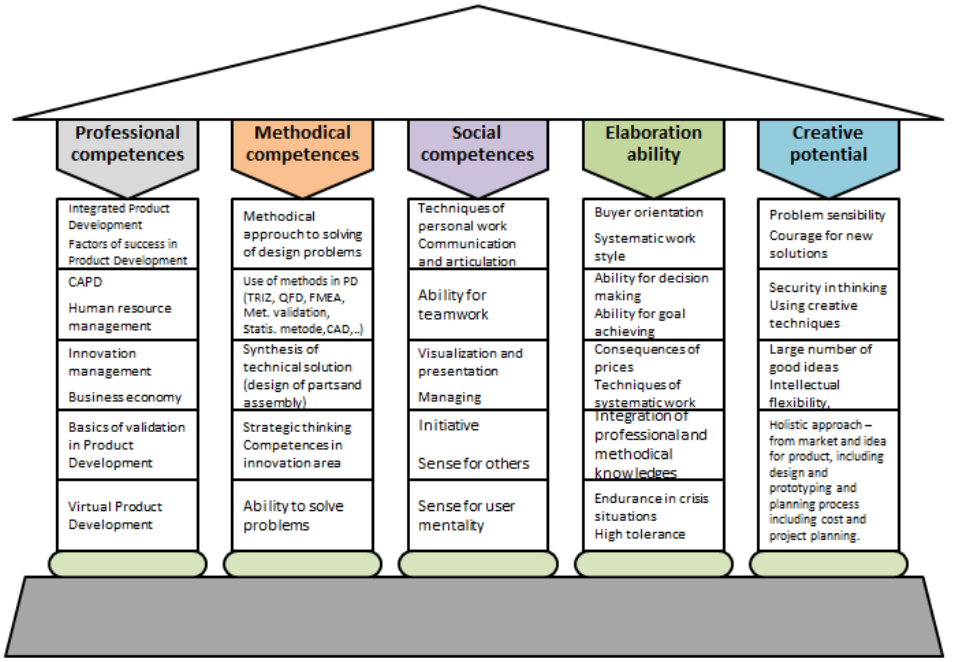


Figure 3. *Authoritative competences in field Product Development on master studies [4]*

Task of teams in Product Development is to achieve multiple compliance, exchange of information, to debate, dispute resolution and formal policies. It is important to establish the personal competencies, which are very important for the successful operation of the team. The real competence, which team members should have in relation to the upcoming task, is also important to successfully solve the task. After extensive research in this direction, clearly defined following relevant competencies: professional competence, methodological competence, social competence, creative potential and ability elaboration. Furthermore, the above mentioned competences will be defined. Figure 3 shows different fields of development engineers competence, which should be acquired.

The most important part of the education of product development engineers and acquiring of the necessary competencies are achieved during the master studies. Professional competence leaning on the knowledge acquired at the bachelor level are primarily oriented towards obtaining knowledge and skills in the areas of product development and the processes. To acquire methodological competencies and their practical application in number of methods to solve problems in Product Development, it is necessary to synthesize technical solutions to achieve successful implementation of innovations. Social competences are focused on communication and articulation skills, teamwork and leadership as well as the ability to solve problems through their own initiatives. Very important are the competences related to the ability of elaboration. These competencies are expressed through the skills of systematic work style, integration of technical and methodological knowledge and managing in crisis situations. Competencies related to the creative potential include acquiring skills for applying creative techniques, safety at work and the implementation of new solutions as well as a holistic approach to product development.

2.3 Significance of scientific research

Scientific research represents a set of deliberate, systematic and methodologically organized activities (disciplinary/interdisciplinary) which enable one to discover and attest scientific truths regarding objects and phenomena in nature and society by means of scientific methods.

Science is, therefore, organized, systematized and certified knowledge of a certain matter, achieved by means of a methodical, careful and conscientious research and contemplation. Knowledge can be defined as an accumulation of objective information related to human beings and their needs. One should make a difference between the amount of knowledge (**quantity**) and its significance (**quality**).

Excellence and relevance are most frequently used as a scientific research quality measure.

Excellence in science is observed as a measure of the quality of the scientific work, primarily from the standpoint of international visibility. Important parameters for evaluating excellence are the number of papers per year in the WoS network, the number of monographs published by prominent international publishers, citation index, etc.

Relevance is also a measure of the quality of the scientific work, but from the standpoint of its impact on social and economic growth. The relevance of scientific research comprises primarily the number of patent applications or patents, inventions which can be applied, the work on projects in which research results are applied, as well as the income obtained in that manner.

Knowledge is a key resource and the only resource which increases when shared. In modern circumstances, the development of science and technology is increasingly rapid and dynamic, which results in an enormously rapid increase in knowledge in various fields of technology. Knowledge is difficult to shield and protect, it quickly loses its market value and it is not subject to known management procedures and methods.

2.4 The transfer of technology, innovations and product development

Knowledge application is primarily reflected in the process of technology transfer, product development and adequate application of innovations.In the narrow

sense, technology transfer can be observed as a process of the flow of knowledge from its source (scientific research) to its user (business entity).

Innovation literally signifies “a change” or “renovation”. The word derives from a Latin word *innovare*which means *to renovate*. Innovation does not necessarily imply invention. However, an invention can be considered innovation. In everyday use, this word is used to denote the application of new ideas and inventions and, consequently, the achieved commercial effects. In the narrow sense, **innovation** is an application of ideas which bring new benefits and qualities in the application of new products, services and processes. In a broad sense, innovations bring improvements in the field of product design (technological innovations), processes, work organisation or management, marketing, service innovation, etc.

According to the degree of innovation, one can distinguish between **radical innovations** (significant, clearly perceptible degree of innovation) and **incremental innovations** (less conspicuous degree of innovation). Innovations can increase competitive advantage of business enterprises by means of developing new high quality products, introduction of new technologies in the production process, introduction of new organisation models into the production process, conquering new markets, establishing new market relations, etc.

Knowledge as a result of work of research organisations is the basic precondition for obtaining quality innovation with a high level of authenticity and a potential for creating commercially competitive products.

Product development implies an interdisciplinary process in the company. This process is based on product planning, and it begins by defining the product profile, within this process continuously running towards development, and ends with the product that is feasible for production and it can properly work. In new, as well as in improved products, the level of product innovation is the factor which mostly contributes to its competitive advantage.

Innovations and product development are tightly connected. The beginning of innovation is in fact the beginning of a product development. In that respect, the phrase “innovative product development” has been introduced. With respect to innovative product development it would be purposeful to obtain answers to the following questions:

- How to generate and evaluate creative and efficient innovative ideas?
- How to turn an idea into innovation which will be applied to a new product development?
- How to systematically manage the innovative process of generating ideas, assess their applicability and their transformation into a commercially competitive product?
- How to master creativity techniques (Brainstorming, Mind Mapping, TRIZ...)?
- How to promote radical innovation and how to apply profitable services from incremental (gradual) innovation?

An important condition for the success of innovation is creating a suitable climate in the society related primarily to the dissemination of scientific, technological and innovation culture.

Table1. *Indicators and Weights of Shanghai Ranking [1]*

Criteria	Indicator	Code	Weight
Quality of Education	Alumni of an institution winning Nobel Prizes and Fields Medals	Alumni	10%
Quality of Faculty	Staff of an institution winning Nobel Prizes and Fields Medals	Award	20%
	Highly cited researchers in 21 broad subject categories	HiCi	20%
Research Output	Papers published in Nature and Science*	N&S	20%
	Papers indexed in Science Citation Index-expanded and Social Science Citation Index	PUB	20%
Per Capita Performance	Per capita academic performance of an institution	PCP	10%
Total			100%

3 SITUATION AT UNIVERSITIES

3.1 Ranking list of world universities

Over the past few decades, universities have become key players in the development of economy and society. Therefore, the quality of the university's work is very significant. In that respect, it is convenient to resort to university ranking according to world standards. In this paper, three ranking lists are considered: the Shanghai Ranking of World Universities [1] (world university ranking since 2003), World University Rankings (Times Higher Education - UK [2]), and Webometrics Ranking of World Universities located in Spain [3].

The Shanghai Ranking of World Universities offers information only for the top 500 universities. Indicators of Shanghai Ranking are Quality of Education (10%), Quality of Faculty (40%), Research Output (40%), Per Capita Performance (10%) – Table 1.
Ranking of universities according to the World University Rankings includes 1250 universities according to 13 carefully calibrated performance indicators among which are: teaching (30%), research (60%), knowledge transfer and international outlook (10%) – Figure 4.

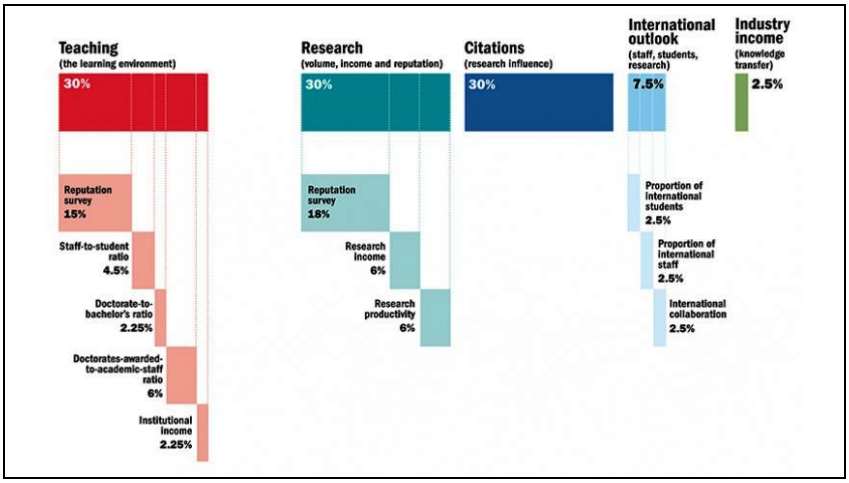


Figure 4. *Criteria and indicatorsof World University Rankings [2]*

The Webometrics currently encompasses the ranking of approximately 25 000 universities worldwide, whereas the ranking list comprises the first 12 000 universities. The Webometrics university ranking methodology [3] relies exclusively on Internet contents. University lists ranked according to the Webometrics methodology are published twice a year on the following web page: www.webometrics.info. University ranking according to the Webometrics methodology is determined on the basis of four indicators classified into two groups: 1. **Visibility**, and 2. **Activity**. The impact of each group is 50% (Table 2).

Table 2.*Webometrics criteria and indicators*

Criteria	Indicator	Code	Weight
Visibility	Number of obtained unique external links to a university website (institutional prestige, academic performance, information value, usefulness of the service)	Impact	50%
Activity	Total number of university web pages from where the data are downloaded via Google	Presence	10%
	Number of rich files, whereby the following formats are taken into consideration: Adobe Acrobat (.pdf), Adobe PostScript (.ps), Microsoft Word (.doc) and Microsoft PowerPoint (.ppt)	Openness	10%
	Quality of scientific papers published by a university - number of citations of scientific papers	Excellence	30%
Total			100%

3.2 The best world universities

Over the past few decades, universities have become key players in the development of economy and society. Table 3 shows the top 10 universities in the world according to the World University Rankings for 2019 and according to the Shanghai Ranking for 2018. On these lists are only the universities from the USA and the UK. The World University Rankings for 2019 is led by the University of Oxford and the University of Cambridge. However, according to Shanghai Ranking for 2018, the first two places occupy Harvard and Stanford University.

Table 3. *Top 10 universities in the world [1] [2]*

Rank	World University Rankings - 2019		Shanghai Ranking - 2018	
	University	Country	University	Country
1	University of Oxford		Harvard University	
2	University of Cambridge		Stanford University	
3	Stanford University		University of Cambridge	
4	Massachusetts Institute of Technology		Massachusetts Institute of Technology	
5	California Institute of Technology		University of California, Berkeley	
6	Harvard University		Princeton University	
7	Princeton University		University of Oxford	
8	Yale University		Columbia University	
9	Imperial College London		California Institute of Technology	
10	University of Chicago		University of Chicago	

The number of universities ranked in the top 100 countries according to World University Rankings is shown in Fig. 5. The US (41), the UK (11) and Germany (8) have the greatest number of universities. China has stopped its ascent of the World University Rankings, since it is trying to establish the same ranking system in Asia.

France's program of university mergers is paying off, improving the research performance and international visibility. For example, Sorbonne University, which was founded in January this year , following the merger of Pierre and Marie Curie University and Paris-Sorbonne University, has joined the list at 73rd place – making it the highest-ranked newcomer in the table. The new Sorbonne, like its individual counterparts, has a particularly strong citation impact and high score for international research collaboration.

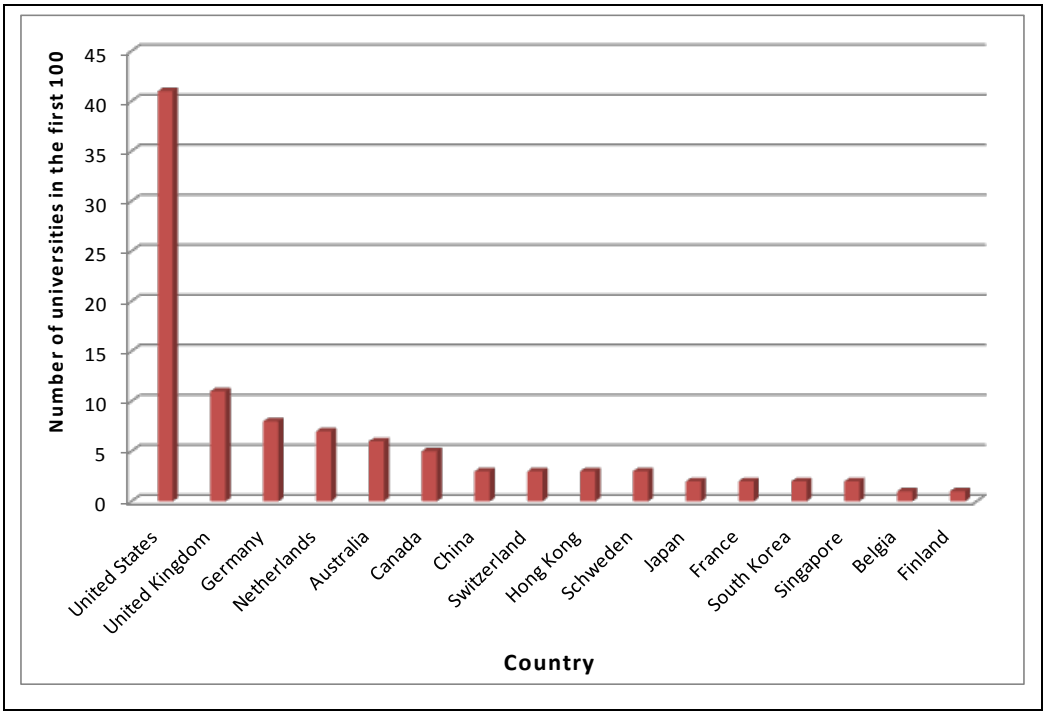


Figure 5. *Number of universities in the first 100 [3]*

3.3 Situation in the region

Only three universities of the region have found themselves in the Shanghai ranking of world Universities: the University of Ljubljana, the University of Zagreb and the University of Belgrade (Fig. 6). The University of Ljubljana found its place on the list for the first time in 2003, only to be left out in the subsequent three years. From 2007 to 2017 it is steadily positioned between 400th and 500th place. The University of Zagreb was on the list between 2011 and 2013, positioned between 400th and 500th place, only to be left out for the subsequent two years. It was placed back on the list in 2016, to be left out again in 2017. The University of Belgrade has been included in the Shanghai Ranking of World Universities since 2012 (position 400-500) and it has advanced significantly ever since, so much so that in 2017 it was positioned between 200th and 300th place, which makes it the best positioned university in the region. However, in 2018 the drop in the Shanghai Ranking was also recorded by the University of Belgrade and the University of Ljubljana.



Figure 6. *The ranking list of the universities in exYU state according to the Shanghai list*

Figure 7 shows the rank of the universities in the region according to the World University Rankings. Universities from Ljubljana and Split are ranked 601-800, anduniversities from Belgrade, Zagreb and Maribor are ranked 801-1000.

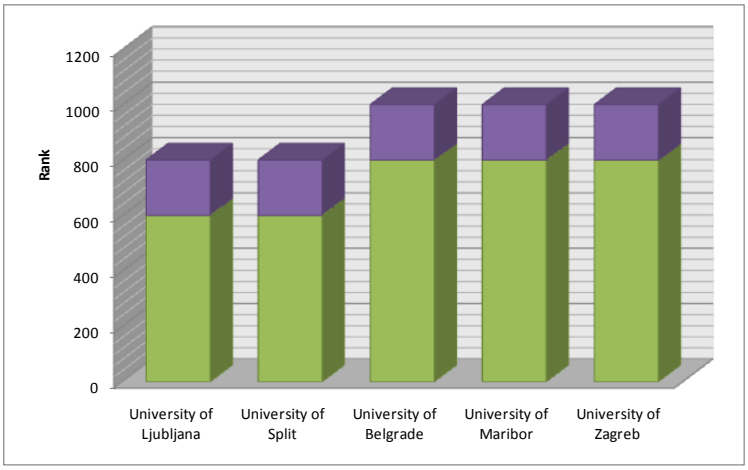


Figure 7. *The ranking list of the universities in ex-YU state according to the [2] list*

On the basis of the Webometrics ranking list (since July 2018) of the first 2000 universities, Table 4 presents the data for all universities of the former Yugoslavia. The list comprises 10 such universities in total: 4 from Serbia, 3 from Croatia, 2 from Slovenia, 1 from Macedonia and 1 from BiH.

Table 4. *Webometrics ranking list for universities in ex-YU countries*

Ran-king	World Rank		University	Presence Rank*	Impact Rank*	Openness Rank*	Excellence Rank*
	July 2018	Jan. 2018					
1	295	325	University of Ljubljana	34	356	763	349
2	668	692	University of Zagreb	86	847	4148	538
3	1028	512	University of Belgrade	284	996	10778	353
4	1096	1108	University of Novi Sad	452	1813	1602	1059
5	1102	1015	University of Split	1238	2980	738	853
6	1169	1244	University of Maribor	41	3499	1466	906
7	1519	1498	University of Niš	770	3358	1921	1265
8	1535	1534	University of Rijeka	1092	2765	990	1630
9	1628	1612	Ss Cyril and Methodius University Skopje	713	2426	2387	1724
10	1676	2019	University of Sarajevo	250	1872	1380	2331
11	1898	1840	University of Kragujevac	1099	4504	1927	1601

Compared to Webometrics ranking list from January 2018, progress was recorded by Universities from Ljubljana, Zagreb, Novi Sad, Maribor and Sarajevo, while other universities across the region (Belgrade, Split, Nis, Skopje and Kragujevac) recorded a decline.

The best ranked university from Montenegro, the state University of Podgorica takes the 3348th place, while according the list from January 2018, it takes 3380th place.

3.4 Situation in Republic of Srpska and Bosnia and Herzegovina

Education in BiH has the key task: how to promote globalization, internationalization and decentralization in education, along with preservation of the existing values that are being respected and guarded in order to develop or improve the sense of acceptance and respect for diversity and responsibility for the development of a democratic society as a whole, where universities play a key role, especially the state universities.

Table 5. Webometrics ranking list for universities in Bosnia and Herzegovina [3]

Ranking	World Rank	University	Presence Rank*	Impact Rank*	Openness Rank*	Excellence Rank*
1	1676	University of Sarajevo	250	1872	1380	2331
2	3411	University of Banja Luka	985	7257	3956	3404
3	3579	International University of Sarajevo	421	6876	4070	3805
4	3586	International BURCH University Sarajevo	1937	6137	3831	3912
5	3763	University of Tuzla	1948	8037	3478	3805
6	4558	University of Zenica	1943	7879	5219	4650
7	5237	University of Mostar	2165	13791	4969	4250
8	5625	Sarajevo School of Science & Technology	18234	13087	3742	4548
9	8061	European University Brčko	11132	9137	7178	6008
10	8467	University of East Sarajevo	3581	21067	6849	4250

It is clear that the ranking of universities attempts to establish transparency in order to compare the indicators to those who choose which university is "the best" and

what perceptions the society (primarily parents and students) has of the position of a university in known world ranks. However, the relatively low level of university organization in BiH, the liberalization of society, and the modification and introduction of more liberal laws in higher education resulting from the war, which enabled a new offer of services in the field of education (private universities), due to which a traditional reputation cannot be longer used as an assessment parameter. Thus, the results of the research carried out in this area show that there is insufficient visibility of relevant and quality data and indicators. Webometric matrix currently shows that the best ranked University in BiH (October 2018) is the University of Sarajevo (1676), then Banja Luka (3411), while the University of East Sarajevo is on the 10th place.

The data shown in this table indicate that the worst indicator, that is, the parameter that evaluates the "Impact rank", (Excellence), i.e., a small number of articles in indexed journals, which raises a large number of questions. Detailed elaboration of the reasons for this fact goes beyond the scope of this paper, but one thing is clear: a greater number of quality research, which have relevant and applicable results that can be published in such journals, cannot be achieved without research and development projects and without larger allocation for science, research and development at the state or entity level, which is impossible in BiH today.

If we are talking about the University of Sarajevo, according to the data given in the "Roadmap for the Improvement and Recognition of Scientific Research Work 2018-2020" [11], it can be stated that the University of East Sarajevo carried a difficult "burden" of the past. It was created in turbulent war times in 1992, infra-structurally devastated, with insufficient material and human resources. In the past two and a half decades, great efforts have been made in providing infrastructure and human resources, that is, the University's management policies have been based on strengthening the organizational units of the University and their potentials.

The foundations of scientific and research work at the University were set up by producing the first self-evaluation reports from 2009. In the 2013 accreditation of the University, the research has been identified as one of the key segments of the organizational units which need to be improved. The "University Development Strategy for the Period 2007-2013" envisaged the improvement of the research segment, while the "Research Development Strategy 2015-2020" identified the research as a priority, and the University has made a plan to accede to the European Charter and the Research Code.

In the aforementioned road map, the basic steps which in a more transparent manner define the path towards the improvement of the current position of the University of Sarajevo:

1. Strengthening human resources institutional support for the management of scientific research
2. Implementation of the Action Plan of the Human Resources Strategy for researchers that includes the European Charter and the Code for Researchers
3. Strengthening cooperation with the economic sector through improvement of research and development work and innovation

4.Developing the quality of scientific conferences, journals, projects and doctoral studies

5. Increasing the visibility and recognition of the teaching and research work and the academic community of the University of East Sarajevo.

Each of the above steps has been elaborated in detail with the holders of responsibilities and execution deadlines, based on the relevant legal acts and strategies adopted at the level of the Government of the Republic of Srpska and line ministries, particularly the Scientific and Technological Development Strategy of the Republic of Srpska "Knowledge for Development" for the period 2017. until 2021. The steps described in the Road map are directly related to the third mission of the university, and society can expect to see some progress if these steps are met.

In general, it can be noted that at the BiH level, by insight into the system of quality assurance in higher education, the system is developed centrally (quality assurance service of the university), but not sufficiently widespread to organizational units (quality representatives) or individuals. Given the fact that the highest number of first-ranked universities in valid rankings are integrated universities (Shanghai Times, Times Higher Education), the significance of integration has been recognized at state faculties (RS), but the size of the universities in BiH is significantly different, and it is necessary to introduce many other parameters in order to make any comparison. From the perspective of a member of the academic community in BiH, ranking can have certain deficiencies taking into account all the differences that exist in this region. Although no other alternative that could have such an importance has not been found yet, more importantly, the issue of achieving the exit competencies of graduates of our higher education institutions, that is, fulfillment of the minimum requirements for achieving internationally measurable competencies of graduates.

4 CHALLENGES AND PERSPECTIVES

There are many challenges in this area whose complete consideration goes beyond the scope of this paper.

As a result of addressing or responding to challenges, there are perspectives and trends that the academic community should follow in the future, in line with world trends, as well as the specifics that exist in exYu, as well as throughout South East Europe.

For this reason, the challenges and perspectives will be given in the following text, in accordance with the author's ideas and possibilities. Everyone should think about the following questions or statement:

Challenges:

- ✓ The danger of ignoring humanistic sciences in relation to the developed areas of applied sciences;
- ✓ The fear that the reduction of state funding will jeopardize the autonomy and research potential of the university;
- ✓ Young researches and students with the best competences are leaving this region, so academic community shall not have the personnel for further development. Can we or do we want to reduce this process?
- ✓ Promoting a Doctor of Science without a scientific basis - reducing the quality of education.

- ✓ Reducing the quality of education by opening a large number of private educational institutions, without adequate governmental control, how to solve or regulate this gap?
- ✓ The negative impact of the politics on university, does it exist or not?
- ✓ Insufficiently quick activity reforms.
- ✓ Insufficient cooperation of universities in the region.
- ✓ Insufficient staffing potential inside the University for International Cooperation (international projects, mobility....) .
- ✓ Insufficient WEB visibility of the universities.
- ✓ Poor cooperation between the university and the economy.
- ✓ Insufficient inter-university cooperation (between faculties) within the university itself.
- ✓ After the Defense of Phd work, the interest for scientific research work decrease.
- ✓ Doctoral Defence (PhD) as the starting point for building a political career?!

Perspectives:

- ✓ Strengthen mobility through international programs.
- ✓ Achievement of adequate excellence and relevance of scientific research.
- ✓ Increase state funding of science and education.
- ✓ Keep young researchers and strengthen the scientific potential through establishment of technology parks,.
- ✓ Is the perspective a sustainable entrepreneurial university?
- ✓ More precise definition and systematically approach for selection criteria in scientificand education titles.
- ✓ The University as the initiator of the society development, does it have a clearly assigned role to do so? The position of academic community in solving key problems in societyhas to be clear.
- ✓ Improving the selection of young researchers in the scientific community.
- ✓ Strengthen education in acquiring competences in the field of creativity and the development of innovative products.
- ✓ Poor and unclear legal regulations at the republic and institutional level (funds for international projects);
- ✓ Demographic trends, as a key reason for declining interest in studying at our universities. Can the academic community influence it?

5 CONCLUSIONS

In recent years, incredibly rapid changes have been taking place worldwide, largely due to the rapid development of science and technology, known as the 4th Industrial Revolution. Activities in higher education institutions and universities related to scientific research, education and technology transfer play a key role in these changes. From the aspect of economic development of the country, the most important activities related to the transfer of technology, innovation and product development are recognized as the third mission of the university.

The presented analysis shows that there is a direct correlation between the degree of economic development of the country and the quality of work and activities at

its universities. In developed countries, universities are one of the key levers of economic development, so an extraordinary attention is devoted to this topic.

Countries that are not quickly and efficiently involved in these changes are lagging behind in all domains: science, economic progress, military strength, civilization. One of the important preconditions for successful inclusion in these flows is the direct cooperation of the university-economy. And in order for universities to successfully contribute to the development of the economy, they must have adequate state support.

As stated in [12], "the economy and society in our Republic at this moment do not have the confidence that the scientific research community can offer useful solutions for the development of the society. In order to change this picture, we need completely new and different solutions and approaches to this problem. The new strategic framework must therefore offer a framework for structural change, instead of insisting on maintaining the existing one. "

The answer lies in the quality and clearly defined cooperation of individuals from the academic community, with line ministries, stimulating that cooperation to prevent the "withdrawal" of competent individuals from the university into the "illegal" and passive observation of the problems in this field. From the position of BiH and the RS, this is the opportunity to create new perspectives and ways to solve problems by forming new governments and choosing responsible individuals, giving the most qualified answers to challenges and realizing possible perspectives that are just mentioned here.

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Publications: Number of publications: about 160. Mentor: 5 doctoral and 11 magister thesis.

Review: 28 books and 132 scientific and professional papers.



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She is the author and co-author of more than 70 scientific and professional papers regarding to the scientific and research field published in the country and abroad, as well as the author and co-author of few university textbooks and monographs used for teaching at the home faculty and related faculties in the surounding. She was coordinator and team member in several EU-funded projects, a president and member of the scientific and organizational committee of conferences in the country and region and a reviewer of scientific and expert papers that were published in related conferences and magazines. She is a member of the Association for Mechanical Elements and Constructions ADEKO.

She is also engaged in the social and political life of the Republic of Srpska, currently she is the President of the Supervisor Committe of the Public Forestry Company "Forests of the Republic of Srpska". She received the Plaques from the Faculty of Mechanical Engineering of the University of East Sarajevo for many years of work and contribution to the development of faculties, as well as the University of East Sarajevo. She is fluent in English language, she uses German language. She is married and she is the mother of two young men.

MANUFACTURING TECHNOLOGIES AND ADVANCED MATERIALS

COMETa 2018
4th INTERNATIONAL SCIENTIFIC CONFERENCE
27th - 30th November 2018
Jahorina, Republic of Srpska, B&H
University of East Sarajevo
Faculty of Mechanical Engineering
Conference on Mechanical Engineering Technologies and Applications

MATERIAL FORMABILITY AT BULK METAL FORMING, CRITERIA, METHOD OF DETERMINATION AND APPLICATION

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Abstract: Material formability it is material ability to deform permanently in different stress condition without structure damage. The fracture limit of material in bulk metal forming is based on fracture and formability criteria. In metal forming, two formability criteria and two workability diagrams are being used: a) the strain based and b) stress based formability diagram. Strain based formability diagram represents the dependence of the principal strains on the free surface of specimen at the moment of the fracture occurrence. The stress based formability diagram represents the relation between limit strain and stress triaxiality ratio in the zone of fracture. In this paper, methodology of formability diagrams determination is presented and application of formability diagram for the limit strain prediction in multi-stage upsetting of prismatic specimen by V-shape dies is performed.

Key words: Material formability, Triaxiality stress ratio, Multy stage upsetting

1 INTRODUCTION

Material formability (or material workability) is material ability to deform permanently in different stress condition without structure damage. It is convenient to distinguish two groups of formability criteria, theoretical and empirical. Empirical criteria are based on experimental investigation of real forming processes and they can be presented by two variants of the formability diagram (FLD): a) the strain-based and b) the stress-based formability limit diagram.

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Formability diagram based on strain criterion represents relationship between two principal strains in the moment of fracture appearance [5-14, 16-19]. Usually this diagram is used in conjuction with upsetting test with different initial geometry. The strain based formability diagram and, therefore, the corresponding fracture criterion are path-independent [19].

According to the stress criteria, limit strain mainly depends on the stress state in the critical zone of the specimen, i.e., in the zone of material damage. Generally, the material formability depends on two groups of factors: 1) type of material, and 2) process conditions.

Quantitative measure of formability limit is effective strain, (φ_e^l), i.e., strain at the moment of material structure damage, strain localization or can be defined by any other criteria. For the given material, with the defined initial microstructure and in cold forming conditions by quasistatic deformation, material formability is a function of stress state only [5]:

$$\varphi_e^l = F(T_\sigma) = F(\beta) \tag{1}$$

where:
T_σ – stress tensor
β – triaxiality stress ratio at the critical point of specimen, i.e., at the point of structure damage. Stress indicator is defined as:

$$\beta = \frac{\sigma_x + \sigma_y + \sigma_z}{\sigma_e} = \frac{\sigma_1 + \sigma_2 + \sigma_3}{\sigma_e} \tag{2}$$

where:
σ_x, σ_y, σ_z– normal stress components in three orthogonal directions (x, y, z)
σ_e – effective stress.

Graphical interpretation of the relationship (1) is the stress-based formability limit diagram [5]. This diagram shows that in bulk metal forming processes in which compressive stresses prevail ($\beta < 0$), values of limit strains achieved are higher than in the processes in which tensile stresses are predominant ($\beta > 0$).

Values of stresses in expression (2) are determined from the stress-strain relation and the Mises yield criterion.

In the upsetting process (Figure 1) crack occurs at the free surface of the cylinder and at that point plain stress state exists, because $\sigma_r = 0$.

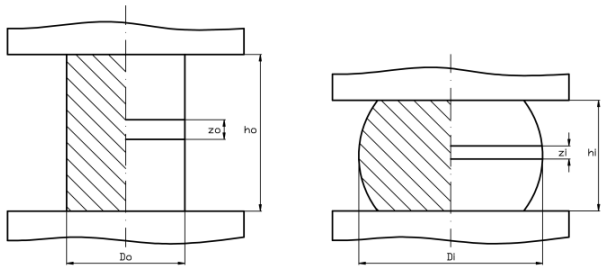


Figure 1.*Upsetting of cylinder*

Axial and tangential stress components could be determined by following

expressions.

$$\sigma_z = \pm K[1+\frac{(1+2\alpha)}{2+\alpha}+(\frac{1+2\alpha}{2+\alpha})^2]^{(-1/2)} \tag{3}$$

$$\sigma_\theta = \sigma_z\left(\frac{1+2\alpha}{2+\alpha}\right) \tag{4}$$

where α is the strains ratio:

$$\alpha = \frac{d\varphi_\theta}{d\varphi_z} \tag{5}$$

φ_θ and φ_z are logarithmic strain components in z and θ direction, experimentally determined by measuring specimen

$$\varphi_{\theta i} = \ln(\frac{d_i}{d_{i-1}})\ \ \varphi_{zi} = \ln(\frac{z_i}{z_{i-1}}) \tag{6}$$

It is also necessary to find relationship between these strain components. This function represents strain path in the area of crack appearance.

$$\varphi_\theta = B\cdot\varphi_z^2 + A\cdot\varphi_z \tag{7}$$

Stress factor β is determined by:

$$\beta = \frac{\sigma_r+\sigma_\theta+\sigma_z}{K} = \frac{\sigma_\theta+\sigma_z}{K} = \pm\frac{1+\frac{1+2\alpha}{2+\alpha}}{\sqrt{1+\frac{1+2\alpha}{2+\alpha}+\left(\frac{1+2\alpha}{2+\alpha}\right)^2}} \tag{8}$$

Stress-based formability limit diagram could be determined experimentally, by employing basic deformation models:

- Uni-axial tensile test, $\beta = +1$
- Torsion test, $\beta = 0$
- Uni-axial compression test, $\beta = -1$

At $\beta=+1$, the limit strain is experimentally determined by tension test at the stage of uniform deformation. It has also been shown that the uniaxial tension test can be replaced with the collar cylinder test for obtaining a point on the formability diagram where the fracture criterion based on an average value of the triaxiality ratio is adopted [12]. It is also shown that the collar test provides a more accurate prediction of the strain to fracture.

A more detailed determination of the formability limit diagram demands application of more sophisticated methods.

In the case of non-monotonous processes, stress indicator (β) changes during deformation and its mean value is inserted in the FLD diagram. The mean value of stress

indicator is defined as [6,7,10,11]:

$$\beta_{av} = \frac{1}{\varphi_e^l} \int_0^{\varphi_e^l} \beta(\varphi_e) \cdot d\varphi_e \tag{9}$$

where:

$\beta(\varphi_e)$ – history of triaxiality stress ratio which indicates change of stress-state as a function of effective strain.

It has been shown in [17] that the average value of the triaxiality ratio is expressed through the in-surface principal strains φl_1 and φ_2^l as:

$$\beta_{av} = \frac{2}{\varphi_e^l}\left(\varphi_1^l + \varphi_2^l\right) \tag{10}$$

In this paper the experimental methodology for determination of formability limit diagrams (strain-based and stress-based) in bulk metal forming is presented. The material used in the experiments was steel C45E (Č.1531).

2 EXPERIMENTAL DETERMINATION OF FORMABILITY DIAGRAMS

The remaining part of this work shows the results of experimental determination of formability diagrams for two variants. The diagram was determined based on the results of basic tests: RT – Rastegaev test (cylinder upsetting without friction influence), BC – cylinder upsetting, T – torsion test, CC – collar cylinder test [7,12,13]. Additional tests (Type 1–5) were performed by die upsetting of five types of non-axisymmetric specimens [18].

Table 1. *Basic formability tests [7,12,13]*

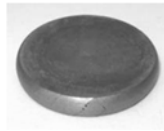
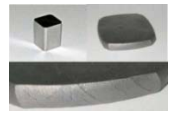
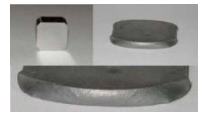
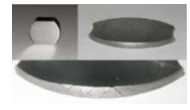
Photo of test specimens				
Type of tests	Rastegev	Basic cylinder	Collar cylinder	Torsion

Table 2. *Additional formability tests [18]*

				
Type 1	Type 2	Type 3	Type 4	Type 5

2.1 Strain based formability limit diagram

Based on the strain path for the different experimental processes (standard and additional test, mentioned before) the strain based formability diagram is determined.

Strain path curves for different specimens are shown in Figure 2. The limit line was derived by approximation of final values for the strains (on the strain path curve) of particular tests – Figure 2.

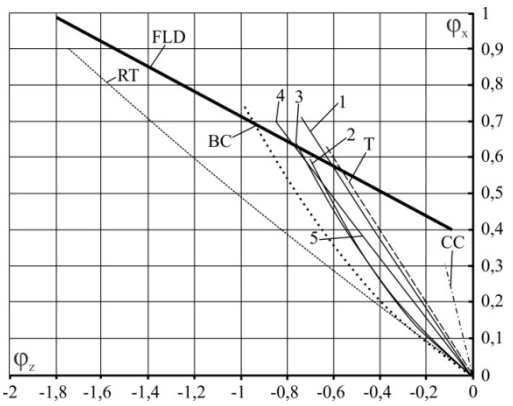


Figure 2.*Strain-based formability diagram for steel C45E [18]*
Basic tests: 1; RT–Rastegev test, BC–basic cylinder test, T–torsion test
CC–collar upsetting test, 1–5 additional tests [18]

2.2 Stress-based formability limit diagram

The stress-based formability diagram (Figure 4) was generated applying the methodology described in the introductory section, based on the experimental data for the basic and additional forming methods. Essentially, the methodology used for constructing this diagram is based on the strain path diagram for the particular forming process shown in Figure 2, which allowed determination the history of triaxiality stress factor (β) using formula (8). The history of triaxiality stress ratio for the standard and additional tests is presented in Figure 3.

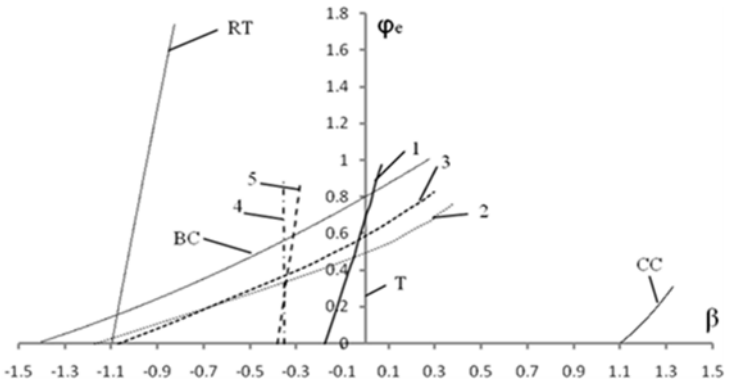


Figure 3. *History of triaxiality stress ratio for different specimens: RT – Rastegaev test, BC – cylinder upsetting, T – torsion test, CC – collar cylinder test, 1–5 additional tests [18]*

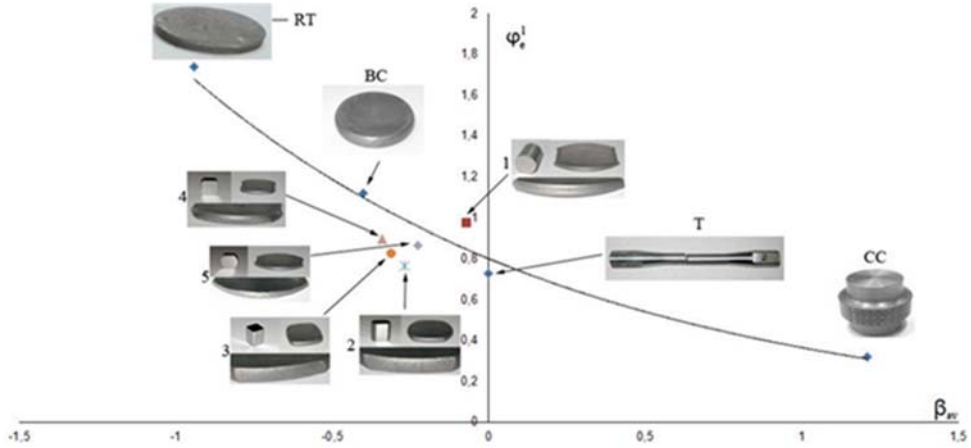


Figure 4. *Stress-based formability limit diagram of steel C45E: RT–Rastegaev test, BC–cylinder upsetting, T–torsion test, CC–collar cylinder test, 1–5 additional tests [18]*

Based on the history of triaxiality stress ratio and using formula (9), mean value of factor β_{av} was calculated.

Stress based formability diagram represents relationship between limit strain (φ_e^l) and average values of triaxiality stress ratio (β_{av}) – Fig. 4.

3 APPLICATION OF FORMABILITY LIMIT DIAGRAM

In metal forming process forming limit diagram is used for fracture prediction, i.e. for the design and optimization of the number of forming phases. Same procedure may be used in metal structure load analysis. At first, it is necessary to create formability limit diagram for specified material and then to analyse the stress state and the triaxiality stress factor at sample bulk. For stress-strain state analysis in bulk specimen finite element method is recommended, i.e. application of proper software (SimufactForming, Abaqus, and Deform, etc.).

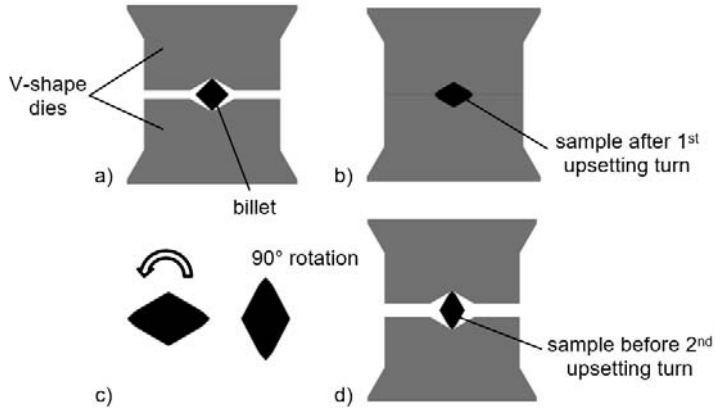
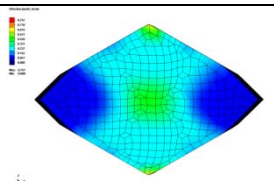
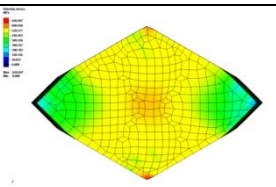
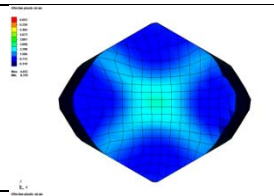
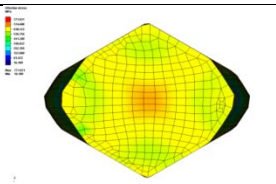
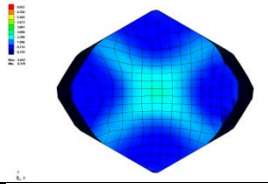
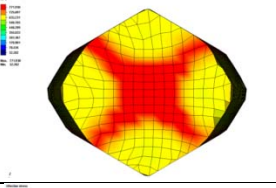
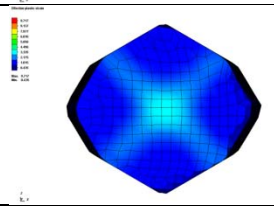
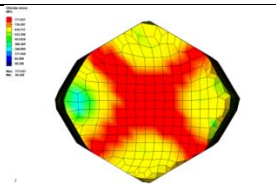
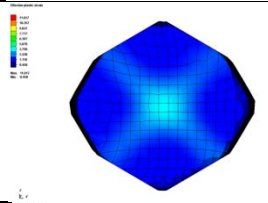
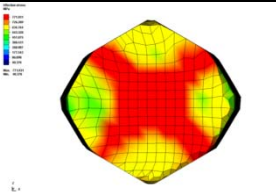
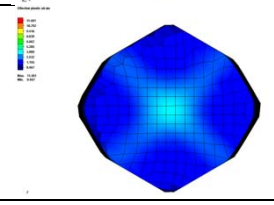
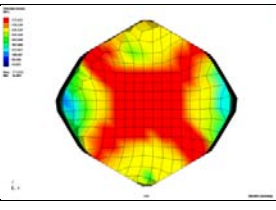


Figure 4.*Multi stage upsetting of prismatic specimen by V-shape dies [20]*

Presented below are the results of material formability analysis for multistage upsetting by V-shape dies of the prismatic billets made of Č.1221 [20]. The purpose of the analysis is to examine potential limit strain in this process, at upsetting with 17 stages, with sample rotation for 90° after each phase. Limit strain prediction is carried out by numerical analysis of upsetting by V shape dies of samples made of Č.1221. For this analysis, SimufactForming V10 software was used.

Table 3. *Numerical simulation of multy stage upsetting by V shape die [20]*

No. Upsetting stage	Effective strain	Effective stress
1		
3		
7		
11		
15		
17		

Triaxiality stress ratio analysis was carried out for the critical point on the specimen that is located at the centre of free (forehead) surface. The triaxiality stress factor is determined from the hydrostatic stress and the effective stress at the centre of the sample surface obtained by numerical simulations. The change of the triaxiality stress factor for different upsetting stages and corresponding effective strain values, at the centre of the sample forehead, is presented in table 4.

Table 4. *Triaxialiti stress factor in correlation with effective strain*

Upsetting stage	1	3	5	7	9	11	13	15	17
φ_e	0,39	1,58	2,29	2,61	2,83	2,98	3,14	3,28	3,34
β	-2,88	-2,38	-1,95	-1,95	-1,91	-1,68	-1,56	-1,44	-1,17

FLD for Č.1221 (annealed) determined experimentally by the cylinder upsetting with flat plates, the torsion test and the tensile test [15]. Based on the data from Table 4, history of triaxiality stress ratio was identified and approximated by following equation:

$$\beta = 0,09 \cdot \varphi_e^2 + 0,156 \cdot \varphi_e - 2,925 \tag{11}$$

Average value of triaxiality factor was determined by formula (9):

$$\beta_{av} = \frac{1}{3,34} \int_0^{3,34} (0,09 \cdot \varphi_e^2 + 0,156 \cdot \varphi_e - 2,925)\, d\varphi_e = -2,32 \tag{12}$$

By using numerical analysis, average value of triaxiality factor β=–2,32 with corresponding value of limit strain $\varphi_e^l = 3,34$ was calculated. The illustration of fracture incidence at multistage upsetting of prismatic sample is presented at Figure 5.

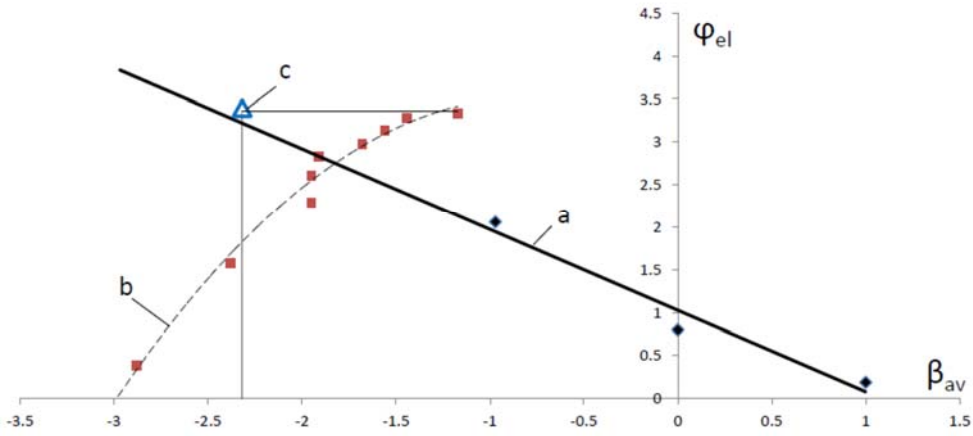


Figure 5. *FLD for Č.1221 and the position of multi stage upsetting by V shape dies after 17 stages: a–FLD, b–history of β factor, c– estimated limit strain*

4 DISCUSSION OF RESULTS AND CONCLUSION

- In the metal forming technology two formability criteria can be applied strain-based and stress-based criterion.
- Strain-based formability criterion is simple for application because it is based on strain determination in the material fracture zone. Due this feature, its application is limited to processes where fracture occurs on the free surface of workpiece.
- Stress-based formability criterion represents limit strain dependence from a stress state in the zone where material fracture occurs. This criterion can also be applied in the case of fractures occurring inside the specimen. In this paper is presented how stress based formability diagram can be determined based on data obtained from the strain-based formability diagram.
- Stress-based formability diagram is more important since its shows a significant impact of stress state on the magnitude of the limit strain (Fig. 4).
- This study showed that strain-based formability diagram can be transformed into a stress-based one.
- The reverse transformation of stress-based formability diagram into a strain-based formability diagram is also possible, as demonstrated in [19].
- The application of FLD enables the prediction of limit strain in real forming processes and the optimization of the number of stages.
- Results of multi stage upsetting of prismatic specimen by V shape die proves the existance of a small reserve of material formability after 17 stages.

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PROJEKTOVANJE TEHNOLOŠKIH PROCESA PROIZVODNJE ZA FLEKSIBILNE PROIZVODNE SISTEME

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Rezime: Fleksibilni proizvodni sistemi (FMS) predstavljaju složene sisteme koji se sastoje od mašina za obradu i/ili montažu koje su međusobno povezane manipulacionim, merno-kontrolnim i transportnim sistemima, čije je upravljanje pomoću računara. FMS imaju visoke proizvodne mogućnosti, ali i visoke troškove investicija, zbog čega se za analizu uslova njihove racionalne primene moraju koristiti pouzdane tehnološke i ekonomske podloge. Uzimajući u obzir sve složenije uslove proizvodnje i plasmana proizvoda, neophodan je sistemski prilaz pri projektovanju i primeni FMS, odnosno njihovih elemenata, različitog nivoa proizvodnosti i fleksibilnosti. FMS su namenjeni za proizvodnju jedne ili više familija proizvoda, zbog čega se njihov razvoj i primena bazira na principima grupne tehnologije. U ovom radu je prikazana metodologija projektovanja tehnoloških procesa proizvodnje za razvoj i primenu FMS, sa verifikacijom na primeru jedne tehnološke grupe rotacionih delova.

Ključne riječi: projektovanje tehnoloških procesa proizvodnje, grupna tehnologija, fleksibilni proizvodni sistemi (FMS)

MANUFACTURING PROCESS PLANNING FOR FLEXIBLE MANUFACTURING SYSTEMS

Abstract: Flexible manufacturing systems (FMS) are complex systems consisting of machines for machining and/or assembly that are interconnected by manipulation, measurement, control and transport systems supported by computers. FMSs have high manufacturing capabilities, but also high price and investment costs, which is why reliable technological and economic bases must be used to analyze the conditions for their rational use. Taking into account increasingly complex conditions in manufacturing and product launch, it is necessary to use systematic approach in design and

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implementation of FMSs, i.e. their elements, of different levels of productivity and flexibility. FMSs are designed for manufacturing one or more product families which is why their development and implementation are based on the principles of the group technology. This paper presents the methodology of manufacturing process planning for design and implementation of FMS with the verification on the product example belonging to a technological group of rotary parts.

Key words: manufacturing process planning, group technology, flexible manufacturing systems (FMS)

1 UVOD

Pred savremene proizvodne sisteme u industriji prerade metala nameću se vrlo oštri zahtevi tržišta u pogledu visokog kvaliteta i niske cene proizvoda, širokog i promenljivog asortimana i različite dinamike isporuke. U uslovima velikoserijske i masovne proizvodnje, zahvaljujući automatizaciji, proizvodnost i ekonomičnost su dostigli relativno visok nivo. Međutim, u ukupnoj strukturi metalske industrije dominiraju pojedinačna i maloserijska proizvodnja, čije se učešće sve više povećava usled težnje potrošačkog društva za sve većim brojem različitih proizvoda. Zbog toga se nameće potreba za savremenim proizvodnim sistemima sa efektima automatizovane velikoserijske i masovne proizvodnje u pogledu proizvodnosti i ekonomičnosti i efektima pojedinačne i maloserijske proizvodnje u pogledu fleksibilnosti i mobilnosti [1].

Fleksibilni proizvodni sistemi (FMS) predstavljaju osnovu da proizvodni sistem istovremeno postigne visok nivo fleksibilnosti i proizvodnosti, odnosno da se smatra agilnim [2, 3]. Osnovne jedinice FMS-a predstavljaju CNC mašine alatke, posebno na današnjem nivou kada su one multifunkcionalne i integrišu različite procese obrade (struganje, glodanje/bušenje, brušenje, itd.) i različite tehnologije obrade (rezanje, termička obrade i dr.). Povezivanjem ovakvih mašina sa manipulacionim, merno-kontrolnim i transportnim sistemima, kao i njihovim upravljanjem pomoću računara nastaju FMS različitog nivoa složenosti, proizvodnosti i fleksibilnosti [4].

FMS zbog svojih visokih proizvodno-tehnoloških mogućnosti, visoke cene i troškova investicija zahtevaju uslove pri kojima se obezbeđuje njihova racionalna eksploatacija. Uzimajući u obzir sve složenije uslove proizvodnje i plasmana proizvoda, neophodan je sistemski prilaz pri projektovanju i primeni FMS-a, koji će obuhvatiti najbitnije tehnološke i ekonomske karakteristike. U ovom radu je na primeru formirane tehnološke grupe rotacionih delova - nastavka prikazana metodologija projektovanja tehnoloških procesa proizvodnje kao podloge za racionalan razvoj i tehnoekonomsku primenu FMS-a, odnosno njegovih sastavnih elemenata.

2 PROJEKTOVANJE TEHNOLOŠKIH PROCESA PROIZVODNJE ZA FMS-TEORIJSKE PODLOGE

Predložena metodologija za razvoj i primenu FMS-a prikazana je u radu [5] i sastoji se od tri integralne celine, odnosno faze:

1. Tehnološke osnove za razvoj i primenu FMS-a,
2. Vrednovanje i izbor elemenata FMS-a i
3. Modeliranje, simulacija i optimizacija FMS-a.

Prva etapa-postavljanje tehnoloških osnova se u suštini odnosi na projektovanje tehnoloških procesa izrade proizvoda iz programa proizvodnje, čime se stvaraju

neophodne podloge za razvoj i primenu FMS-a. Ova etapa se sastoji od sledećih zadataka [6]:

- Analiza proizvodnog programa i formiranje tehnoloških/operacijskih grupa,
- Projektovanje ili izbor kompleksnih delova,
- Projektovanje grupnih tehnoloških procesa proizvodnje,
- Preciziranje tehnoloških procesa i određivanje vremena pojedinih zahvata, operacija i tehnoloških procesa u celini,
- Određivanje nivoa složenosti i broja elemenata FMS-a (mašina/radnih mesta, pribora, alata, merno-kontrolnih sistema, itd.),
- Analiza tehnoekonomskih efekata primene elemenata FMS-a

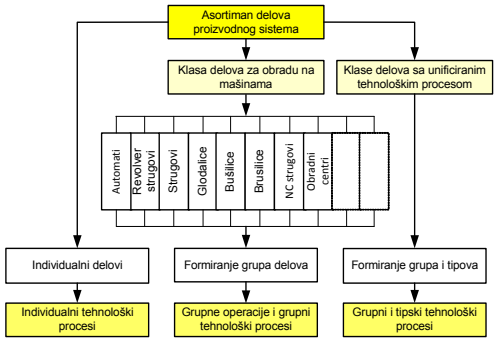
Iako istaknute karakteristike i ciljevi FMS-a tretiraju rešavanje problema pri njihovom projektovanju, može se istaći da je ista situacija i kada se radi o njihovoj primeni. Naravno da se pri primeni FMS-a najveći deo problema rešava projektovanjem, optimizacijom i terminiranjem tehnoloških procesa izrade proizvoda, prilagođenih karakteristikama i ograničenjima FMS-a.

Polazeći od principa klasifikacije i grupisanja proizvoda, ukupan asortiman delova proizvodnog sistema se može sistematizovati prema konstrukciono-tehnološkoj sličnosti, odnosno podeliti na određene celine za koje je racionalno primeniti koncept grupne tehnologije, slika 1. Na osnovama grupne tehnologije koju je uspostavio Mitrofanov [7] i kao rezultat istraživanja koje je realizovao Burbidge [8] razvijen je novi pristup u proizvodnji - grupni prilaz u projektovanju efektivne proizvodnje i proizvodnih struktura. Koristeći ovaj pristup, na osnovu klasifikacije delova u proizvodnom procesu, kreiraju se grupe geometrijski i tehnološki sličnih delova – operacijske grupe (familije), koje predstavljaju osnovu za grupni pristup u projektovanju tehnoloških procesa, slika 2. Spajanjem pojedinih operacijskih grupa koje imaju slične tehnološke procese u veće tehnološke grupe stvara se mogućnost za njihovu izradu na odgovarajućim fleksibilnim proizvodnim sistemima. Na slici 3 dat je prikaz proizvodnih tokova baziranih na principima projektovanja individualnih tehnoloških procesa i uređenih tokova za slučaj primene koncepta grupne tehnologije, odnosno grupnih tehnoloških procesa i primene FMS-a.

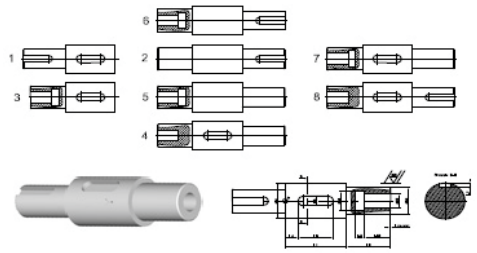
Projektovanje tehnoloških procesa na principima grupne tehnologije ima za cilj povećanje količina proizvoda u okviru proizvodnog programa na principima sličnosti, čime se povećava serijnost delova i prelazi na više tipove proizvodnje, omogućujući primenu obradnih sistema povišenog stepena efikasnosti. Prilaz na povećanju količina se zasniva na objedinjavanju proizvoda sličnih karakteristika, odnosno sistematizaciji i grupisanju proizvoda na osnovu njihove sličnosti, najčešće primenom odgovarajućih konstrukciono-tehnoloških klasifikatora u cilju standardizacije tehnoloških procesa izrade. Grupni tehnološki proces i grupne operacije izrade, projektuju se i realizuju u proizvodnji, za formiranu tehnološku grupu delova, odnosno operacijske grupe, primenom zajedničkih obradnih sistema, odnosno istih grupa mašina, pribora i alata, uz jednu njihovu osnovnu pripremu. Kako bi se po grupnom konceptu mogli obrađivati svi delovi iz jedne grupe, grupni tehnološki proces mora obuhvatiti sve operacije, a grupna operacija mora obuhvatiti sve zahvate, kojima će se obraditi svi tipski oblici i/ili površine delova iz grupe. Zbog toga se projektovanje grupnog tehnološkog procesa vrši za predstavnika grupe koji se naziva kompleksan deo. Ovaj kompleksan deo može biti stvaran deo iz grupe, ako sadrži sve tipske oblike (features) ostalih delova i imaginaran kompleksan deo, ako se on projektuje samo u cilju definisanja grupnog tehnološkog procesa [5, 6, 9].

Definisanjem sadržaja grupnog tehnološkog procesa za određenu tehnološku grupu utvrđuju se vrste i nivoi potrebnih mašina i radnih mesta, dok se definisanjem

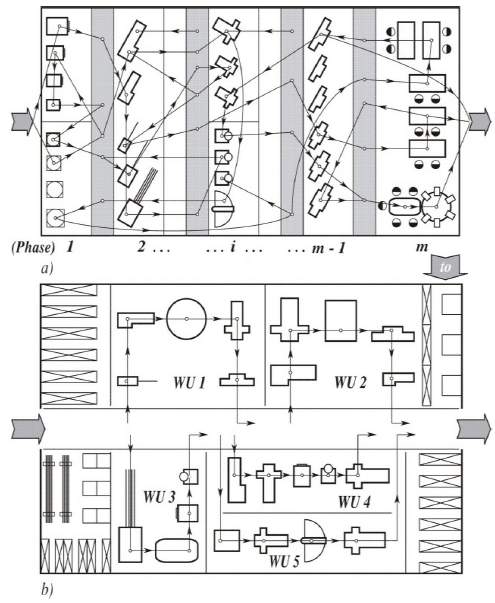
pojedinih grupnih operacija stvaraju podloge za izbor vrste i nivoa drugih elemenata FMS-a, kao što su alati, pribori, merno-kontrolni sistemi, itd.



Slika 1. *Sistematizacija delova iz programa prozivodnje* [7]



Slika 2. *Primer jedne operacijske grupe delova* [5]



Slika 3. *Proizvodni tokovi kod individualnih i grupnih tehnoloških procesa izrade* [10]

Grupni tehnološki procesi i odgovarajuće grupne operacije omogućuju lako i brzo preciziranje tehnološkog procesa izrade delova iz grupe. Preciziranje tehnoloških procesa za sve delove se radi za slučaj detaljnog/konačnog projektovanja FMS-a, pri čemu se dobijaju precizni tehnoekonomski podaci (vreme, troškovi, stepen iskorišćenja...). Preciziranje tehnološkog procesa samo za predstavnike odgovarajuće grupe se radi za slučaj konceptualnog/prethodnog projektovanja FMS-a, pri čemu se dobijaju približni tehnoekonomski podaci, čija tačnost zavisi od metodologije koja se primenjuje. U cilju što racionalnijeg i bržeg određivanja komadnog vremena operacija izrade tehnološke grupe kod konceptulanog projektovanja, potrebno je precizirati operacije izrade za odgovarajuće predstavnike, u zavisnosti od metode koja se koristi za određivanje ovog vremena. One se u praktičnoj primeni koriste kao analitičke ili grafičke, dok će se ovde prikazati studija slučaja primene metode sličnosti, koja spada u grupu grafoanalitičkih metoda.

Ova metoda obezbeđuju približno određivanje komadnih i pripremno-završnih vremena, čime se u proizvodnoj praksi dobijaju zadovoljavajući rezultati pri određivanju normativa vremena za pojedine operacije obrade, a time i podloga za određivanje nivoa složenosti, broja elemenata obradnih sistema i utvrđivanja vremenskog stepena njihovog iskorišćenja. Na osnovu geometrijskih karakteristika delova iz grupe, zahteva predviđenih projektovanim tehnološkim procesom i karakteristika raspoloživih resursa biraju se nivoi složenosti elemenata FMS-a.

U posmatranom slučaju za formiranu tehnološku, odnosno operacijsku grupu rotaciono simetričnih delova – nastavaka prikazana je metodologija definisanja

tehnoloških osnova za razvoj i primenu FMS-a, dok je određivanje vremena i resursa prikazano na primeru grupne operacije struganja na bazi metode sličnosti.

3 PODLOGE ZA RAZVOJ I PRIMENU FMS – STUDIJA SLUČAJA

3.1.1 Projektovanje grupnih tehnoloških procesa izrade

Analizom proizvodnog programa posmatranog proizvodnog sistema, primenom konstrukciono-tehnološkog klasifikatora formirana je tehnološka grupa rotaciono-simetričnih delova, među kojima je izdvojena jedna operacijska grupa za razmatranje. Ovu grupu delova čine nastavci, čiji su osnovni podaci dati u tabeli 1.

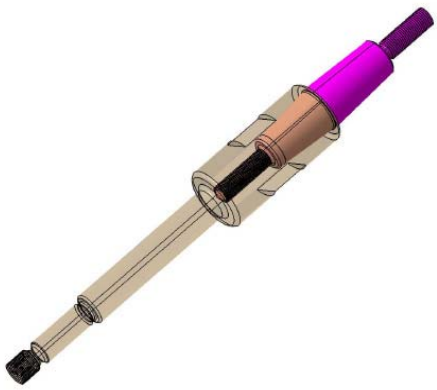
Na osnovu geometrijskih i tehnoloških karakteristika delova iz grupe projektovan je imaginarni kompleksan deo, sa svim pripadajućim tipskim oblicima (features), slika 4. Na osnovu definisanog modela kompleksnog dela, obima proizvodnje, raspoloživih resursa i drugih potrebnih podataka projektovan je grupni tehnološki proces, čiji je sadržaj prikazan u tabeli 2., a karta grupne operacije obrade 20/1 na slici 5.

Tabela 1. *Osnovni podaci tehnološke grupe nastavaka*

No.	Oznaka dela	Obim proizvodnje (kom/ser)	Masa dela (kg)	Vrednost (n.j./kom.)
1	708 033	320	0,126	15.000
2	708 038	300	0,134	15.400
3	708 041	280	0,109	14.200
4	708 046	400	0,109	14.200
5	708 047	350	0,109	14.200
6	708 169	260	0,133	15.400
7	708 170	340	0,133	15.400
8	708 181	360	0,149	15.700

Tabela 2. *Sadržaj tehnološkog procesa izrade kompleksnog dela grupe nastavaka*

R.br.	Naziv operacije	Mašina/uređaj/radno mesto
10	Odsecanje	Testera
20/1	Struganje leve strane	CNC strug
20/2	Struganje desne strane spoljašnje i unutrašnje	
30	Kontrola	Kontrolni sto
40	Glodanje	NC glodalica
50	Doterivanje	Radni sto
60	Poboljšanje	Peć za T.O.
70	Kontrola T.O.	Uređaj za merenje tvrdoće
80	Brušenje središnjeg gnezda	NC brusilica
90	Brušenje otvora	NC brusilica za unutrašnje brušenje
100	Brušenje spoljašnje strane	NC brusilica za okruglo brušenje
110	Završna kontrola	Radni sto



Slika 4. *3D model kompleksnog dela*



Slika 5. *Karta grupne operacije obrade 20/1*

3.1.2 Određivanje komadnih vremena grupne operacije struganja – primena metode sličnosti

Da bi se odredilo potrebno vreme operacije obrade posmatrane grupe delova metodom sličnosti potrebno je izdvojiti tehnološki najjednostavniji i najsloženiji deo te grupe i na osnovu projektovane grupne operacije izvršiti preciziranje operacije za njih. Kao kriterijum za izbor najjednostavnijeg i najsloženijeg dela grupe najčešće se primenjuje broj zahvata u posmatranoj operaciji obrade.

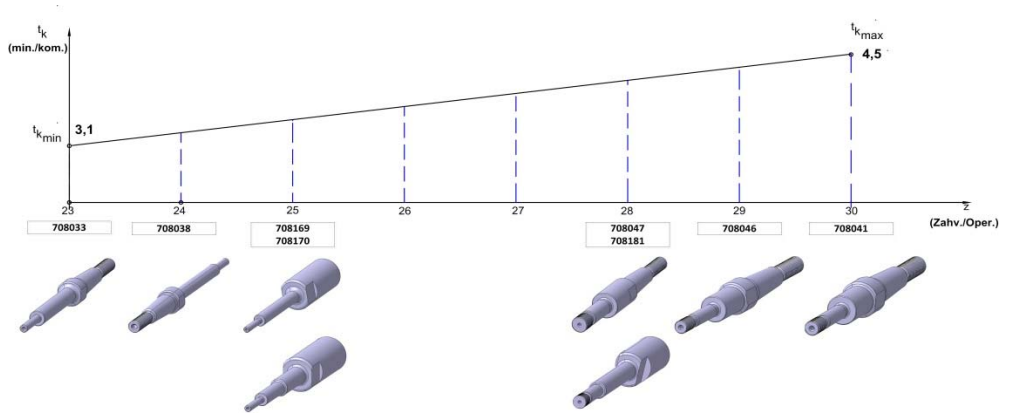
Ukupno ciklusno (komadno) vreme operacije obrade jedne operacijske grupe proizvoda, odnosno delova, može se odrediti na osnovu izraza:

$$t_k = \sum_{i=1}^{k} (Q_i t_{k_i}) \qquad (1)$$

gde su:

- k- broj različitih delova operacijske grupe
- Q_i-broj pojedinih delova operacijske grupe
- t_{ki}-komadna vremena operacije izrade pojedinih delova operacijske grupe

Komadna vremena operacije izrade (t_{ki}) koja, kao što je poznato, obuhvataju osnovna (glavna) i pomoćna vremena, određuju se iz dijagrama sličnosti. U posmatranom slučaju dijagram komadnog vremena grupe nastavaka na operaciji obrade struganjem na CNC strugu, ima izgled kao na slici 6. Dijagram prikazuje zavisnost komadnog vremena i broja zahvata, pri čemu najjednostavniji deo ima 23 zahvata i komadno vreme od 3,1 min/kom, a najsloženiji deo ima 30 zahvata i komadno vreme od 4,5 min/kom. Komadna vremena operacija obrade za pojedine delove operacijske grupe mogu se odrediti grafički, koristeći dijagram na slici 6 ili analitički, uz prethodno određivanje koeficijenta pravca koji opisuje promenu komadnog vremena (t_k) u zavisnosti od broja zahvata (z).



Slika 6. *Zavisnost komadnog vremena operacije struganja od broja zahvata*

Na osnovu slike 6, određen je koeficijent pravca k:

$$k = \frac{t_{kmax} - t_{kmin}}{z_{max} - z_{min}} = \frac{4,5 - 3,1}{30 - 23} = 0.2 \quad (2)$$

Kao primer prikazan je postupak određivanja komadnog vremena za deo No.5 - nastavak oznake 708 047, koji u ovoj operaciji ima 28 zahvata:

$$t_{k5} = t_{k_1} + k \cdot (z_5 - z_1) = 3,1 + 0,2 \cdot (28 - 23) = 4,1 \text{ (min/kom)} \quad (3)$$

U tabeli 3 dati su podaci o vremenima operacije obrade struganjem za sve delove iz grupe, dobijenih primenom posmatrane metode.

Tabela 3. *Podaci za komadna vremena operacije struganja delova iz grupe*

Oznaka dela (nastavka)	708033	708038	708041	708046	708047	708169	708170	708181
Komadno vreme (min/kom)	3,1	3,3	4,5	4,3	4,1	3,5	3,5	4,1

Na osnovu prethodno definisanih podataka određeno je ukupno ciklusno vreme operacije obrade struganjem posmatrane tehnološke grupe prema (1), koje iznosi:

$$T_c = 320 \cdot 3,1 + 300 \cdot 3,3 + (260 + 340) \cdot 3,5 + (350 + 300) \cdot 4,1 + 400 \cdot 4,3 + 280 \cdot 4,5 = 9973 \text{(min/ser)}$$

3.1.3 Proračun potrebnog broja i stepena iskorišćenja elemenata FMS

Ako je planirani obim proizvodnje nekog proizvoda Q_i, onda je ukupno vreme zauzetosti obradnog sistema na određenoj operaciji u tehnološkom procesu izrade ovog proizvoda na godišnjem nivou određeno izrazom (4):

$$T_i = Q_i \cdot t_{ki} + Q_i \cdot \frac{T_{pz\,i}}{z_s} = Q_i \cdot t_{ki} + n_{s\,i} \cdot T_{pz\,i} \text{ (min/god)} \quad (4)$$

gde su:

- t_{ki} – komadno vreme (min/kom)
- T_{pz} - pripremno – završno vreme za seriju delova (min/ser)
- z_s - predviđena veličina serije (kom/ser)
- n_s – broj serija u određenom vremenskom periodu (ser/god)

Ako se uzme da posmatrani pogon radi m_e=250 dana/god., s_e=2 smene/dan, sa n_e= 7,5 čas./smeni i stepenom iskorištenja η_e=0,8, sledi da je efektivni kapacitet rada obradnog sistema K_e=180000 (min/god).

Na osnovu prethodno proračunatog ciklusnog vremena, uzimajući da je n_s=6 ser/god, potreban broj i stepen iskorišćenja obradnog sistema na posmatranoj operaciji obrade struganjem je:

$$T = 6 \cdot 9973 + 6 \cdot 30 = 60018 \ \text{(min/god)} \tag{5}$$

$$N = \frac{60018}{180000} = 0{,}333 \tag{6}$$

$$\eta = \frac{0{,}333}{1} = 33{,}3\% \tag{7}$$

Na osnovu prethodnog, stepen iskorišćenja CNC struga na godišnjem nivou za obradu posmatrane grupe delova iznosi 33,3%, dok je za radnika/poslužioca η=66,6% (pri čemu je s_e=1 smena/dan). U cilju definisanja i drugih elemeneta FMS-a, potrebno je odrediti i neophodan kvalitet i kvantitet alata, pribora, merila i dr., što ovde nije prikazano zbog obima rada. Na osnovu prethodnih podataka se vrlo efektno mogu realizovati 2 i 3 faza, vrednovanja i izbora elemenata FMS-a, odnosno modeliranje, simulacija i optimizacija rada FMS-a [5, 6, 11].

4 ZAKLJUČCI

Projektovani grupni tehnološki procesi za odgovarajuće tehnološke/operacijske grupe delova omogućuju preciziranje tehnoloških procesa izrade njihovih reprezenata, čime se stvaraju kvalitetne tehnološke osnove za razvoj i primenu FMS-a. Definisanjem sadržaja grupnih tehnoloških procesa i odgovarajućih grupnih operacija na bazi realnih ili imaginarnih kompleksnih delova, stvaraju se tehnološke osnove za izbor vrsta i nivoa složenosti elemenata FMS-a za pojedine grupne operacije.

Proračun potrebnih kapaciteta, odnosno nivoa složenosti, broj i stepena iskorišćenosti elemenata FMS-a za pojedine operacije grupnog tehnološkog procesa izrade određene tehnološke grupe, baziran na preciziranim vremenima operacija obrade reprezenata i metodi sličnosti, obezbeđuje rešavanje i ovih, komplikovanih zadataka na racionalan, dovoljno pouzdan način. Razvijena metodologija verifikovana je na prikazanom primeru operacijske grupe delova - nastavaka.

Na osnovu dobijenih podataka iz prikazane faze postavljanja tehnoloških osnova za razvoj i primenu FMS-a, vrlo se efektno mogu realizovati i ostale faze koje se odnose na vrednovanje i izbor elemenata FMS-a, odnosno modeliranje, simulaciju i optimizaciju primene FMS-a.

ZAHVALNOST

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EKSPERIMENTALNO DEFINISANJE KARTE STABILNOSTI PRI OBRADI ČELIKA Č4732 POSTUPKOM GLODANJA

Aleksandar Košarac[1], Cvijetin Mlađenović[2], Milan Zeljković[3], Lana Šikuljak[4]

Rezime: Samoizazvane vibracije su neželjena pojava koja se može javiti pri različitim postupcima obrade metala rezanjem. Samoizazvane vibracije predstavljaju fenomen koji ima negativan uticaj na produktivnost, dovodi do ubrzanog habanja ili loma alata, a u nekim slučajevima može dovesti i do loma elemenata pribora ili dijelova mašine. Kako bi se proces nastanka samoizazvanih vibracija mogao predvidjeti, odnosno kontrolisati, razvijene su različite metode. Jedan od načina za predviđanje pojave samopobudnih vibracija je karta stabilnosti (engl. Stability Lobe Diagram), kojom se definiše granica stabilnog, uslovno stabilnog i nestabilnog rada, pri čemu se posmatraju kombinacije dubine rezanja, brzine rezanja, odnosno broj obrtaja i pomaka. Metode za definisanje karte stabilnosti mogu se podijeliti na analitičke, i eksperimentalne. Ovaj rad prezentuje eksperimentalno definisanje karte stabilnosti, pri obradi glodanjem čelika Č4732. Obrada se izvodi na verikalnom obradnom centru, alatom od brzoreznog čelika (HSS). Metodologija definisanja karte stabilnosti podrazumjeva izvođenje serije eksperimenata, pri kojima se vrši obrada glodanjem opitnog radnog predmeta, pri čemu je površina koja se obrađuje izrađena sa nagibom od 3°. Na taj način se pri kretanju alata dubina rezanja postepeno povećava, sve do trenutka nastanka samoizazvanih vibracija. Pojava nastanka vibracija se registruje mjerenjem ubrzanja u vremenu, pri čemu je akcelerometar postavljen na nosač glavnog vretena, što je bliže moguće alatu. Nakon nastanka samoizazvanih vibracija, što se manifestuje naglim skokom amplitude ubrzanja, te promjenom zvuka u zoni rezanja, proces rezanja se prekida i metodom tangente utvrđuje aksijalna dubina pri kojoj je došlo do pojave vibracija. Dobijena karta stabilnosti je u dvije dimenzije, što znači da se sva mjerenja vrše za jednu, konstantnu vrijednost pomaka po zubu.

Ključne riječi: karta stabilnosti, obrada glodanjem, samoizazvane vibracije

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EXPERIMENTAL METHOD FOR IDENTIFICATION THE STABILITY LOBE DIAGRA IN MILLING Č4732 STEEL

Abstract: Self-exciting vibration (chatter) is an unwanted phenomenon that can occur in metal cutting. Self-exciting vibrations are a phenomenon that has a negative effect on productivity, leads to accelerated wear or breakage of the tool, and in some cases can lead to breakage of elements of jigs and fixtures or elements of the machine tools. In order to predict and control the process of creating self-excited vibrations, different methods have been developed. One way of predicting self-excited vibrations is defining Stability Lobe Diagram, which shows the boundary between stable, conditionally stable and unstable cutting process, whereby combinations of cutting depth, cutting speed, i.e. spindle speed and feed rate are observed. Methods for defining the stability lobe diagram can be analytical, and experimental. This paper shows the experimental method of defining the stability lobe diagram, on machining steel Č4732. Metal cutting is carried out on a vertical machining center, where two different tools are used, one high speed steel (HSS), and second one HSS tool coated with TiAlN . The methodology for defining the stability lobe diagram implies that series of experiments were done, were workpiece surface to be milled is made with a slope of 3°. In this way, when moving the tool, the cutting depth gradually increases until the moment of self-excited vibration occurs. The occurrence of the vibration is registered by measuring the acceleration, where the accelerometer was being mounted on the main spindle carrier, as close as possible to the tool. After the self-excited vibrations occurred, which is manifested by a sudden jump of acceleration amplitude, and by the change in the sound, the cutting process is interrupted and then the axial depth of the cutting at which the vibrations occur determined by tangent method in Matlab.The obtained stability lobe diagram has two dimensions, which means that all measurements are performed for one, constant value of feed rate per tooth.

Key words: Milling, Self-excited vibrations, Stability lobe diagram,

1 UVOD

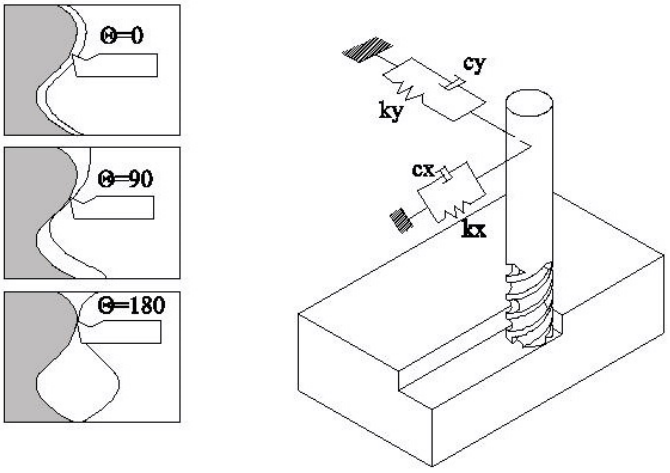
Pojava samoizazvanih vibracija pri obradi rezanjem je odavno uočena, ali i danas predstavlja vrlo aktuelno polje istraživanja kako sa stanovišta matematičkog modelovanja i predikcije, tako i sa stanovišta eksperimentalnog ispitivanja i upravljanja obradnim procesom. Razvojem NU mašina alatki i sve većom primjenom visokobrzinske obrade, pomenuti problemi su postali još izraženiji, pa su detekcija i prevencija nastanka samoizazvanih vibracija postale suštinski važne za eksploataciju ovih obradnih sistema.

U radu je prikazan način utvrđivanja trenutka nastanka samoizazvanih vibracija pri obradi glodanjem, kao jednog od indikatora dinamičke nestabilnosti obradnog sistema, uz primjenu savremene dijagnostičke opreme National Instruments, LabView i Matlab softvera. Na osnovu eksperimentalno dobijenih rezultata, određene su granične vrijednosti dubine rezanja pri kojima dolazi do nastanka samoizazvanih vibracija, kao osnove za definisanje karte stabilnosti obradnog sistema, i identifikaciju najosjetljivijeg elementa, sa stanovišta dinamičkog ponašanja, mehaničke strukture mašine alatke.

U procesu rezanja mogu se javiti tri tipa vibracija koje nastaju usljed nedovoljne dinamičke krutosti jednog ili više elemenata sistema mašina alatka – alat – pribor – obradak, i to slobodne (prirodne), prinudne i samoizazvane vibracije. Slobodne vibracije nastaju kada se mehaničkom sistemu, izvedenom iz ravnotežnog položaja, omogući slobodno oscilovanje bez spoljašnjih uticaja.

Prinudne vibracije nastaju usljed spoljašnje periodične pobude. Slobodne i prinudne vibracije se, ukoliko je poznat njihov izvor, mogu efikasno izbjeći, redukovati ili ukloniti iz procesa obrade.

Samoizazvane vibracije predstavljaju najnepovoljniji tip vibracija, i energiju za svoj nastanak i rast amplitudne crpe iz samog procesa rezanja, a mogu nastati usljed trenja u sistemu alat – obradak, usled termo – mehaničkih efekata, ili kako posljedica regenerativnog efekta tj. variranja poprečnog presjeka strugotine tokom obrade, slika 1.



Slika 1. *Šematski prikaz regenerativnog efekta*

Ove vibracije često dovode do nestabilnog rada mašine alatke, tzv. podrhtavanja (engl. Chatter), a za posljedicu imaju smanjenje kvaliteta obrađene površine, pojavu buke, ubrzano trošenje reznog alata i elemenata mašine alatke, itd.

Da bi se izbjegle posljedice samoizazvanih vibracija, pri radu mašine alatke često nije moguće koristiti određene režime rezanja jer uzrokuju nestabilan rad mašine. Dijagrami koji prikazuju područje stabilnog i nestabilnog rada mašine alatke nazivaju se karte stabilnosti, a formiraju se na osnovu kritičnih dubina rezanja pri kojima dolazi do pojave samoizazvanih vibracija.

Karte stabilnost mogu se odrediti analitičkim, eksperimentalno-analitičkim ili eksperimentalnim metodama.

Analitičko-eksperimentalni model predikcije samoizazvanih vibracja zahtjeva određivanje prenosne funkcije mehaničke strukture mašine alatke, dok se eksperimentalno ispitivanje svodi na određivanje intervala pojedinih parametara rezanja pri kojima je proces rezanja stabilan.

Ispitivanja u cilju identifikacije samoizazvanih vibracija i njihovog uticaja na stabilnost mašina alatki među prvima su ispitivali sredinom prošlog vijeka Tlusty [1] i Tobias [2], skoro istovremeno ali u potpuno odvojenim istraživanjima. Oni su predložili određene metode za analizu stabilnosti mašina kao što je određivanje granične dubine rezanja i formiranje karte stabilnosti. Pri ispitivanju stabilnosti mašina alatki metodom granične dubine rezanja, veliki uticaj na pojavu samoizazvanih vibracija imaju parametri procesa rezanja. Altintas [3] i Song [4] koristeći analitički i eksperimentalni pristup razmatraju uticaj različitog broja zuba i ugla zavojnica na istom vretenastom glodalu na pojavu samoizazvanih vibracija, obrađujući pri tome leguru aluminijuma

7075. Zataraina [5] razmatra uticaj ugla zavojnice, vršeći obradu legure aluminijuma 7075 alatima različitog ugla zavojnice.

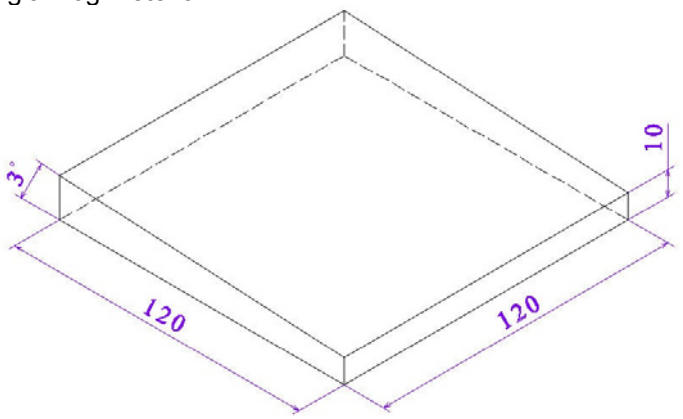
Quintana [6] određuje kartu stabilnosti pri obradi glodanjem eksperimentalnim putem, pri čemu vrši obradu opitnog izradka sa zakošenom radnom površinom. Pojava samoizazvanih vibracija se registruje snimanjem i analizom emisije zvuka, primjenom savremenih tehnika obrade signala. Na osnovu FFT analize zvuka, utvrđuje se trenutak pojave samoizazvanih vibracija, čime se isključuje mogućnost greške usljed subjektivnog osjećaja operatera.

2 OPIS IZVEDENIH EKSPERIMENTALNIH ISPITIVANJA

Eksperimentalno ispitivanje pojave samoizazvanih vibracija sprovedeno je na verikalnom obradnom centru EMCO Concept Mill 450 u okviru Laboratorije za mašine alatke i CIM sisteme Mašinskog fakulteta Istočno Sarajevo.

Sproveden je niz eksperimenta uz konstantnu vrijednost pomaka 0,02 mm/z i varirani brojevi obrtaja u rasponu od 1000 do 3010 o/min, uz povećanje od 300 o/min pri svakom narednom ispitivanju. Obradak korišćen pri eksperimentalnim ispitivanjima je od čelika Č4732, oblika i dimenzija datih na slici 2. Alat korišćen pri obradi je vretenasto glodalo Φ10 od HSS, sa četiri zuba i uglom zavojnice 30°. Pri obradi nije korišćeno sredstvo za hlađenje i podmazivanje SHP.

Za svaki usvojeni broj obrtaja u kombinaciji sa izračunatom vrijednosti pomaka, kontinualno je povećavana dubina rezanja i pri tome se registruje veličina amplitude oscilovanja nosača glavnog vretena.



Slika 2. *Oblik i dimenzije pripremka za eksperimentalno ispitivanje*

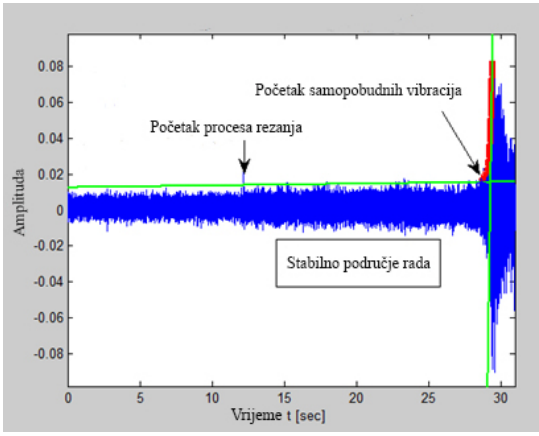
Kontinualna promjena dubine rezanja obezbjeđena je samom konfiguracijom obradka, odnosno nagibom površine koja se obrađuje. Usljed pomenute promjene dubine rezanja, dolazi i do vrlo blagog rasta amplitude oscilovanja reznog alata, a u trenutku kada dubina rezanja dostigne graničnu vrijednost, dolazi do naglog skoka amplitude što ukazuje na pojavu samoizazvanih vibracija.

Parametar vibracija koji se direktno mjeri kontaktonom metodom je ubrzanje, pri čemu se koristi instrumentacija National Instrumets. Instrumentacija se sastoji od šasije National Instrumets cDAQ 9172, (slika 5a) i analogne kartice NI 9233 sa četiri analogna ulaza opsega napona ±5 V i maksimalne brzine odabiranja signala po kanalu 50 kS/s (kilosamples per second). Senzor ubrzanja akcelerometar METRIX Instruments osjetljivosti 100mV/g sa piezo-keramikom se pomoću magnetnih držača postavlja na nosač glavnog vretena, što je bliže moguće alatu. Pri akviziciji

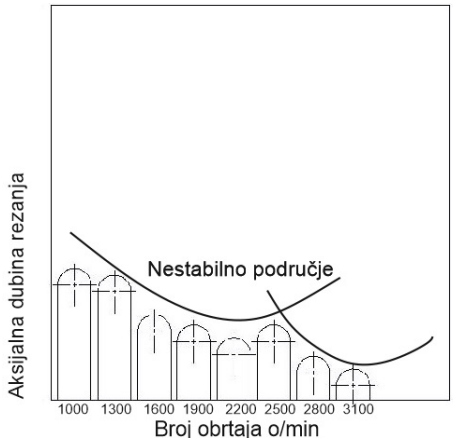
(prikupljanju) podataka koristi se grafički programski jezik LabVIEW, a pri obradi rezultata mjerenja Matlab okruženje. Također, treba napomenuti da se, pri obradi rezultata mjerenja u cilju određivanja granične dubine rezanja, ne uzima u obzir apsolutna vrijednost amplitude vibracija jer nije mjerodavna za utvrđivanje trenutka nastanka samoizazvanih vibracija. Ovaj trenutak, osim naglog skoka amplitude vibracija, karakteriše i promjena reljefa i izgleda strugotine, kao i pojava prodornog, intenzivnog zvuka, koji je indikator da mašina radi u nepovoljnom režimu obrade.

3 PRIKAZ DOBIJENIH REZULTATA

Pri pojavi zvuka, operater zaustavlja rad mašine, s tim da se granična (aksijalna) dubina rezanja naknadno utvrđuje, primjenom metoda tangente, slika 3. Na slici 4. data je karta stabilnosti sa eksperimentalno definisanim graničnim dubinama. U tabeli 1. prikazani su parametri obrade, broj obrtaja i vrijednost pomaka u mm/min, dok je u koloni Y data izmjerena vrijednost koju je alat prešao u pravcu Y ose do trenutka pojave samoizazvanih vibracija.

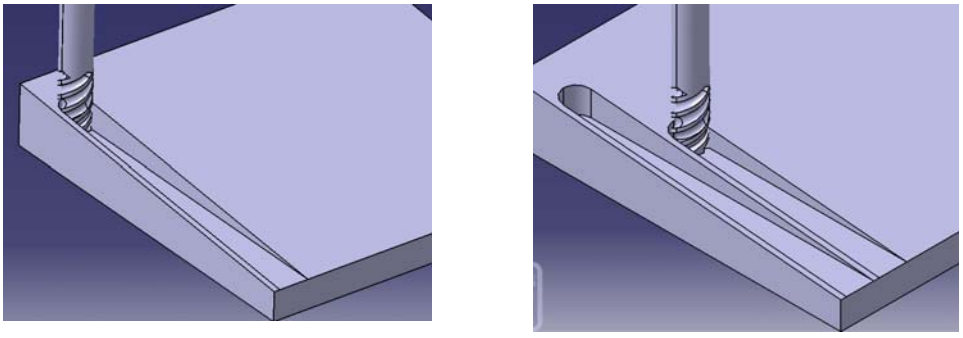


Slika 3. *Promjena amplitude oscilovanja u vremenu i pojava samoizazvanih vibracija*



Slika 4. *Karta stabilnosti sa eksperimentalno definisanim graničnim dubinama*

Pri svakom novom prolazu alata, povećava se broj obrtaja, slika 5. Shodno tome, izračunava se brzina pomoćnog kretanja, tako da pomak po zubu ima konstantnu vrijednost 0,02 mm/z.



Slika 5. *Šematski prikaz procedure izvođenja eksperimenta*

Table 1. *Planirani parametri obrade i dobijeni rezultati*

R.br.	*Broj obrtaja (o/min)*	*Pomak (mm/min)*	*Y (mm)*	*Maks. dubina rezanja (mm)*
1	*1000*	*80*	*40*	*2.1*
2	*1300*	*100*	*38*	*2*
3	*1600*	*130*	*26*	*1.4*
4	*1900*	*150*	*22.9*	*1.2*
5	*2200*	*180*	*19*	*1*
6	*2500*	*200*	*22.9*	*1.2*
7	*2800*	*224*	*13.3*	*0.7*
8	*3100*	*250*	*9.54*	*0.5*

4 ZAKLJUČAK

Karta stabilnosti, kao granica između stabilnog i nestabilnog procesa obrade, funkcija je parametara obrade, broja obrtaja i aksijalne dubine rezanja. U ovom radu prikazana je jednostavna eksperimentalna metoda za definisanje karte stabilnosti pri obradi glodanjem. Granica između stabilnog i nestabilnog procesa obrade može se odrediti primjenom mjerno akvizicionih sistema kojima se mjeri nivo vibracija, u vremenskom domenu, a primjenom metode "tangenti", obrađuju dobijeni podaci, što je izloženo u ovom radu. Takođe, dubina rezanja pri kojoj nastaju samoizazvane vibracije može se odrediti i mjerenjem aksijalne dubine rezanja na samom opitnom radnom predmetu, na kome su jasno uočljiva područja stabilnog i nestabilnog procesa obrade i gdje se mogu odrediti kritične dubine rezanja pri kojima proces obrade postaje nestabilan. Izložena metodologija je pogodna za određivanje karte stabilnosti pri obradi glodanjem kanala i utora, pri čemu je širina glodanja jednaka prečniku alata, odnosno pri obradama kod kojih ugao zahvata materijala ψ iznosi180°.

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NUMERICAL AND EXPERIMENTAL MODAL ANALYSIS OF HIGH SPEED SPINDLE

Miloš Knežev[1], Aleksandar Živković[2], Milan Zeljković[3], Cvijetin Mlađenović[4]

Abstract: The need for bigger productivity has increased drastically over the last period, to cope with these increasing demands manufacturing companies are trying to improve and speed up their machining processes. The geometric quality of high-precision parts is highly dependent on the dynamic performance of the entire machining system, which is determined by the interrelated dynamics of machine tool mechanical structure and cutting process. This paper takes a grinding high-speed motorized spindle system, as a example for obtaining a finite element model analysis. The model takes into account bearing support contact interface, which is established by spring-damper element with appropriate stiffness. Furthermore, modal analysis and critical speed were done by means of ANSYS commercial software. The proposed model has been verified experimentally by measuring the natural frequencies of the spindle, and the simulated results are compared well against the experimental measurement.

Key words: Motorized spindle, Spindle dynamics, FEM

1 INTRODUCTION

High-speed machining (HSM) technology has been widely used in automotive, aerospace, die making, electronics and many other industries to increase productivity and reduce production costs. This technology is mainly limited by the performance of the spindle, which has a significant influence on the machining accuracy [1]. Spindle system is one of the key components of machine tools, which will determine the machining quality directly [2]. Classically, main spindles were driven by belts or gears and the rotational speeds could only be varied by changing either the transmission ratio or the number of driven poles by electrical switches. Later simple electrical or hydraulic controllers were developed and the rotational speed of the spindle could be changed by means of infinitely adjustable rotating transformers. The need for increased productivity

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led to higher speed machining requirements which led to the development of new bearings, power electronics and inverter systems. The progress in the field of the power electronics led to the development of compact drives with low-cost maintenance using high frequency three-phase asynchronous motors [3]. The safety and reliability due to imperfect dynamic performance have become the primary problem of structural design and machine operation. As the number of revolutions of the machine tool main spindles is increasingly approaching first natural frequency, there is a risk of resonance [4] Therefore, the dynamic performance research of the high-speed motorized spindle has an important theoretical and practical significance [5].

2 DYNAMIC MODEL OF THE SPINDLE

The dynamic analysis of spindle bearing system plays a crucial role as it directly affects the machining, productivity as well as the quality of the product [6]. The aim of this paper is to establish a FEM model of the high-speed motorized spindle. The model takes into account bearing support contact interface. Modal analysis is conducted by using ANSYS commercial software.

A schematic of the spindle-bearing assembly of a high-speed grinding motorized spindle shown in figure 1. The rotor of the spindle is supported by two pairs of angular contact ball bearings. To drive this spindle-bearing system, an integral induction motor is located between the front and rear bearings, and the maximum rotating speed of the spindle is 90000 [rpm].

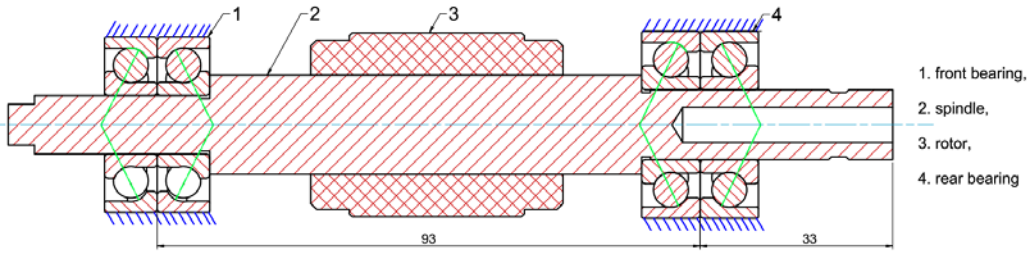


Figure 1. *The spindle-bearing assembly scheme*

The model of main spindle is built by using ANSYS APDL beam modeler module and the structure such as thread hole, keyhole, chamfer, fillet and so on are simplified. This features, has no effects on the analysis result. Due to simple axial-symmetric nature of the spindle system, the spindle is described by one dimensional element type with two nodes BEAM188, which is six degree element, (3 translational and 3 rotational) based in Timoshenko beam theory, it is one-dimensional line element in space and requires cross-sectional details for modelling, which is suitable for representing the stepped nature of spindle. Steel property was used in the mathematical model as follows: Young's modulus, E = 210 [GPa], density ρ= 7850 [Kg/m^3], Poisson`s ratio 0.3. Stiffness of bearings is defined by equivalent spring-dumper element type COMBIN14 on every bearing location, whereby radial stiffness value of bearings is defined according to producer catalogue, for front bearing k=240 [N/μm], and rear bearing k=156 [N/μm], both in "O" arrangement, with the fixed preload. On the same locations rotational and translational degrees of freedom along the X and Z-axis was constrained. And rotational speed of spindle was given around the Z axis. The dynamic finite element model is shown on figure 2.

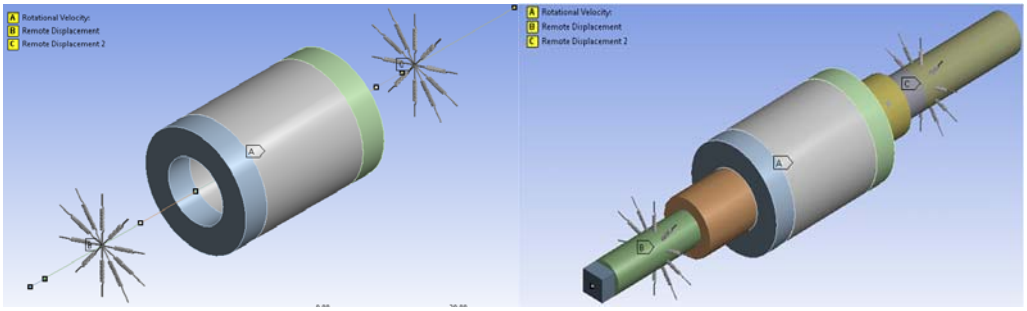


Figure 2. *FE model of the spindle system*

2.1 Boundary conditions

Modal analysis is the basis of dynamic analysis. The modal can be obtained by analyzing the system frequency, vibration mode, natural frequency. For modal analysis it is required to establish the dynamic equation of the spindle bearing system. The dynamic equation of spindle bearing system is shown below [6]:

Equation of forced vibration:

$$m\ddot{x} + c\dot{x} + kx = F(x) \tag{1}$$

where $F(x) = F_o \cos \omega t$

Where (m) is the mass of the system (kg), (c) is damping coefficient (Nsec/mm), (k) is the stiffness (N/mm), F(x) is the excitation vector, Fo is the constant excitation force and (x) is the displacement vector (mm).

From modal analysis the natural frequency of the spindle is found by the material properties, structure, and the damping will have very little effect on the natural frequency of spindle bearing system, therefore F(x)=0, [6]

Equation of free vibration:

$$m\ddot{x} + kx = 0 \tag{2}$$

Assuming the spindle bearing system in the simple harmonic vibration

$$x(t) = x_o sin(\omega t + \emptyset) \tag{3}$$

Where: x_0 – Amplitude, ω – Angular frequency and ϕ – Phase angle. Substituting (3) in (2):

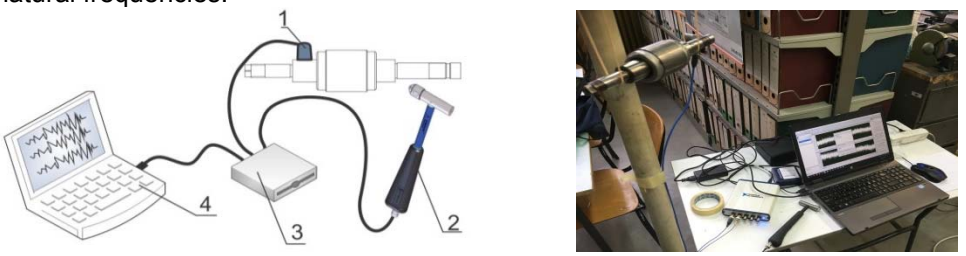
$$(k - \omega^2 M)\emptyset = 0 \tag{4}$$

The formula (4) is used to calculate the modes of spindle bearing system where ϕ_i(i = 1,2,3, …., n)

2.2 Experimental setup

In order to verify the numerical model, impact tests was performed on the spindle. The impact force was provided by the hammer Bruel & Kjaer type 8206 and the vibrations of the system were captured using the accelerometer PCB 352C33 as shown

on figure 3. The electrical signals from the sensor were transferred to the A/D converter, which converts them into digital signals. These were processed and analyzed by the data acquisition software and the final FFT graphs were plotted, the FFT provides values of natural frequencies.



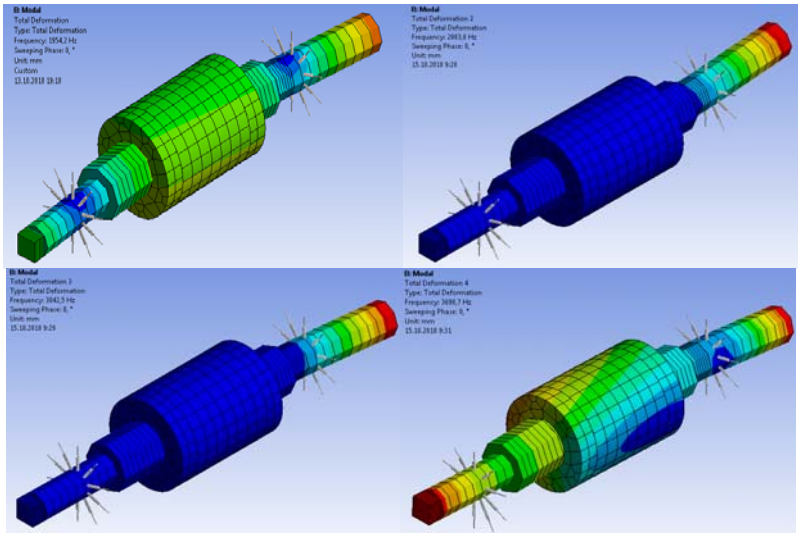
a) b)

Figure 3. *Experimental setup a) Scheme 1. sensor, 2. impact hammer, 3. A/D converter, 4. computer b) physical experiment*

3 RESULTS AND DISCUSION

3.1 Modal analysis

The analysis of dynamic characteristics of the spindle system includes natural frequencies. Figure 4 shows the first six natural frequencies of spindle. The spindle was not constrained along its longitudinal translational direction and also along its axis of rotation. This translational and rotational freedom was the reason for the first natural frequency is close to zero i.e., rigid body mode. Therefore, from modal analysis it is clear that the critical frequencies are well beyond the working speed. In [8] states that the maximum rotating speed cannot exceed 75 [%] of its critical speed. For first mode the working speed are 117252 [rpm], which is around 1/3 above the working range of spindle, 0 – 90000 [rpm].



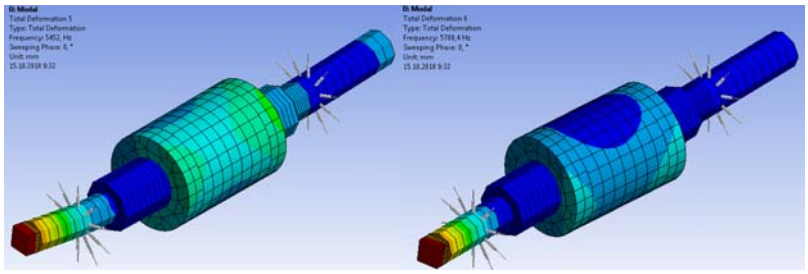


Figure 4. *First six mode shapes (respectively) for spindle system*

3.2 Critical speed and Campbell Diagram

In this paper, in order to prove previous notion i.e. investigate the dynamic behavior of the spindle at operating speeds, the Campbell diagrams, critical speeds are obtained. The numerical analyzes are performed considering speeds ranging from 0 to 90000 [rpm]. Figure 5 shows the Campbell diagrams obtained by the FEM model, where could be seen that the spindle is stable in whole range of revolution.

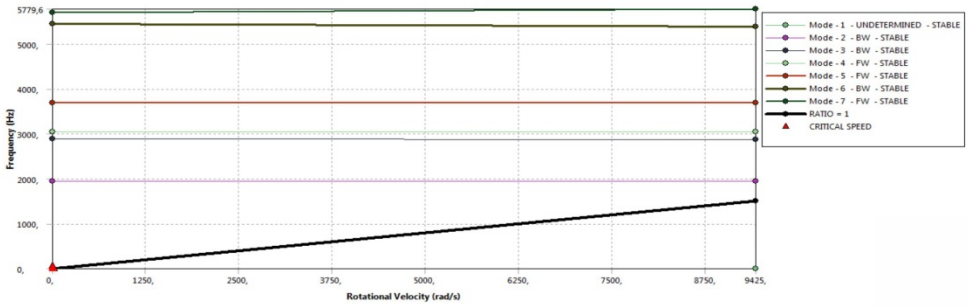


Figure 5. Campbell diagram from FEM model

3.3 Experimental results

The experimental vibrational analysis of the spindle was used for validation of the numerical model, procedure is discussed in previous chapter. From the experimental impact tests, the natural frequency of the spindle was measured and found value of first was 1907 [Hz], as shown on figure 6. A difference of around 2 [%], between the simulation and the experimental results of the spindle setup is acceptable.

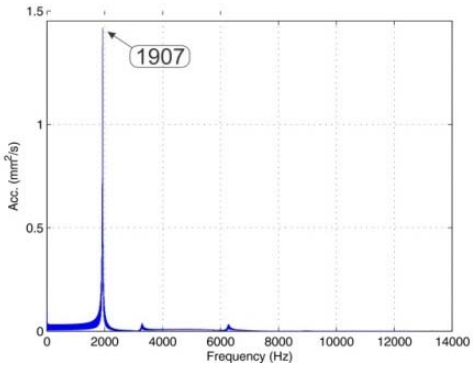


Figure 6. *FFT plot for spindle*

4 CONCLUSION

Spindle structure and bearings, plays an important role in failure of spindle bearing system. The mathematical model of the spindle system using beam elements was developed using, finite element method in ANSYS Workbench software using BEAM 188 for model, and COMBIN 14 element for modeling the bearing.

This approach was chosen because of its major advantage, which is that dynamic condition can be easily integrated with complex geometries and physical conditions, especially for any further analyses of the influence of temperature or static behavior of the spindle.

Impact test was carried out on spindle, with force provided by hammer and displacement were captured using accelerometer. Data acquisition system was used to measure and analyze the output from the accelerometers, and natural frequencies of the system were found from the FFT analysis.

On the other hand this paper presents a method for calculating natural frequencies, modal shapes. Additionally, the simulation errors of the natural frequencies are around 1 [%], which in turn confirms the effectiveness of the simulated model proposed in this paper.

ACKNOWLEDGMENT

In this paper some results of the project: Contemporary approaches to the development of special solutions related to bearing supports in mechanical engineering and medical prosthetics – TR 35025, carried out by the Faculty of Technical Sciences, University of Novi Sad, Serbia, are presented. The project is supported by the Ministry of Science and Technological Development of the Republic of Serbia.

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UTICAJ REŽIMA NA TEMPERATURU REZANJA

Obrad Spaić[1], Mirjana Jokanović[2], Aleksandra Koprivica[3], Miloš Lambeta[4], Veljko Vasiljević[5]

Rezime: Na složenost uslova koji vladaju u zoni rezanja, od kojih zavisi karakter i intenzitet trošenja reznih alata, utiče veliki broj faktora, kao što su: vrsta materijala alata i predmeta obrade, režimi rezanja (brzina rezanja, korak i dubina rezanja), geometrija reznog dijela alata i primjena sredstva za hlađenje i podmazivanje, kao i veći broj nekontrolisanih faktora. Trošenje reznih alata odvija se neprekidno u svim trenucima rezanja, kao i u svim uslovima obrade, što se odražava na promjenu oblika i dimenzija reznog dijela alata i izlaznih parametara procesa rezanja, kao što su: kvalitet obrađene površine, dimenzije predmeta obrade, temperatura rezanja, sile (otpori) i obrtni moment rezanja, dinamička krutost obradnog sistema itd. U ovom radu je analiziran uticaj režima rezanja na temperaturu rezanja, kao jedan od izlaznih parametara procesa rezanja i jedan od pouzdanih nosilaca informacija o fenomenu trošenja reznih alata, pri obradi struganjem brzoreznog čelika, alatima sa pločicama od tvrdog metala. Temperatura rezanja je mjerena pomoću termovizijske kamere FLIR E4.

Ključne riječi: režimi rezanja, temperatura rezanja, termovizijska kamera

THE INFLUENCE OF THE REGIMES ON THE CUTTING TEMPERATURE

Abstract: The complexity of the conditions that prevail in the cutting zone, on which the character and intensity of the cutting tools are dependent, is influenced by a large number of factors, such as: type of tool material and processing objects, cutting regimes (cutting speed, step and depth of cutting), cutting geometry tools and application of cooling and lubricating agents, as well as a number of uncontrolled factors. The cutting takes place continuously at all cutting times, as well as in all processing conditions, which reflects the change in the shape and dimensions of the

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cutting part of the tool and the output parameters of the cutting process, such as: the quality of the treated surface, the dimensions of the machining object, cutting temperature, forces (resistance) and cutting torque, dynamic rigidity of the treatment system, etc. This paper analyzes the influence of the cutting regime on the temperature as one of the output parameters of the cutting process and one of the reliable information of the phenomenon of wearing cutting tools when processing by turning, the high speed steel, with tools with hard metal plates. The cutting temperature was measured using the FLIR E4 thermal camera.

Key words: cutting regimes, cutting temperature, thermal imaging camera

1 UVOD

Glavni uzročnici trošenja reznog klina, kao krajnje negativne pojave, su visoki pritisci, visoke temperature i mehanička opterećenja koji vladaju u zoni rezanja. U tako složenim uslovima zone rezanja dolazi do razvoja triboloških procesa na sva četiri elementa tribomehaničkog sistema, čija je posljedica mehaničko, hemijsko i termičko trošenje reznih alata, koja se manifestuju kao habanje, krzanje i odlamanje i plastično deformisanje [1].

Relativno visoki pritisci, visoke temperature i mehanička opterećenja na kontaktnim površinama spregnutih parova (alata, strugotine i obrađene površine), kao i visoke relativne brzine spregnutih parova dovode do postepenog odnošenja čestica materijala sa kontaktnih površina alata, što ima za posljedicu promjenu geometrijskog oblika reznih elemenata alata u procesu rezanja, koja se naziva habanje alata.

Na brzinu, intenzitet i karakter procesa habanja reznog alata utiče veliki broj faktora kao što su: geometrijski, kinematički, metalurško-hemijski, te faktori vezani za mašinu itd [1, 2].

S druge strane, intenzitet i brzina habanja reznog klina utiču na stanje i ponašanje svih jedinica obradnog sistema i stoje u određenim korelacionim odnosima sa nizom karakteristika obradnog procesa. Ove karakteristike, odnosno signali, predstavljaju nosioce informacija o veličini i brzini habanja radnih elemenata reznog klina. Najčešće se, kao nosioci informacija (signali) o habanju alata u procesu rezanja, koriste: sile i otpori rezanja, obrtni momenti, temperature rezanja, karakteristike kvaliteta (dimenzije i površinska hrapavost obrađenih površina), vibracije i šum, snaga rezanja itd. [1, 3].

Za mjerenje habanja reznih alata, mogu se koristiti dvije grupe mjernih sistema: vanprocesni i procesni. Procesni mjerni sistemi obuhvataju veliki broj metoda, među kojima su najznačajnije direktne i indirektne. Usljed velike kompleksnosti direktnih metoda, kao alternativne, razvile su se indirektne metode mjerenja, čija je osnovna karakteristika jednostavnost principa i tehnika mjerenja.

Indirektne metode mjerenja habanja zasnivaju se na praćenju i mjerenju promjena na obratku, odvojenoj čestici ili promjena nekih veličina procesa, kao što su temperatura, sila, snaga, moment ili emisija zvuka.

Temperatura je najčešće mjerena veličina u procesima neprekidne proizvodnje i obuhvata oko 60% svih mjerenja u ovoj oblasti. I pored velike složenosti, za određivanje temperature rezanja, kao jednog od ključnih nosioca informacija o habanju reznog alata, razvijen je veći broj analitičkih, numeričkih i eksperimentalnih metoda.

Za mjerenje temperature tačke ili cijele površine, bez direktnog kontakta sa objektom čija se temperatura mjeri, razvijene su i metode zasnovane na zračenju. U

ovom radu je zavisnost temperature od režima rezanja mjerena termovizijskom kamerom, kao jednom od bezkontaktnih metoda zasnovanih na zračenju.

2 TERMOVIZIJA

Nazivi termovizija ili termogram potiču od grčke riječi *termo* - toplo i latinskog glagola *video, videre* - vidjeti, gledati i predstavlja sistem snimanja toplote posmatranog predmeta. Termovizijsko snimanje je bezkontaktna metoda mjerenja raspodjele temperature po površini posmatranog tijela. Zasniva se na znanju da sva tijela temperature veće od apsolutne nule u prostor odašilju elektromagnetne talase. U spektru elektromagnetskih talasa pojavljuje se i zračenje kome je uzrok temperatura tijela (toplotno zračenje) i to u području talasnih dužina od 3 do 400 *nm* - ultraljubičasto (UV) zračenje, od 0,4 do 0,76 *μm* - vidljiva svjetlost i u pojasu talasnih dužina od 1 do 1000 *μm* - infracrveno (IC) zračenje [4].

U ovom širokom području IC zračenja za praktičnu primjenu koristi se samo usko područje talasnih dužina od 0,7 do 20 *μm* [5].

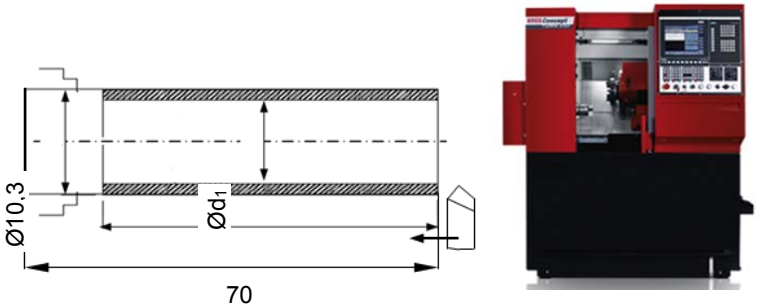
Kako IC zračenje nije vidljivo, za praktičnu primjenu se mora pretvoriti u drugi oblik energije: električnu, mehaničku ili hemijsku. To pretvaranje se vrši u IC uređajima koji se nazivaju termovizijska kamera, čija je uloga da prenese sliku iz oku nevidljivog područja u vidljivu sliku. Po spoljašnjem izgledu, kamera za termovizijsko snimanje, ne odstupa puno od filmskih kamera, a budući da je izrađena s ciljem da uoči dio infracrvenog spektra, koji je za ljudsko oko nevidljiv, često se naziva i infracrvenom kamerom [5].

Rezultati IC zračenja se prikazuju slikom koja se naziva termogram, a predstavlja registrovanu energiju zračenja. U savremenim termovizijskim kamerama integrisani su programski paketi pomoću kojih se, iz registrovane energije zračenja, jednostavno dobija temperatura površine objekta, uz uslov poznavanja vrjednosti fizičkih veličina kao što su temperatura i vlažnost vazduha, emitivnost objekta, udaljenost mjerenja itd. [5].

3 EKSPERIMENTALNE POSTAVKE I EKSPERIMENTALNO ISTRAŽIVANJE

U cilju istraživanja uticaja režima rezanja na temperaturu rezanja, kao jedan od pouzdanih nosioca informacija o trošenju reznih alata, izvedena su odgvarajuća eksperimentalna ispitivanja.

Eksperimentalna ispitivanja su izvedena u laboratoriji Fakulteta za proizvodnju i menadžment Trebinje, pri obradi pripremaka Φ 10,3 x 70 mm od čelika Č.7680 (S6-5-2, M2), na CNC strugu EMCO Concept Turn 250 (Slika 1).



Slika 1. *Obrada pripremka Φ 10,3 x 70 mm na CNC strugu*

Čelik Č.7680 pripada grupi standardnih molibdenovih brzoreznih čelika, velike žilavosti i odlične rezne sposobnosti u preporučenim uslovima obrade. Od svih brzoreznih čelika ovaj brzorezni čelik se u svijetu koristi u najvećim količinama i to najčešće u području grube obrade, dok za vrlo finu obradu i pored dobre rezne sposobnosti nije najprikladniji.

Struganje je izvedeno strugarskim nožem SDJCL 1212 F 07 8141 02, sa pločicom od tvrdog metala DCGT070202F-AL, KX, bez primjene sredstva za hlađenje i podmazivanje, prema Boks-Wilsonovom planu prvog reda, čija je plan matrica prikazana Tabelom 1.

Tabela 1. *Plan matrica Boks-Wilsonovog plan eksperimenta*

P L A N - M A T R I C A								
Eks. tačke	Kodirane vrijednosti				Stvarne vrijednosti			
	x_0	x_1	x_2	x_3	**a** [mm]	**n** [o/min]	**s**	
							[mm/o]	[mm/min]
1	+1	-1	-1	-1	0.25	2000	0.15	300
2	+1	+1	-1	-1	0.50	2000	0.15	300
3	+1	-1	+1	-1	0.25	3000	0.15	450
4	+1	+1	+1	-1	0.50	3000	0.15	450
5	+1	-1	-1	+1	0.25	2000	0.30	600
6	+1	+1	-1	+1	0.50	2000	0.30	600
7	+1	-1	+1	+1	0.25	3000	0.30	900
8	+1	+1	+1	+1	0.50	3000	0.30	900
9	+1	0	0	0	0.354	2450	0.212	520
10	+1	0	0	0	0.354	2450	0.212	520
11	+1	0	0	0	0.354	2450	0.212	520
12	+1	0	0	0	0.354	2450	0.212	520

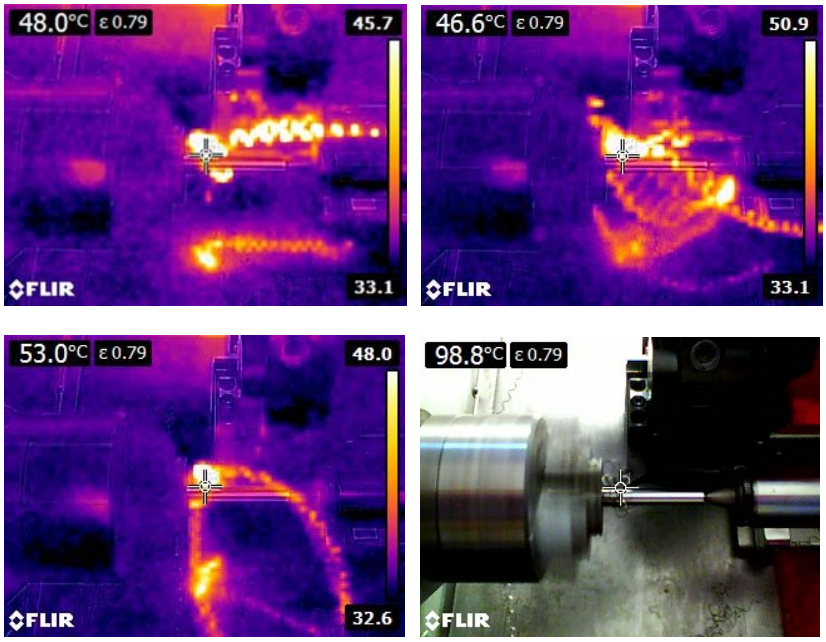
Snimanje raspodjele temperature po površini spregnutih parova kao i mjerenje temperature u tački kontakta predmeta rada i alata, pri dužini struganja l = 35 mm, izvedeno je termovizijskom kamerom FLIR E4. Prilikom izvođenja eksperimenta, vrijednost faktora emisivnosti izabrana je u zavisnosti od vrste materijala (brzorezni čelik), dok je baždarenje kamere izvršeno pomoću kontaktnog termometra. Termovizijska kamera sa osnovnim karakteristikama prikazana je na Slici 2.

Dimenzije	244x95x140 mm
Težina sa baterijom	0,575 g
Ekran	3 in; 320x240 LCD u boji
Polje snimanja	45˚x 34˚
Frekvencija slike	9 Hz
Rezolucija dig. kamere	640x480; 55˚x43˚
Tačnost mjerenja	+/- 2˚C
Raspon mjerenja	-20-250˚C
Način snimanja slike	Termalna, digitalna i MSX®



Slika 2. *Izgled kamere sa njenim osnovnim karakteristikama*

Za sve kombinacije režima rezanja, prikazane plan matricom (Tabela 1), snimljena su po 4 snimka, pri čemu su po tri snimka urađena pomoću MSX® moda na termovizijskoj kameri, koji predstavlja kombinaciju termalnog moda sa jasnim konturama predmeta i po jedan snimak digitalnog moda, koji u centralnoj tački prikazuje temperaturu, ilustrovano na slici 3.



Slika 3. *Snimci termovizijske kamere kod prvog režima rezanja*

Rezultati sva četiri mjerenja temperature u izabranoj tački kontakta radnog predmeta i alata, za sve planirane kombinacije režima rezanja, prikazani su u Tabeli 2.

Tabela 2. *Rezultati mjerenja temperature u tački kontakta predmeta rada i alata*

P L A N - M A T R I C A												
Eks. tačke	Kodirane vrijednosti				Stvarne vrijednosti				Vektor izlaza [T]			
					a	**n**	**s**		Mjerenje [˚C]			
	x_0	x_1	x_2	x_3	[mm]	[o/min]	[mm/o]	[mm/min]	I	II	III	IV
1	+1	-1	-1	-1	0.250	2000	0.150	300	48	46.6	**53**	98.8
2	+1	1	-1	-1	0.500	2000	0.150	300	**47.3**	76.2	76.6	139
3	+1	-1	1	-1	0.250	3000	0.150	450	92.5	**47.8**	105	97.8
4	+1	1	1	-1	0.500	3000	0.150	450	**37.1**	37.8	127	62.8
5	+1	-1	-1	+1	0.250	2000	0.300	600	**85.9**	60.1	105	170
6	+1	1	-1	+1	0.500	2000	0.300	600	46.5	**52.1**	37.9	87
7	+1	-1	1	+1	0.250	3000	0.300	900	47	111	106	**73.1**
8	+1	1	1	+1	0.500	3000	0.300	900	91.8	127	44	**46.8**
9	+1	0	0	0	0.350	2450	0.212	520	**50.4**	36.2	94.4	111
10	+1	0	0	0	0.350	2450	0.212	520	**58.7**	87.8	87.6	77.6
11	+1	0	0	0	0.354	2450	0.212	520	76.9	112	124	**67.1**
12	+1	0	0	0	0.354	2450	0.212	520	153	54	**59.9**	88.4

Iako je temperatura mjerena 4 puta, za svaku kombinaciju režima rezanja, navedenih u tabeli 1, u istom trenutku, došlo je do velikog rasipanja izmjerenih veličina. U nekim slučajevima, za isti režim rezanja, razlika u izmjerenoj temperaturi iznosila je i do 100 ˚C. Ova odstupanja potvrđuju činjenicu da je teško pozicionirati kameru da svaki put mjeri temperaturu u istoj tački predmeta rada ili alata. Osim toga čest je i slučaj da strugotina zakloni pozicioniranu tačku. Tako je temperatura nekada mjerena na predmetu rada, nekada na alatu, a nekada na strugotini. Iz teorije rezanja je poznato da strugotina odvodi najveći dio stvorene toplote, a alat najmanji, kao i da je koeficijent emisije toplote, od čije vrijednosti zavisi izmjerena temperatura, u funkciji karakteristika površine čija se temperatura mjeri.

S obzirom da je veoma teško pozicionirati termovizijsku kameru FLIR E4 za mjerenje temperature u izabranoj tački alata ili predmeta rada, dobijeni rezultati temperature nisu pouzdani za praćenje stanja alata. Međutim, u ovom radu su, za matematičko modeliranje temperature rezanja, iz dobijenih rezultata izabrane vrijednosti temperature (boldirane vrijednosti u Tabeli 2) za koje se smatra da pripadaju izabranoj tački na predmetu rada.

3.1 Matematičko modeliranje temperature rezanja

Za adekvatno opisivanje funkcije temperature rezanja, u zavisnosti od režima rezanja, kao uticajnih faktora, može se koristiti empirijski model, u obliku složene stepene funkcije:

$$T = C_T \cdot a^{x_1} \cdot n^{x_2} \cdot s^{x_3} \tag{1}$$

na koji se, nakon linearizovanja, može primijeni ortogonalni plan prvog reda sa konstantnim članovima oblika:

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 \text{ , gdje je} \tag{2}$$

$$y = \ln T,\ b_0 = \ln C_T,\ x_1 = \ln(a),\ x_2 = \ln(n) \text{ i } x_3 = \ln(s).$$

Korespodentna plan matrica, sa rezultatima ispitivanja (eksperimenta) prikazana je Tabelom 2, a kodiranje je izvedeno pomoću jednačina transformacije.

$$X_1 = 2\frac{\ln(D) - \ln(D_{max})}{\ln(D_{max}) - \ln(D_{min})} + 1,$$

$$X_2 = 2\frac{\ln(n) - \ln(n_{max})}{\ln(n_{max}) - \ln(n_{min})} + 1 \text{ i} \tag{3}$$

$$X_3 = 2\frac{\ln(s) - \ln(s_{max})}{\ln(s_{max}) - \ln(s_{min})} + 1$$

Vrijednosti parametara modela dobijene su primjenom obrazaca (4) i prikazane u Tabeli 3.

$$b_0 = \frac{1}{M}\sum_{u=1}^{M} x_{0u} \cdot y_u$$

$$b_i = \frac{1}{N}\sum_{u=1}^{N} x_{iu} \cdot y_u,\ (i = 1,2,\ldots,k) \tag{4}$$

$$b_{ij} = \frac{1}{N}\sum_{u=1}^{N} x_{iu} \cdot x_{ju} \cdot y_u,\ (i,j = 1,2,...,k)$$

Računske vrijednosti odnosa varijansi (Studentovih kvantiteta) mjerodavanih za ocjenu značajnosti parametara modela, prema Student-ovom kriterijumu, dobijeni su po obrazcu (5) i takođe prikazani u Tabeli 3.

$$t_{bi} = \frac{|b_i| \cdot \sqrt{N}}{s_E} \tag{5}$$

Tabela 3. *Parametri modela i Studentovi kvantiteti*

Parametri modela i Studentovi kvantiteti								
Parametri modela	b_0	b_1	b_2	b_3	b_{12}	b_{13}	b_{23}	b_{123}
	4,0033	-0,1641	-0,0768	0,1546	-0,0107	-0,0723	0,0097	0,0242
Studentovi kvantiteti	t_{b0}	t_{b1}	t_{b2}	t_{b3}	t_{b12}	t_{b13}	t_{b23}	t_{b123}
	112,625	3,77	1,765	3,551	0,246	1,662	0,223	0,556
Ocj. sign.	signif.	signif.	nesign.	signif.	nesign.	nesign.	nesign.	nesign.

Ocjena signifikantnosti parametara modela prvog i nepotpunog drugog reda primjenom Student-ovog kriterijuma, izvedena je za usvojeni nivo značajnosti α = 0,05 i stepene slobode:

$$f_{b0} = M - 1 = 11 \text{ i}$$

$$f_{bi} = N - 1 = 7,$$

za koje su tablične vrijednosti Studentovih kvantiteta [6]:

$$t_{t0,1-\alpha/2,11} = 2{,}20 \text{ i}$$

$$t_{ti,1-\alpha/2,7} = 2{,}36.$$

Izračunate vrijednostima Studentovih kvantiteta t_{bi} se porede sa tabličnim vrijednostima t_{ti}, i ako se pokaže da je $t_{bi} > t_{ti}$ za određeni nivo značajnosti (α), nulta hipoteza da je odstupanje datog parametra od nule posljedica djelovanja slučajnih faktora, a ne mjerljivih upravljivih faktora, se odbacuje, pa je parametar modela b_i signifikantan ($\beta_i \neq 0$). U suprotnom slučaju nulta hipoteza se prihvata, odnosno parametar modela je nesignifikantan ($\beta_i = 0$).

I ocjene signifikantnosti parametara modela navedene su u tabeli 3, iz koje se vidi da su nesignifikantni parametri b_2, b_{12}, b_{13}, b_{23} i b_{123}, pa se, nulta hipoteza ($\beta = 0$) ne odbacuje na usvojenom nivou značajnosti, odnosno nesignifikantni parametri modela mogu se isključiti iz modela, ne korigujući vrijednosti signifikantnih parametara.

Međutim, zbog postizanja tačnijih rezultata, u ovom radu, i nesignifikantni parametri su zadržani u modelu.

Na osnovu navedenih parametara došlo se do empirijskog modela temperature rezanja:

$$Y = 4{,}003 - 0{,}164 x_1 - 0{,}077 x_2 + 0{,}154 x_3 \tag{6}$$

Vraćanjem na prvobitne koordinate, preko jednačina transformacije 3, dobijen je konkretni empirijski model temperature rezanja:

$$T = \frac{1287{,}56 \cdot s^{0{,}446}}{a^{0{,}474} \cdot n^{0{,}379}} \tag{7}$$

Provjera adekvatnosti definisanog modela izvršena je po Fišer-ovom kriterijumu, tako što je izračunat disperzioni odnos F_{rLF} po obrazcu (8) i upoređen sa tabličnom vrijednosti.

$$F_{rLF} = \frac{s_{LF}^2}{s_E^2} \tag{8}$$

gdje su:

S_{LF} - disperzija srednjih vrijednosti eksperimentalnih rezultata u odnosu na liniju regresije,

S_E - greška eksperimenta.

Navedena provjera pokazuje da je model adekvatan jer je disperzioni odnos:

$$F_r = 0{,}787 < F_{t(5\%;5;3)} = 9$$

4 ZAKLJUČCI

Jedna od osnovnih eksploatacionih karakteristika alata, kao i jedna od osnovnih funkcija obradivnosti materijala predstavlja funkcija postojanosti alata. Kako postojanost alata, u prvom redu, zavisi od intenziteta, karaktera i brzine habanja pojedinih reznih elemenata, praćenje habanja reznih elemenata alata daje najvjerniju sliku o stanju alata u realnom vremenu.

Kao alternativa kompleksnim direktnim metodama mjerenja habanja alata razvile su se indirektne metode mjerenja, koje se zasnivaju na praćenju i mjerenju promjena na obratku, odvojenoj čestici ili alatu. Jedna od pouzdanih nosilaca informacija o fenomenu habanja alata je temperatura rezanja.

Matematičko modeliranje temperature rezanja, primjenom potpunih ortogonalnih planova prvog reda, izvedeno na osnovu rezultata eksperimentalnih ispitivanja, pri struganju brzoreznog čelika, pokazuje da temperatura rezanja zavisi od većine variranih faktora. Međutim, važno je napomenuti da je prilikom mjerenja temperature rezanja termovizijskom kamerom FLIR E4 došlo do velikog rasipanja izmjerenih veličina, tako da se ne može smatrati pouzdanom metodom praćenja stanja alata.

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LAYERS OPTIMISATION OF THE PLA PARTS FORMED BY ADDITIVE TECHNOLOGIES

Miloš Pjević[1], Mihajlo Popović[2], Ljubodrag Tanović[3], Radovan Puzović[4], Goran Mladenović[5],

Abstract: Achieving required layer quality and its consistency is one of the key things for the effective implementation of the additive technologies, such as 3D printing. Experiments which were conducted at the Department of the Production Engineering, Faculty of Mechanical Engineering, University of Belgrade, were acquired optimal parameters that led to better parts quality produced of PLA polymer with widely used commercial 3D printers. Parameters that were varied during the experiments were nozzle temperature and printing speed. After production, all parts were microscopically observed and their surfaces roughnesses were measured. It is established that different values of these parameters can lead to diametrically different quality of layers that cause different quality of the printed parts.

Key words: Rapid prototyping, 3D printing, PLA polymer, Layer quality

1 INTRODUCTION

Rapid prototyping [1-3], need for custom parts, requirements for the complex shape parts for medical purpose [4-8], etc. are one of the main reasons for introducing additive technologies. Conventional technologies such as cutting or plastic deformation are very expensive to be applied in these fields and, on the other hand, inadequate in some cases [9]. The intensive development of additive technologies has led to the possibility of parts producing using different types of starting material which play a key role in the Additive Manufacturing process (liquid resin, polymer powder, polymer filament, polymer films) [9-11]. As the deposition of these material layers is accomplished by different methods, additive technologies can be divide into many groups, and one of them is Fused Filament Fabrication (FFF). This method of forming the parts that belongs to additive technology was created in early 1990s. The accuracy of the obtained parts

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depends from generated shrinkage [12]. Fused Deposition Modeling (FDM)/Fused Filament Fabrication (FFF) and Stereolithography (SLA) present two most common 3D printing technologies nowadays [13]. First of these two technologies (FFF/FDM) uses preformed polymer as the building material in the form of filament. Practical use of these technology to the real application is widespread among industries and household around the world. One of the reasons is that these technologies are very simple to use. However, producing the parts that meet required surface roughness and part geometry can be very hard.

2 FUSED FILAMENT FABRICATION

By using the Fused Filament Fabrication method (Figure 1), parts are being built by the layers deposition of melted polymer. At first they are build on the printing bed, and later every new layer is formed on the previous one. As have been already told, this method uses preformed polymer in the way of filament that can be different sizes (diameter of the filament). Printing nozzle is fed with the filament by the feeder that pools the filament from the spool. Speed of pooling the filament is in the function of the printing bed travelling speed. As the polymer travels through the nozzle, it becomes melted, which is then applied to the desired surface according to the programmed path of the printing bed, and in some cases nozzle or combined. In order to maintain the stickiness of the first layer on the printing bed, printing bed needs to be heated to the certain temperature that depends of the polymer itself. To achieve fast curing of the melted polymer, special part cooler has to be used. Moreover, for preventing melting the filament in the nozzle throat, nozzle cooler is needed.

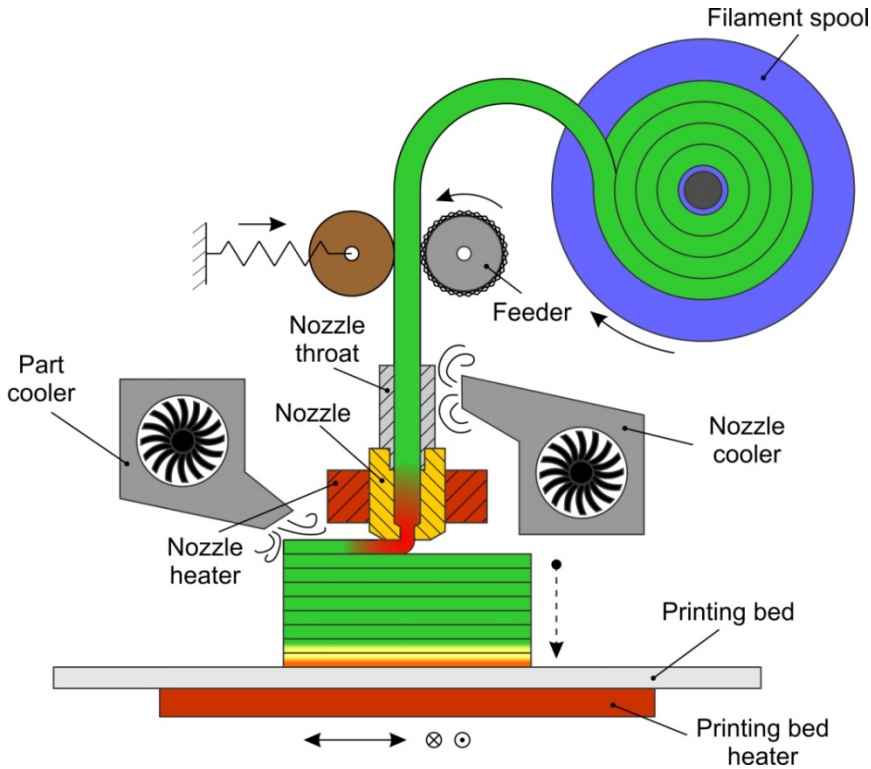


Figure 1. *Schematic representation of Fused Filament Fabrication method*

3 DEFINING OF THE ISSUE

Filaments which are printed can be formed from various materials such as PLA, ABS, etc. Each of these materials have their recommended melting or printing temperature, that values in the range from 170 up to 255 °C. However, not all temperatures provide the same printing results. Adequate binding of the layers directly depends on the printing temperature. Moreover, consistency and desired shape of the layer, and essentially, the entire part geometry depends on the printing temperature. Depending on how the layers are bonded, the roughness of the surface may vary.

Another parameter that can significantly affect the quality of the layer or whole part is the printing speed. In the most cases, the printing speed is in the function of the rigidity of the printer itself.

In order to make the product that meets the minimum requirement in the way of surface quality, geometry and integrity of the structure, it is necessary that these parameters be precisely determined. This is also the goal of this paper, more precisely, to determine printing temperature and optimum printing speed for making the parts of PLA polymer on commercial 3D printer.

4 EXPERIMENTAL SETUP

Conducted experiments were based on the formation of the parts that had same dimensions and geometry (Figure 2). Parts were printed from PLA polymer by varying the printing temperature and speed, whose values are in the Table 1.

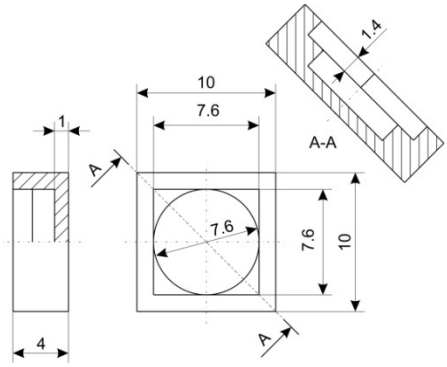


Figure 2. *Test part drawing.*

Printing bed was being preheated on the 60 °C which is adequate for achieving stickiness of the first layer to the printing bed. In order to achieve faster curing of the layers, during every experiment, part cooler was used. Height value of every layer was selected to be 0.2 mm. In order to achieve more smoother surface, layer height can be even lower, but the printing time is increased.

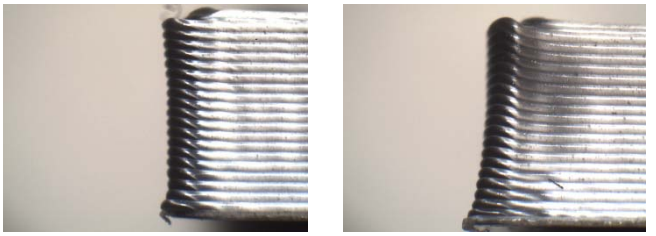
After printing of the parts was finished (15 in total), each part was microscopically observed for analyzing bindings of the layers and possible undesired phenomena. Moreover, roughness of the outer surfaces was measured in order to determine the influence of the varied parameters.

Table 1. *Experiment plan*

Exp. no.	Printing temperature [°C]	Printing speed [mm/s]
1.	170	40
2.		80
3.		120
4.	180	40
5.		80
6.		120
7.	190	40
8.		80
9.		120
10.	200	40
11.		80
12.		120
13.	210	40
14.		80
15.		120

5 RESULTS

Before the printing process or the first part of the experiments were conducted, it was necessary to establish if the part cooler was necessary to be used. After tests, it was determined that the part cooler exclusion led to high intensity of the part deformation. This could be explained as the consequence of the insufficiently fast part curing (Figure 3).



a) b)

Figure 3. *Side surfaces profiles a) with and b) without part cooler.*

Even when the part was cooled by a cooler, there was a slight degree of deformation between the initial layers due to the heating bed. This led to unequal curing of the whole part.

In the next conducted experiments done by the plan presented in the Table 1, 15 parts, in total, were formed. In order to determine the influence of the regimes on the parts geometry, side surfaces profiles of the every printed part were measured. It was determined that the best results were obtained when the nozzle temperature value was 180 °C and the printing speed 40 mm/min (Figure 4). Partially poorer printing results were obtained while the value of the nozzle temperature was 190 °C. In the case when

the nozzle temperatures were lower, printing speed had a major impact on the print quality, while with the nozzle temperature increase, this influence became negligible.

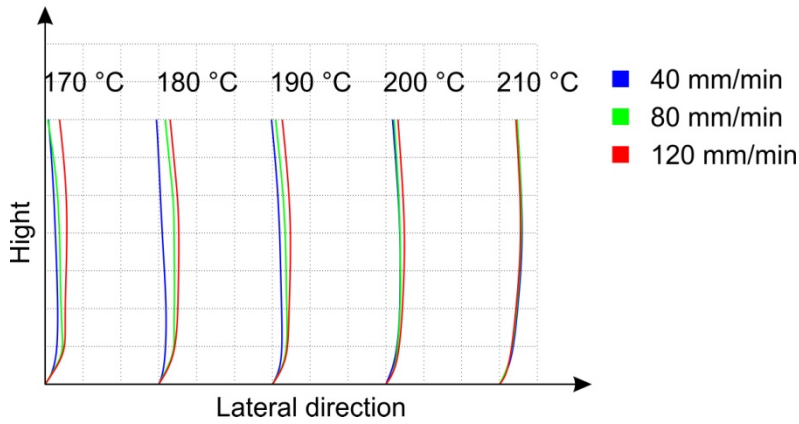


Figure 4. *Profiles of the side surfaces in the function of nozzle temperature and printing speed.*

With the increase of the nozzle temperature, longer time was necessary for layer to be cured. During this time, in small percentage, layer became squeezed and more oval. The greater the nozzle temperature, the greater the degree of the layer deformation was (Figure 5).

Results from microscopic observations were presented in the Figure 6. It can be observed clearly visible change in the part quality, depending on the nozzle temperature and printing speed. During the change of the printing nozzle direction, it was very important to obtain desired edge geometry of the printed part. By varying the nozzle temperature and printing speed, for the PLA polymer, the best results of the 3D printing when changing the direction of the nozzle (print) can be expected when the value of the nozzle temperature is 180 °C and the printing speed 40 mm/min (Figure 6). Moreover, the best upper surface quality was obtained with the same parameters of the 3D printing. For both types of nozzle trajectory, it can be clearly seen that with the increase of the nozzle temperature, a shiner surfaces were obtained. The dominant influence of the printing speed referred to the part quality in the form of unwanted phenomena caused by vibration of the system. These undesired phenomena can be clearly seen on the horizontal surfaces in the Figure 6 in terms of the variable density of the applied layer.

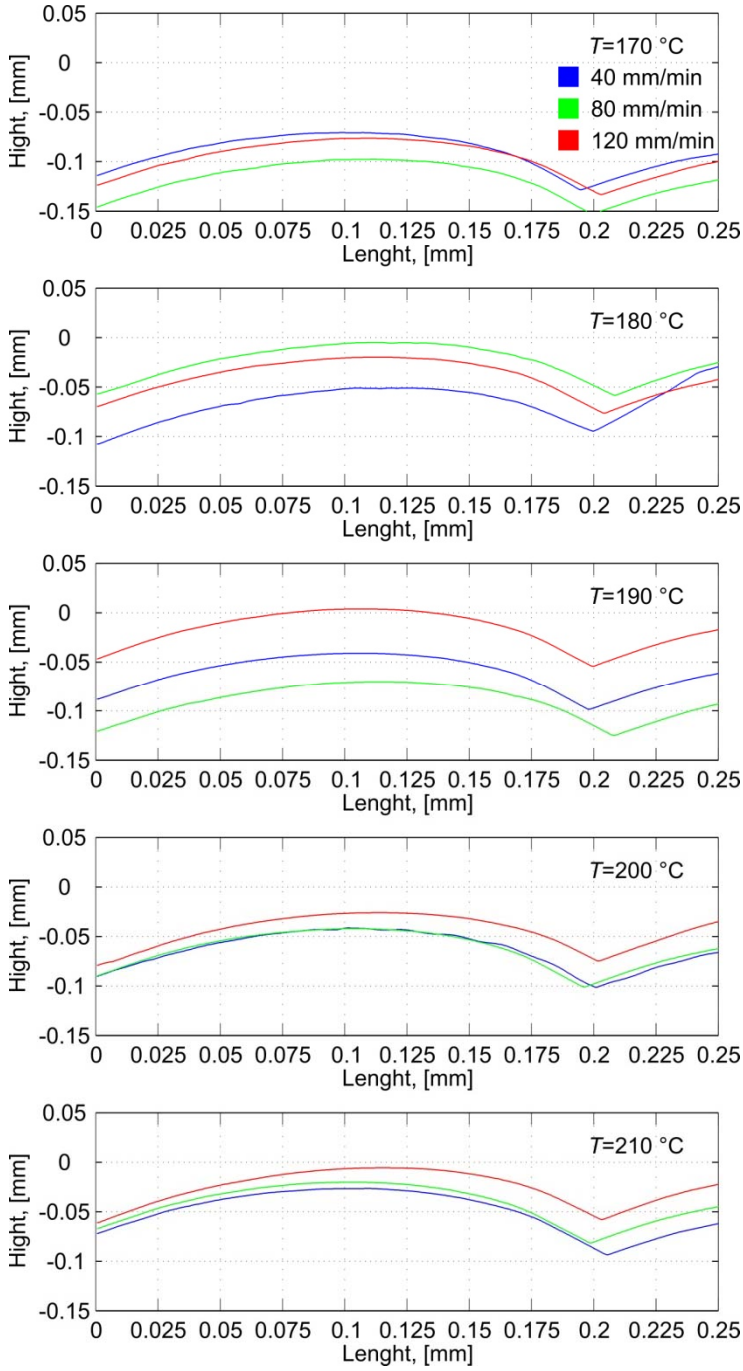


Figure 5. *Profiles of the layers in the function of nozzle temperature and printing speed.*

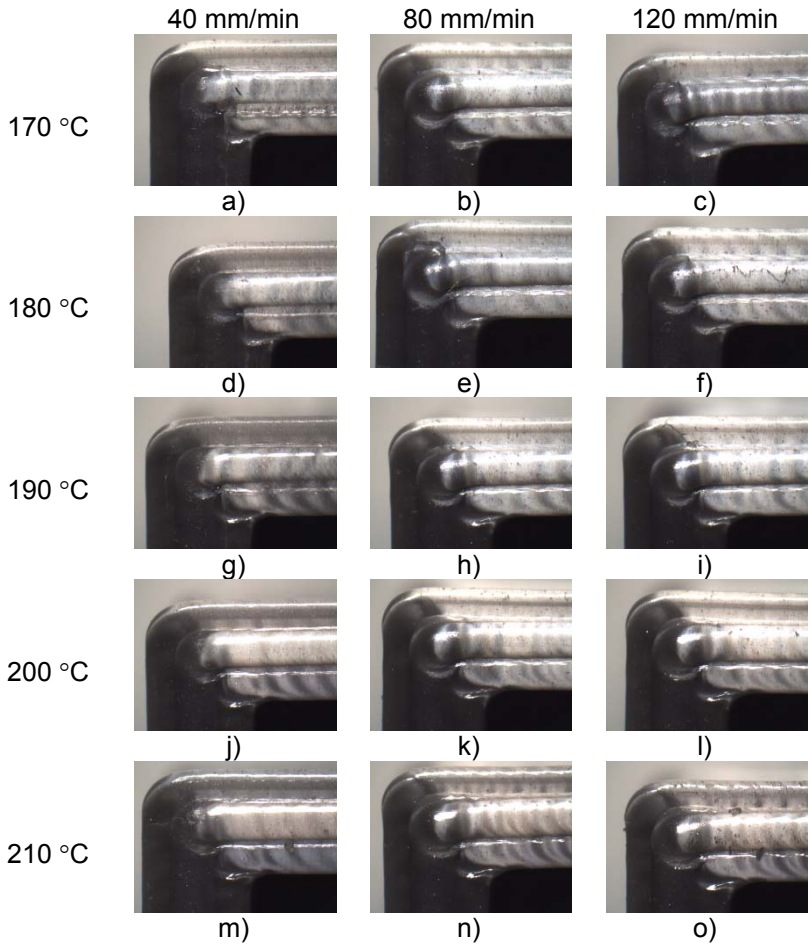


Figure 6. *Corner and upper surface results.*

6 CONCLUSION

Usage of the Fused Filament Fabrication (FFF) technologies has great potential in the different industries such as military, pharmaceutical, automotive, etc.. One of the main problems that arise in its application is obtaining a part with desired quality, which mainly depends on the process regimes.

With the experiments conducted at the Department of Production Engineering, Faculty of Mechanical Engineering, University of Belgrade, optimal parameters for the production of the parts of PLA polymers using Fused Filament Fabrication (FFF) technology were determined.

It was found that the best parts quality was obtained in the case when the value of the nozzle temperature was 180 °C, and the printing speed 40 mm/min, although the recommendation of the polymer manufacturer for the nozzle temperature value was 215 °C. Additionally, by using the part cooler, better part geometry was achieved. When printing the parts with higher nozzle temperatures, 200 °C and above, printing speeds did not have a significant impact on the quality of the tested parts.

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MONITORING POTROŠNJE SNAGE PRI GLODANJU POMOĆU UTROŠENE ELEKTRIČNE ENERGIJE

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Rezime: Danas su preduzeća prinuđena da smanjuju potrošnju energije zahvaljujući visokim troškovima energije, rastućim zahtevima proizvodnje i problemima životne sredine. Za postizanje ovog cilja potreban je tačan model potrošnje energije. U ovom radu je za procenu potrošnje energije predložen model zasnovan na empirijskom modeliranju i eksperimentima pri procesu glodanja. Eksperimentalni rezultati pokazuju da model može lakše i preciznije predvideti potrošnju energije pri glodanju. Prikazana je takođe i analiza uticaja uslova rezanja na potrošnju energije i modeliranje pomoću centralnog kompozicionog plana. Model je od velike vrednosti za razvoj energetski efikasnih strategija optimizacije procesa obrade.

Ključne riječi: model potrošnje energije, proces glodanja, režimi rezanja

POWER CONSUMPTION MONITORING IN MILLING WITH CONSUMED ELECTRICITY

Abstract: Manufacturing enterprises are forced to reduce energy consumption due to high energy costs, growing production demands, and environmental problems in today's days. An exact energy consumption model is urgently needed to achieve this goal. In the paper, a model based on empirical modeling and experiments is proposed to estimate energy consumption for the milling process. Experimental results show that the model can make more light and accurate predictions of energy consumption. Presented is the analysis of the influence of cutting conditions on power consumption and response surface central compositional model. The model is of great value to develop energy - efficient optimization.

Key words: power consumption model, milling process, cutting conditions

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1 UVOD

U današnje vreme se prirodni resursi ozbiljno troše. Očekuje se da će mnogi energetski resurse biti iscrpljene ako se trenutna brzina potrošnje nastavi u narednim decenijama. Preduzeće za proizvodnju naročito troši veliku količinu energije i ima veliki uticaj na životnu sredinu [1, 2]. Danas se proizvodne kompanije suočavaju sa velikim pritiskom zbog moguće cene energije i jačanjem vladinog zakonodavstva za održivost i zaštitu životne sredine. Štaviše, proizvodnja energije, koja je uslovljena velikom potražnjom potrošača, ima veliki uticaj na emisiju CO_2 i klimatske promene [3]. Stoga smanjenje potrošnje energije u proizvodnim procesima ne samo da ekonomski koristi proizvodnoj industriji, već će nam pomoći da unapredimo našu životnu sredinu u dugoročnom periodu, a proizvodne industrije postaju sve više zainteresirane za energetski efikasne i ekološke benigne proizvodne procese.

Modeli potrošnje energije alatnih mašina mogu se podeliti u dve kategorije: modeli zasnovani na stanju mašine i modelima zasnovanim na parametrima procesa obrade [4]. Potrošnja energije uzimajući u obzir razne mašine, u obzir je isključenje mašina, start, zaustavljanje u slučaju nužde, mašina spremna, aktivni pogoni, vreteno i nastajanje strugotine [5].

U ovom radu predlaže se novi model zasnovan na empirijskom modeliranju i eksperimentima za procenu potrošnje energije za postupke obrade. Eksperimentalni rezultati pokazuju da novi model može preciznije predvideti potrošnju energije u odnosu na postojeće modele. Novi model je od velike koristi preduzećima za razvoj energetski efikasnih strategija optimizacije [6].

Rad [7] predstavlja generalizovani model matematičkog predviđanja snage postupka glodanja koji se koristi u proizvodnji. Predloženi model je eksperimentalno verifikovan upoređivanjem modelske i izmerene potrošnje energije.

Analizirana je efektivna snaga rezanja na obrađenoj površini, a integral od gustine energetske snage iznad dubine i snage uskladištene energetske sile trebalo bi da budu energetski kriterijumi ostatka stresnog polja. Integral gustine napona preko dubine raste linearno sa efektivnom snagom rezanja pod eksperimentalnim uslovima kao u studiji [8].

Brza metoda za procenu potrošnje energije za rezanje mašinšine alatke data je za drugi model. Pored toga, rad [9] daje unapređeni model snage rezanja, koji uzima u obzir uticaj brzine rotacije vretena na snagu skidanja materijala tokom procesa glodanja.

Studija u kojoj je izvršena energetska i eko-efikasnost proizvodnih procesa nalazi se u radu [10].

2 METODA I EKSPERIMENT

Prilikom izvođenja eksperimenta korišćena je glava za glodanje proizvodnje "JUGOALAT" G.037 Ø100 mm sa mehanički pričvršćenim pločicama od tvrdog metala sa sledećim karakteristikama: - broj zuba z = {1, 2, 3, 4, 5} -napadni ugao k = 75 ° grudni ugao = 0 °. Korišćene su izmenljive pločice kvaliteta P25 od tvrdog metala. Eksperiment je obavljen na obratku od sivog liva, koji je stegnut na sto vertikalne glodalice FSS.

2.1 Snaga tokom obrade

Ukupna snaga modela potrošnje energije, Pc je podeljena na dve komponente. - Pr (snaga potrebna za uklanjanje materijala) - Pcp (potrošnja energije tokom rada mašine u praznom hodu) Pod uticajem Pr parametara rezanja i materijala radnog

komada imaju vezu sa silama rezanja. Na osnovu teorije dinamike proizvođača, postupak uklanjanja materijala završava se okretanjem vretena i pomeranjem koje pokreće glavni motori i servomotori. Shodno tome, potrošnja energije tokom procesa stvaranja materijala može se izračunati dodavanjem rotacije vretena. Snaga vretena i snaga servo (servo motor snage), mogu izračunati sile rezanja Fi pomnožene brzinom glavnog kretanja i duž pravca komponente sile rezanja. Pcp (potrošnja energije u praznom hodu) odnosi se na potrošnju energije sile pomoćnog kretanja. Zahvaljujući dodatnom opterećenju tokom mašinske obrade, potrošnja pomoćnih komponenti Pcp se razlikuje od potrošnje u stanju mirovanja. Sa druge strane, Pcp je povezana sa parametrima kretanja i drugim uslovima pri rezanju.



Slika 1. *Proces i alat*

2.2 Merenje električne energije

HIOKI PV3360-20 električni merač snage je uređaj koji može meriti količine električne energije od jednofaznih do trofaznih i četvoro žičnih sistema. Osim osnovnih merenja koja uključuju napon, struju, faktor snage, energiju, ovaj instrument može meriti tražnju i harmonična merenja koji su važni parametri u upravljanju energijom. Podržava i prikupljanje podataka i automatsko merenje zahvaljujući korišćenju SD memorijske kartice i USB / LAN interfejsa.

Kliješta za merenje su povezana u željenom pravcu kao što je prikazano na slici, zbog smera protoka struje, inače će se dobiti negativne vrednosti. Naponski kablovi su priključeni na ulazne priključke instrumenta. Instrument se isporučuje sa jednim crvenim, crnim, žutim i plavim naponskim kablom i aligatorskim klipovima koji se nalaze na drugoj strani kabla. Crni priključak se stavlja na neutralan (neutralan), drugi po redosledu su crveni, žuti i plavi, a oni se postavljaju na faze. PV3360-20 može da memoriše sledeće podatke na SD kartici ili u sopstvenoj unutrašnjoj memoriji:

- snimanje i merenje (.csv)
- harmonični podaci (.hrm)
- snimak s ekrana (.bmp)
- dužinu talasa (.vui)
- podešavanja (.set)

Pover Logger Viever je softverska aplikacija namenjena za crtanje dijagrama zasnovanih na mernim podacima memorisanim sa uređajem PV3360.

Table 1. *Nivoi eksperimentalnih parametara*

Nivoi	Brzina rezanja (m/min)	Brzina rezanja (m/s)	Pomak (mm/z)	Dubina rezanja (mm)	Broj obrtaja (o/min)
Najveća +2	351,86	5,864	0.223	2.6	1120
Velika +1	282,74	4,712	0.177	1.72	900
Srednja 0	223,05	3,717	0.141	1.14	710
Mala -1	175,93	2,932	0.112	0.75	560
Najmanja -2	141,37	2,356	0.089	0.5	450

Table 2. *Plan Eksperimenta*

Redni broj	Kod faktora				Faktor			Izmerena snaga	Rezimi obrade	
	x_0	x_1	x_2	x_3	v [m/s]	s_1 [mm/z]	a [mm]	Pi [kW]	n [o/min]	S [mm/min]
1	1	-1	-1	-1	2.93	0.112	0.75	1.69	560	63
2	1	1	-1	-1	4.71	0.112	0.75	2.10	900	100
3	1	-1	1	-1	2.93	0.177	0.75	1.75	560	100
4	1	1	1	-1	4.71	0.177	0.75	2.28	900	160
5	1	-1	-1	1	2.93	0.112	1.72	1.87	560	63
6	1	1	-1	1	4.71	0.112	1.72	2.43	900	100
7	1	-1	1	1	2.93	0.177	1.72	2.05	560	100
8	1	1	1	1	4.71	0.177	1.72	2.69	900	160
9	1	0	0	0	3.71	0.141	1.14	2.00	710	100
10	1	0	0	0	3.71	0.141	1.14	2.02	710	100
11	1	0	0	0	3.71	0.141	1.14	2.03	710	100
12	1	0	0	0	3.71	0.141	1.14	2.02	710	100
13	1	-2	0	0	2.35	0.141	1.14	1.60	450	63
14	1	2	0	0	5.86	0.141	1.14	2.67	1120	160
15	1	0	-2	0	3.71	0.089	1.14	1.97	710	63
16	1	0	2	0	3.71	0.223	1.14	2.24	710	160
17	1	0	0	-2	3.71	0.141	0.5	1.79	710	100
18	1	0	0	2	3.71	0.141	2.6	2.51	710	100
19	1	-2	0	0	2.35	0.141	1.14	1.62	450	63
20	1	2	0	0	5.86	0.141	1.14	2.65	1120	160
21	1	0	-2	0	3.71	0.089	1.14	1.95	710	63
22	1	0	2	0	3.71	0.223	1.14	2.16	710	160
23	1	0	0	-2	3.71	0.141	0.5	1.79	710	100
24	1	0	0	2	3.71	0.141	2.6	2.50	710	100

Dodatni eksperimenti su prikazani u Tabeli 3. na osnovu kojih su analizirani dijagrami zavisnosti uticajnih faktora. U tabeli 4. su prikazane izmerene i modelirane vrednosti koristeći softverski paket SF1001.

.

Table 3. *Dodatni eksperimenti*

Redni broj	*Kod faktora*				*Faktor*			*Izmerena snaga*	*Rezimi obrade*	
	x_0	x_1	x_2	x_3	*v [m/s]*	s_1 *[mm/z]*	*a [mm]*	*Pi [kW]*	*n [o/min]*	*S [mm/min]*
1	*1*	*0*	*0*	*-1*	*3.71*	*0.141*	*0.75*	*1.89*	*710*	*100*
2	*1*	*0*	*0*	*1*	*3.71*	*0.141*	*1.72*	*2.25*	*710*	*100*
3	*1*	*0*	*-1*	*0*	*3.71*	*0.112*	*1.14*	*2.00*	*710*	*80*
4	*1*	*0*	*1*	*0*	*3.71*	*0.177*	*1.14*	*2.17*	*710*	*125*
5	*1*	*-1*	*0*	*0*	*2.93*	*0.141*	*1.14*	*1.80*	*560*	*80*
6	*1*	*1*	*0*	*0*	*4.71*	*0.141*	*1.14*	*2.33*	*900*	*125*

Table 4. *Merene vrednosti i modelske vrednosti snage određene pomoću softvera SF1001*

Redni broj	*Kod faktora*				*Faktor*			*Izmerena snaga*	*Modelska vrednost snage*
	x_0	x_1	x_2	x_3	*v [m/s]*	s_1 *[mm/z]*	*a [mm]*	*Pi [kW]*	*Pi [kW]*
1	*1*	*-1*	*-1*	*-1*	*2.93*	*0.112*	*0.75*	*1.69*	*1.56*
2	*1*	*1*	*-1*	*-1*	*4.71*	*0.112*	*0.75*	*2.10*	*2.11*
3	*1*	*-1*	*1*	*-1*	*2.93*	*0.177*	*0.75*	*1.75*	*1.69*
4	*1*	*1*	*1*	*-1*	*4.71*	*0.177*	*0.75*	*2.28*	*2.29*
5	*1*	*-1*	*-1*	*1*	*2.93*	*0.112*	*1.72*	*1.87*	*1.88*
6	*1*	*1*	*-1*	*1*	*4.71*	*0.112*	*1.72*	*2.43*	*2.55*
7	*1*	*-1*	*1*	*1*	*2.93*	*0.177*	*1.72*	*2.05*	*2.04*
8	*1*	*1*	*1*	*1*	*4.71*	*0.177*	*1.72*	*2.69*	*2.76*
9	*1*	*0*	*0*	*0*	*3.71*	*0.141*	*1.14*	*2.00*	*2.07*
10	*1*	*0*	*0*	*0*	*3.71*	*0.141*	*1.14*	*2.02*	*2.07*
11	*1*	*0*	*0*	*0*	*3.71*	*0.141*	*1.14*	*2.03*	*2.07*
12	*1*	*0*	*0*	*0*	*3.71*	*0.141*	*1.14*	*2.02*	*2.07*
13	*1*	*-2*	*0*	*0*	*2.35*	*0.141*	*1.14*	*1.60*	*1.55*
14	*1*	*2*	*0*	*0*	*5.86*	*0.141*	*1.14*	*2.67*	*2.78*
15	*1*	*0*	*-2*	*0*	*3.71*	*0.089*	*1.14*	*1.97*	*1.92*
16	*1*	*0*	*2*	*0*	*3.71*	*0.223*	*1.14*	*2.24*	*2.25*
17	*1*	*0*	*0*	*-2*	*3.71*	*0.141*	*0.5*	*1.79*	*1.72*
18	*1*	*0*	*0*	*2*	*3.71*	*0.141*	*2.6*	*2.51*	*2.51*
19	*1*	*-2*	*0*	*0*	*2.35*	*0.141*	*1.14*	*1.62*	*1.55*
20	*1*	*2*	*0*	*0*	*5.86*	*0.141*	*1.14*	*2.65*	*2.78*
21	*1*	*0*	*-2*	*0*	*3.71*	*0.089*	*1.14*	*1.95*	*1.92*
22	*1*	*0*	*2*	*0*	*3.71*	*0.223*	*1.14*	*2.16*	*2.25*
23	*1*	*0*	*0*	*-2*	*3.71*	*0.141*	*0.5*	*1.79*	*1.72*
24	*1*	*0*	*0*	*2*	*3.71*	*0.141*	*2.6*	*2.50*	*2.51*

3 ANALIZA REZULTATA

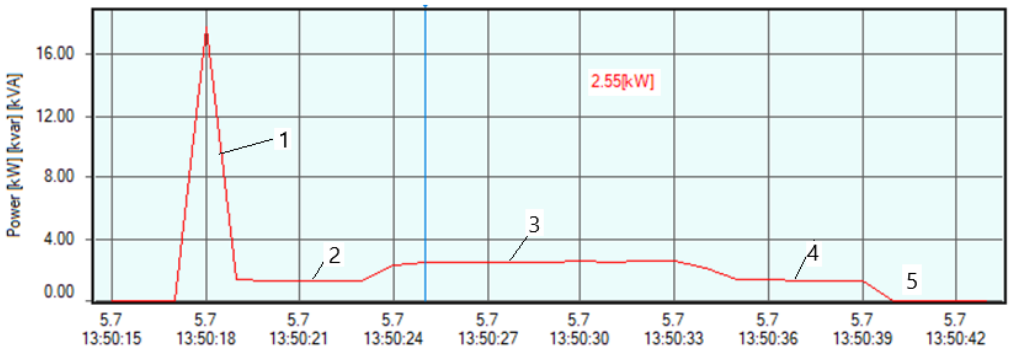
Dobijeni model snage potrebne za proces glodanja u zavisnosti od režima rezanja:

$$P_i = 1.2212 \cdot v^{0.641} \cdot s_1^{0.174} \cdot \mathrm{a}^{0.229} \quad (1)$$

Brzina rezanja ima najveći uticaj na utrošenu snagu pri glodanju, zatim sledi dubina rezanja, dok najmanji uticaj ima pomak po zubu. Povećanjem bilo kog od pomenutih elemenata u režimu rezanja povećava se potrošnja energije.

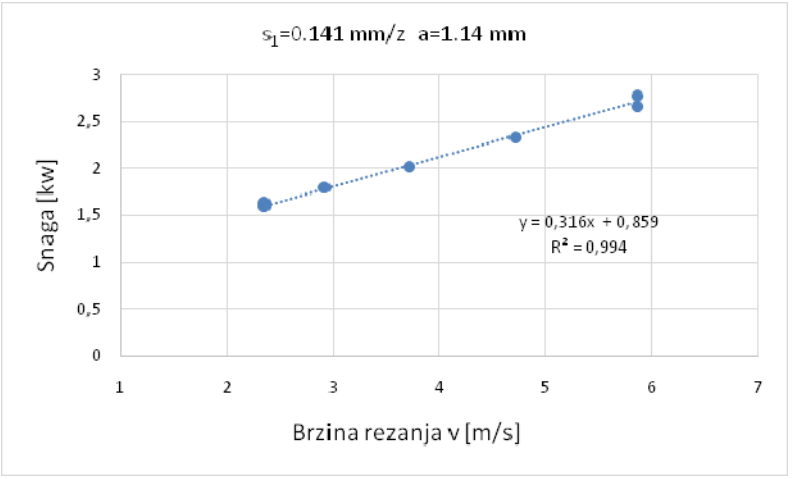
Na slici 2 je prikazana vrednost potrošene snage od pokretanja vretena ulaska alata u zahvat do kraja postupka obrade i isključenje vretena:

1. pokretanje vretena
2. rezanje u vazduhu
3. stalno sečenje
4. prazan hod
5. vreteno isključeno

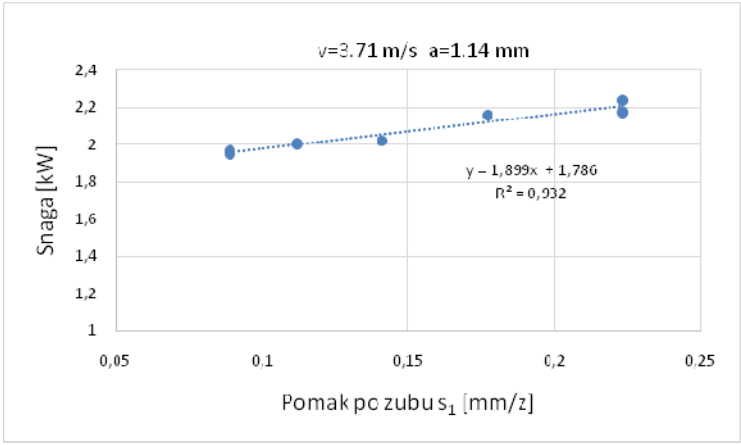


Slika 2. *Vrednost potrošene snage od pokretanja vretena, ulaska alata u zahvat i do kraja zahvata obrade*

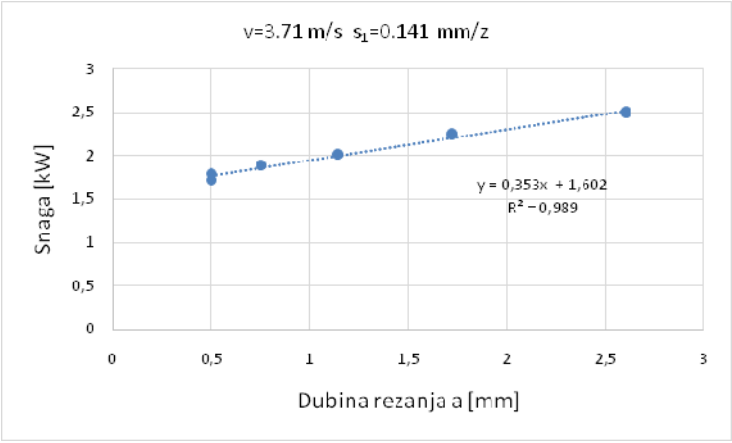
Slika 3 prikazuje potrošnju snage u zavisnosti od brzine rezanja. Slika 4 prikazuje potrošnju snage u zavisnosti od pomaka po zubu. Slika 5 prikazuje potrošnju snage u zavisnosti od dubine rezanja. Jedan od parametara pri eksperimentu je variran dok su ostali bili konstantni.



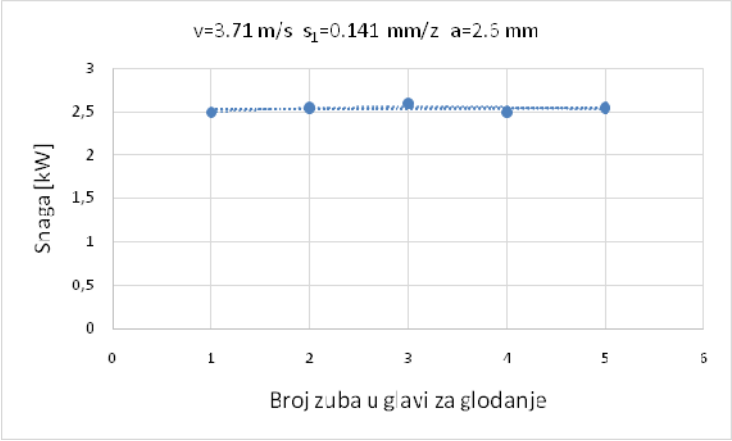
Slika 3. *Potrošnja snage u zavisnosti od brzine rezanja*



Slika 4. *Potrošnja snage u zavisnosti od pomaka*



Slika 5. *Potrošnja snage u zavisnosti od dubine rezanja*



Slika 6. *Potrošnja električne energije u zavisnosti od broja pločica u glavi za glodanje pri konstantnoj brzini stola i dubini rezanja*

Brzina stola se izračunava po sledećoj formuli:

$$S = s_1 \cdot z \cdot n \tag{2}$$

Slika 6 prikazuje potrošnju energije glodanja u zavisnosti od broja zuba u glavi za glodanje pri konstantnoj brzini stola, pomaku i dubini rezanja. Sa dijagrama se može videti da je konzumirana snaga ostala približno konstantna iako se broj zuba povećao. Međutim broj zuba u zahvatu je takođe ostao konstantan.

Pošto je merenje izvršeno pri konstantnoj brzini stola S prilikom dodavanja zuba, došlo je do podele preseka strugotine (pomeranja) na nekoliko zuba, a potrošnja energije ostala je konstantna jer je presek strugotine za 1 obrtaj bio i dalje konstantan, a uređaj nije bio osetljiv na brzu promenu snage - oko 10 okretaja u sekundi.

4 ZAKLJUČAK

U ovom radu predstavljen je model potrošnje energije za proces glodanja, što je funkcija brzine rezanja, pomaka po zubu i dubine rezanja. Izvedeni su eksperimenti pri procesu glodanja radi validacije efektivnosti predloženog modela. Analiziran je i uticaj režima rezanja na potrošnju snage. Rezultati eksperimenata pokazuju da razvijeni model za predviđanje snage nudi preciznije procene potrošnje energije od postojećih modela.

Modeliranje potrošnje energije je osnova za energetsku optimizaciju za proizvodne procese. Predloženi model preciznosti predviđanja omogućava proizvodnoj industriji da razvija energetski efikasne strategije optimizacije tokom faze projektovanja proizvoda i planiranja proizvodnje (tj. operacija, planiranje procesa i raspoređivanje).

NOMENKLATURA

a dubina rezanja, mm
s_1 pomak po zubu, mm/z
v brzina, m/s
n broj obrtaja, o/min
S brzina stola glodalice, mm/min
Pi snaga, kW

LITERATURA

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POZICIONIRANJE I STEZANJE PREDMETA OBRADE PO JEDNOJ RAVNI

Bekir Novkinić[1], Aleksandar Košarac[2], Nebojša Radić[3], Milan Jurković[41]

Rezime: Mašine alatke su sistemi namjenjeni za obavljanje obradnih procesa rezanja pri kojim se skida višak materijala. Mašine alatke moraju udovoljiti tržišnim zahtjevima kroz ispunjenje kriterija maksimalne proizvodnosti, tačnosti mjera, eksploatacione pouzdanosti, što niže cijene koštanja i lakog opsluživanja. Da bi to bilo moguće potrebno je posebnu pažnju posvetiti steznom priboru kao neizostavnom dijelu sistema alatne mašine, kojim se steže predmet obrade u toku obradnih procesa. Stezni pribor treba da omogući izvršenje svih zahtjeva tehnološkog postupka kroz pouzdano pozicioniranje i stezanje predmeta obrade. U ovom radu predstavljen je dio istraživanja iz doktorske disertacije autora, čija tematika realizuje ideju da se stezanje predmeta obrade vrši svjesnim deformisanjem zone kontakata oslonaca ili stezača. Za pomenutu namjenu konstruisan je stezni pribor, te su mjerenja urađena u stvarnim, industrijskim uslovima, zahvatima rezanja u pet osa. Šesta osa je bazna površina na kojoj su izrađeni tehnološki otvori u koje se utiskuju stezači u zonama kontakata. Teorijskom analizom i numeričkim proračunima je dokazano da nema ograničenja u smislu postizanja visokog nivoa krutosti i deformabilnog tijela sa aspekta malih dozvoljenih pomjeranja što omogućuje deformisanje materijala u zatvorenom prostoru tehnoloških otvora predmeta obrade.

Ključne riječi: mašina alatke, krutost, predmet obrade,stezni pribor, zona kontakta,

LOCATING AND CLAMPING OF WORKPIECE BY ONE SURFACE

Abstract: Machine tools are systems designed to perform machining processes where the excess material is removed. Machine tools needs to comply with market requirements by meeting the criteria of maximum productivity, accuracy of measures, exploitation reliability, lower costs and easy servicing. In order to achieve this requirements, it is necessary to pay special attention to jigs and fixtures, as an indispensable part of the machine tool system with which the workpiece is clamped during the production. Jigs and fixtures should enable the performance of all requirements of the technological process through the reliable locating and clamping of the workpiece. In this paper, a part of the research from the doctoral dissertation of the

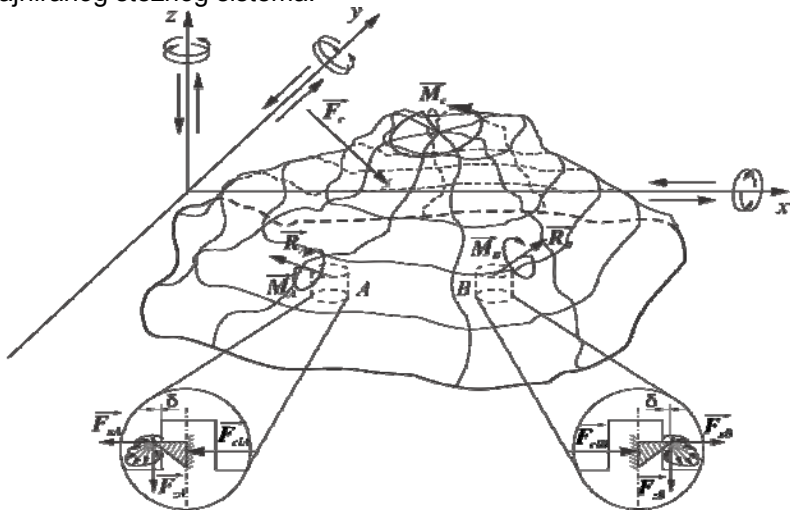
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author is presented. This paper shows the idea that the clamping of the workpiece is done by a conscious deformation of the zone of contacts of the locator or fixtures. For this purpose, fixture were constructed, and the measurements were done in real, industrial conditions, during five-axis cutting process. The sixth axis is the base surface, at which technological hole are made into which the clamping elements are pinpointed in contact zones. By theoretical and numerical analysis have been proven that there are no restrictions in terms of achieving a high level of stiffness and deformable body from the aspect of small permissible displacements. This is possible thanks to deformation of the materials in the enclosed space of the technological holes of the workpiece.

Key words: machine tools, stiffness, workpiece, jigs and fixtures, contact zone

1 UVOD

U ovom radu, razmatra se predmet obrade složene kofiguracije kod kojeg je potrebno pri jednom pozicioniranju i stezanju obradu izvesti u pet ravni. Na slici 1. prikazan je opšti slučaj obrade takvog tipa predmeta. Razmatra se mogućnost pozicioniranje i stezanja takvog predmeta obrade, uslovno rečeno, po preostaloj šestoj ravni. Polazi se od ideje da se na šestoj ravni, u ovom slučaju površini za pozicioniranje, izrade dva ili više tehnoloških otvora koji će omogućiti ugradnju specijalno dizajniranog steznog sistema.



Slika 1. *Šematski prikaz stezanja predmeta složene konfiguracije*

Sistem stezanja treba da osigura jednoznačan položaj predmeta obrade u odnosu na koordinatni sistem x, y, z, sa steznim elementima smještenim u relativno malom prostoru tehnoloških otvora, pri čemi bi sile stezanja obezbjedile pouzdano nalijeganje predmeta obrade na baznu površinu i reakcije koje uravnotežavaju sile i momente rezanja bez obzira na njihov intenzitet, pravac i smjer. Naime, sila rezanja Fc i moment rezanja Mc, koji djeluju na predmet obrade teže da dio izvedu iz ravnotežnog položaja i djeluju, kao što je prikazano na slici 1. U opštem slučaju sila rezanja i moment rezanja djeluju u prostoru, odnosno imaju komponente po x, y i z osi. Da bi sistem stezanja bio efikasan neophodno je da se obezbjede reakcije steznih elemenata koje bi silu rezanja Fc i moment rezanja Mc koji se javljaju prilikom rezanja,

dovele u stanje ravnoteže. Vrijednosti sila i momenata reakcija steznih elemenata R_A, R_B, M_A i M_B koji se javljaju u tehnološkim otvorima A i B (slika 1) u toku procesa rezanja ne smiju ni u jednom trenutku biti manje od rezultujućih sila rezanja i momenata rezanja, jer bi u tom slučaju jednoznačan položaj koji je prethodno definisam bio narušen.

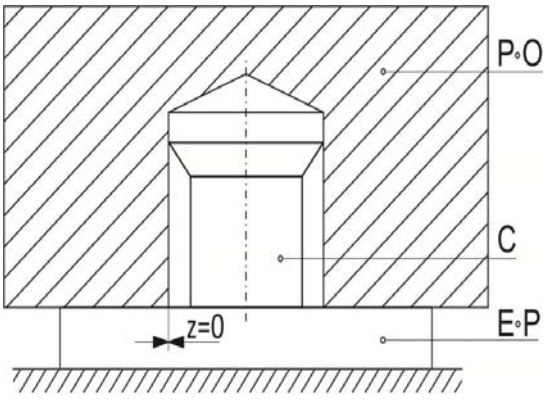
Teorijski posmatrano, stezni element je zamišljen kao konusni klin koji se utiskuje i lokalno deformiše mali dio zapremine tehnoloških otvora.

Na detaljima koji prikazuju okoline tačaka A i B, slika 1, vidi se zona kontakta steznog elementa i predmeta obrade, odnosno globalno polje napona i sila reakcije steznog elementa projektovana na ravan π, koja je paralelna yz ravni. Reakcija steznih elemenata se obezbjeđuje pomoću pravolinijskog kretanja steznog konusnog klina duž x ose, koji na stezne elemente djeluje silama stezanja F_{clA} i F_{clB}. Usljed dejstva ovih sila stezanja dolazi do utiskivanja steznih konusnih elementa, u mali dio zapremine tehnoloških otvora predmeta obrade po x osi do dubine δ (slika 1, detalji u okolini tačaka A i B). Da bi ovaj proces stezanja uopšte bio moguć neophodno je da materijal od kojeg je sačinjen stezni element bude znatno veće tvrdoće od materijala predmeta obrade. Sile stezanja F_{clA} i F_{clB} djeluju na stezne elemente A i B i obezbjeđuju neophodne reakcije R_A, R_B, M_A i M_B. Planirano je da se pogodnim izborom oblika steznog klina steznog elementa koji se utiskuje u površine prethodno urađenih tehnoloških otvora ostvari sila po z osi koja ima veoma korisnu ulogu u smislu ostvarivanja nalijeganja predmeta obrade na baznu površinu, dok će sile F_{xA} i F_{xB} koje su po intenzitetu iste, ali su suprotnog smjera, u najvećoj mjeri uravnotežavati dinamičke sile i momente nastale u procesu rezanja.

Intenzitet sila reakcije i momenata svakog steznog elementa definišu uslove ravnoteže prikazane jednačinama datim u vektorskom obliku:

$$\begin{aligned} \overrightarrow{R_A} + \overrightarrow{R_B} &= \overrightarrow{F_C} \\ \overrightarrow{M_A} + \overrightarrow{M_B} &= \overrightarrow{M_C} \end{aligned} \tag{1}$$

Predloženi model podrazumijeva da će sistem stezanja obezbjediti potrebne nivoe reakcija pri relativno malim dubinama prodiranja konusnih klinova u površine prethodno urađenih tehnoloških otvora. Na slici 2. prikazan je položaj stezača – steznog čepa „C“ u prethodno urađenom tehnološkom otvoru izrađenom na predmetu obrade „PO“. Stezni čep „C“ je učvršćen na elementu za pozicioniranje steznog pribora „EP“.

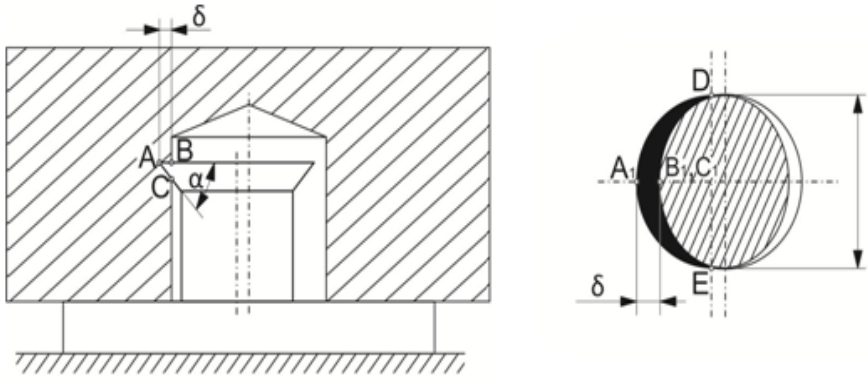


Slika 2. *Položaj steznog čepa u tehnološkom otvoru pri nultom zazoru (z=0)*

Nakon dejstva sile stezanja stezni čep „C“ se u tehnološkom otvoru nalazi u položaju koji je prikazan na slici 3. Kružni klin steznog čepa prodire u materijal predmeta obrade do određene dubine definisane veličinom „δ“. Dubina prodiranja „δ“ zavisi od veličine sile stezanja i mehaničkih karakteristika predmeta obrade. Teorijski se razmatra slučaj u kojem je:

- Stezni čep izrađen od materijala velike tvrdoće tako da se deformacije steznog čepa u odnosu na deformacije materijala predmeta obrade mogu zanemariti,
- Geometrija steznog čepa (odnos visine steznog čepa i njegovog prečnika) osigurava vrlo visoku krutotost veze steznog čepa sa elementima steznog pribora, tako da su sve deformacije elemenata pribora i steznog čepa, u poređenju sa deformacijama na predmetu obrade nastalim u zoni kontakta kružnog klina po površinama ograničenim tačkama A, B, C,A_1, B_1, D i E umanjene.

Treba naglasiti da su prethodno navedene teorijske pretpostavke opravdane sa aspekta tehnoških mogućnosti ostvarivanja realnih konstrukcija pribora u kojima će deformacije steznog čepova „C“i elemenata pribora „EP“ biti zanemarive u odnosu na deformacije u zonama kontakta steznih čepova sa materijalom predmeta obrade.



Slika 3. *Položaj steznog čepa „C“ u tehnološkom otvoru predmeta obrade „PO“ nakon dejstva sile stetanja*

Pri dejstvu spoljašnjih sila $\overrightarrow{F_c}$ i momenta $\overrightarrow{M_c}$ koji nastaju u prosesu obrade rezanjem (Slika 1.) u zonama kontakta steznih čepova „C“ nastaju određene reakcije $\overrightarrow{R_A}$, $\overrightarrow{R_B}$, $\overrightarrow{M_A}$,$\overrightarrow{M_B}$. Veličine ovih reakcija i popustljivost zona kontakta steznih čepova pri dejstvu sila i momenata na proizvoljno izabranoj konturi predmeta obrade u velikoj mjeri zavisiće od veličine realne površine kontakta i napona koji djeluju na površinama kontakta dva ili više steznih čepova i predmeta obrade. Ukupna površina kontakta prema slici 4. može se izračunati u funkciji dubine prodiranja „δ“ preko približno tačnog obrasca, odnosno:

$$A \cong d \cdot \delta \left(1 + \frac{1}{\cos \alpha} \right) \tag{2}$$

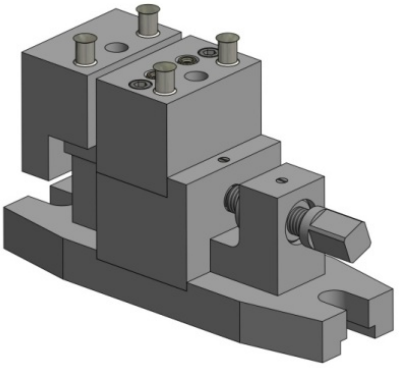
Ako se usvoji maksimalni prečnik steznog čepa $d = 10\ mm$ i dubina prodiranja steznog čepa $\delta = 0{,}5\ mm$, i $\alpha = 30^{\circ}$, može se na osnovu prethodno datog obrasca izračunati da realna površina kontakta koju ostvaruje jedan stezni čep sa deformisanim

materijalom predmeta obrade približno iznosi: $A = 10{,}18\ mm^2$.

Izračunata vrijednost realne površine kontakta predstavlja vrlo visoku vrijednost s obzirom na relativno malu dubinu prodiranja vrijednosti $\delta = 0{,}5\ mm$. Imajući navedeno u vidu, pretpostavlja se da će velika površina kontakta vrlo povoljno uticati na krutost samog kontakta i njegovu malu popustljivost pri dejstvu dinamičkih sila i momenata nastalih u procesu rezanja.

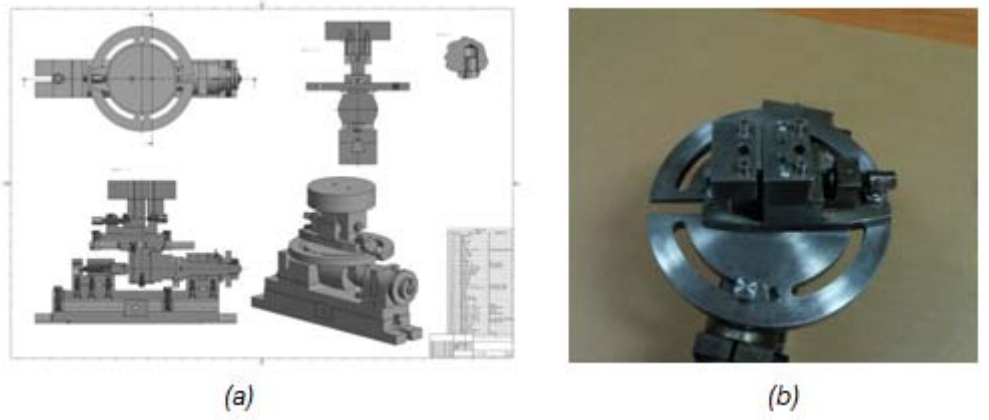
2 EKSPERIMENTALNA ISTRAŽIVANJA

Za potrebe verifikacije teorijskog modela projektovan je stezni pribor čiji je CAD model prikazan je na slici 4.



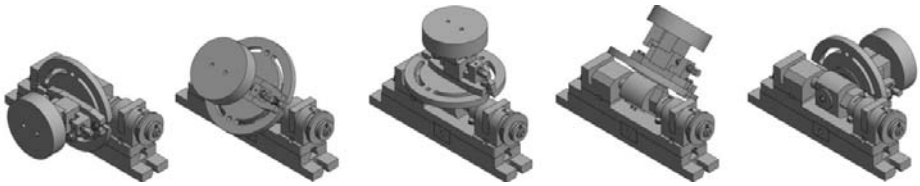
Slika 4. *CAD model steznog pribora korištenog u eksperimentu*

Stezni pribor prikazan na slici 4. pričvršćen je na platformu koja omogućuje da prikazani stezni pribor i predmet obrade dobiju i mogućnost dodatnog pozicioniranja u odnosu na rezni alat. Naime, platforma omogućava zakretanje pribora po vertikalnoj i uzdužnoj osi. Na slici 5.a,b, prikazan je CAD model sklopa platforme, pribora i predmeta obrade i fotografski prikaz pribora i platforme, u nekim od mogućih pozicija na radnom stolu alatne mašine.



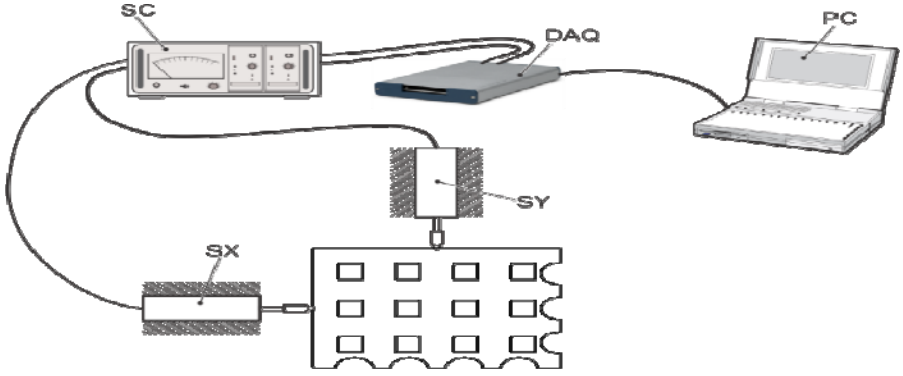
Slika 5.- *CAD model sklopa platforme, pribora i predmeta obrade - a) i fotografski prikaz pribora i platforme - b)*

Prikaz mogućih pozicija pibora na platformi i radnom stolu alatne mašine dat je na slici 6.



Slika 6. *Mogući položaji steznog pribora i predmeta obrade u toku procesa rezanja*

Eksperimentalna istraživanja obuhvatila su mjerenja pomjeranja predmeta obrade u steznom priboru u realnim uslovima tokom procesa rezanja. Pomjeranja predmeta obrade su mjerena u dva pravca, duž x i y ose, što se može primjetiti preko položaja senzora pomjeranja prikazanih na slici 7.

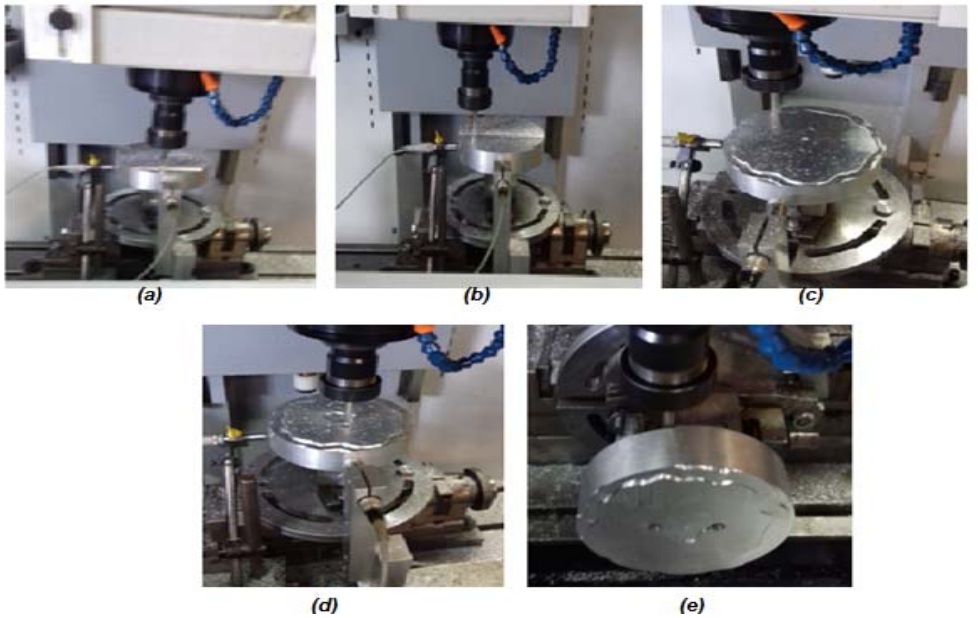


Slika 7. *Mjerni lanac za mjerenje pomjeranja u odnosu steznog pribora sa predmetom obrade i njegov ilustrativni prikaz*

Na slici 7. prikazana je ilustracija mjernog lanca koji se sastoji od slijedećih elemenata:

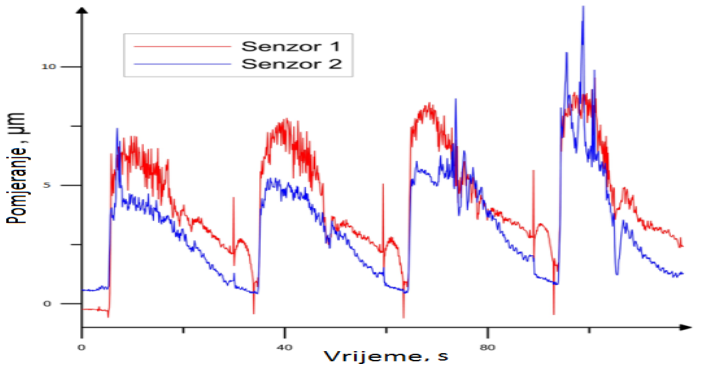
- Induktivni transduktor W1T (sensori pomjeranja SX i SY) sa nominalnom mogućnošću mjerenja pomjeranja od ± 1 mm;
- Dvokanalni HBM signalizator u kojem se procesuiraju podaci dobiveni od senzora SY i SX;
- Osmokanalni ulazni kanali simultano dobijaju podatke od modula sa šesnaestobitnom rezolucijom (DAG na slici 7), koji se koriste za uzimanje signala od senzora SY i SX i
- Računar sa kojim se vrši kontrola DAQ modula i pohranjuju rezultati mjerenja za dalju opservaciju.

Operacija izvedene mašinske obrade sadržana je u zahvatima: a) poravnavanje čeone površine (slika 8. a i b); b) obrada po spoljašnjoj konturi (slika 8.c); c) obrada ukopavanjem po unutrašnjoj konturi (slika 8, d); d) obrada dijela bazne površine (slika 8,e). Na datim slikama mogu se vidjeti i položaji senzora koji registruju pomjeranje predmeta obrade. Materijal predmeta obrade koji je korišten u eksperimentu je legura aluminijuma EN AW-6082 (AlMgSi1).



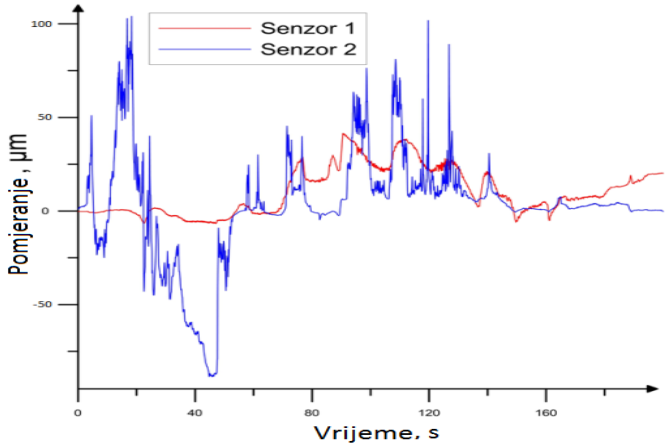
Slika 8 *Operacije mašinske obrade u toku eksperimenta i položaji senzora pomjeranja (a-e)*

Pomjeranja predmeta obrade tokom izvođenja zahvata poravnavanja čeone površine prikazana su dijagramom na slici 9.



Slika 9. *Registrovana pomjeranja prilikom izvođenja zahvata poravnavanja čeone površine predmeta obrade*

Sa dijagrama se može vidjeti da se pomjeranja predmeta obrade kreću u granicama od nule do stotog dijela milimetra. Pomjeranja predmeta obrade tokom izvođenja zahvata grube profilne obrade po spoljašnjoj konturi prikazana su dijagramom na slici 10., dok su pomjeranja predmeta obrade tokom izvođenja zahvata profilne obrade po unutrašnjoj konturi prikazana dijagramom na slici 11.

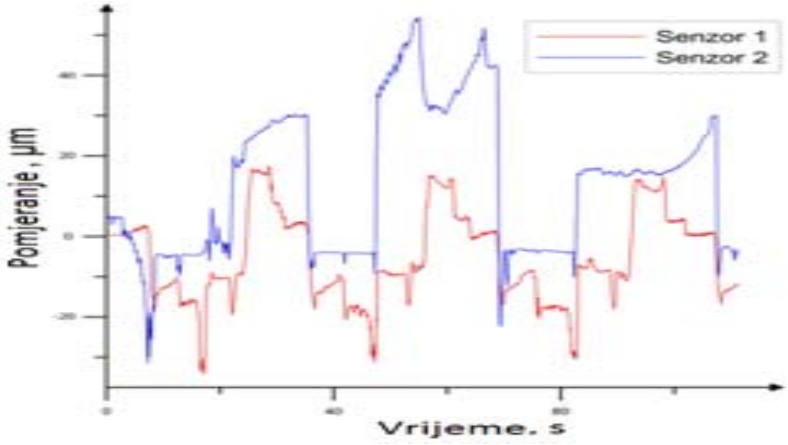


Slika 10 *Registrovana pomjeranja prilikom izvođenja zahvata obrade po spoljašnjoj konturi predmeta obrade*

Sa dijagrama na slici 10. može uočiti da pomjeranja tokom vremena mjenjaju intenzitet i smjer što je sasvim logično s obzirom da je riječ o obradi po spoljašnjoj konturi i velikim opterećenjima u zonama kontakta steznih čepova i površina tehnoloških otvora. Pomjeranja su i većeg intenziteta i kreću se u granicama od -0,1 mm do 0,1 mm.

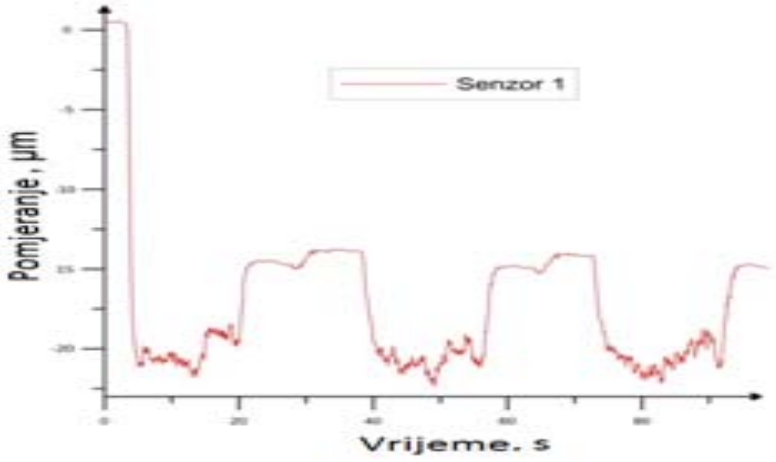
Pomjeranja predmeta obrade tokom izvođenja zahvata profilne obrade po unutrašnjoj konturi prikazana dijagramom na slici 11.

Analizom dijagrama prikazanih na slikama 10. i 11. može se zaključiti da su pomjeranja nastala tokom izvođenja operacije ukopavanja po unutrašnjoj konturi, u prosjeku približno dva puta manja od pomjeranja koja se javljaju pri obradi glodanjem po spoljašnjoj konturi. Razlozi prvenstveno leže u činjenici da je riječ o različitim vrijednostima radijus vektora napadne tačke sile rezanja.



Slika 11. *Registrovana pomjeranja prilikom izvođenja zahvata obrade ukopavanjem po unutrašnjoj konturi*

Pomjeranje predmeta obrade u pravcu obrade pri izvođenju operacije obrade bazne površine (ukopavanje kanala – flaka) prikazano je na slici 12.



Slika 12. *Registrovano pomjeranje prilikom izvođenja zahvata obrade po baznoj površini*

Mjerenje pomjeranja u ovom zahvatu obrade izvedeno je samo po uzdužnoj osi (x-osi) iz razloga što, s obzirom na raspoloživu opremu, nije bilo moguće pozicioniranje drugog senzora pomjeranja. Sa dijagrama se može uočiti da je u ovom zahvatu obrade pomjeranje značajno manje i kreće se u granicama od nule do - 0,023 mm.

Treba naglasiti da izmjerene vrijednosti pomjeranja predstavljaju ukupna pomjeranja predmeta obrade u odnosu na radni sto mašine. Dakle, pomjeranja sadrže, ne samo pomjeranja u zonama kontakta steznih čepova sa površinama tehnoloških otvora, već ukupna pomjeranja svih elemenata pribora i platforme korištenih u toku izvođenja eksperimenta. Sa tim u vezi može se zaključiti da su stvarna pomjeranja nastala kao posljedica popustljivosti u zonama kontakta steznih čepova i površina tehnoloških otvora značajno manja.

3 ZAKLJUČCI

Stezni pribor kao element obradnog sistema, u savremenim uslovima proizvodnje, zauzima ključnu ulogu. Može se slobodno reći da razvoj steznih pribora u teorijskom, a posebno u industrijskom smislu, ne prati razvoj alatnih mašina i reznih alata kao preostala dva elementa obradnog sistema. Ova tvrdnja obrazlaže se činjenicim da su, globalno posmatrano, mogućnosti savremenih alatnih mašina i savremenih reznih alata po pitanju postizanja kvaliteta obrade (tačnost geometrijskih mjera i kvalitet obrađene površine) u uslovima visoke proizvodnosti i produktivnosti neuporedivo veće. Evidentne prednosti savremenih alatnih mašina i savremenih reznih alata u odnosu na stezne pribore u najvećoj mjeri su posljedica male krutosti velikog broja industrijskih steznih pribora. Prema literaturnim izvorima problem krutosti konstrukcija steznih pribora predstavlja veoma aktuelnu problematiku i veliki izazov mnogih istraživača. Veliki broj radova objavljenih u istaknutim svjetskim časopisima razmatra pojedinačne specijalne slučajeve steznih pribora. U tim radovima se primjenom savremenih teorijskih metoda i numeričkih proračuna dolazi do optimalnih

rješenja pojedinačnih konstrukcija steznih pribora. Određeni broj radova [1,2,3,4,5,6,7,8 i 9] prikazuje rezultate istraživanja u oblasti steznih pribora koja imaju dimenziju globalnog karaktera.

Ova istraživanja zasnovana su na svjesnom deformisanju predmeta obrade prilikom stezanja i očigledno predstavljaju veoma aktuelnu problematiku. Rezultati prikazani u navedenim radovima istražuju problem popustljivosti kontakta steznih elemenata i predmeta obrade i ukazuju na značajne tehno-ekonomske efekte koji se mogu postići povećanjem krutosti ovog kontakta. Izloženi rad prati ideju mogućih efekata baziranja i stezanja pri svesnom deformisanju dijela materijala predmeta obrade. Sama ideja pokriva oblast složene mašinske obrade na petoosnim mašinama pri čemu se kompletno pozicioniranje i stezanje predmeta obrade izvodi po jednoj ravni, dok su preostalih pet ravni slobodne za pristup alatima i mašinsku obradu. Pored toga deformisani dio materijala predmeta obrade je nevidljiv i ne narušava estetiku obrađenih dijelova što otvara mnoga fenomenološka pitanja u smislu mogućnosti velike industrijske primjene i efekata koji se mogu postići.

Na osnovu teorijskih razmatranja, i rezultata eksperimentalnih istraživanja prikazanih u ovom radu može se zaključiti:

- Pozicioniranje i stezanje predmeta obade kod kojih se obrada vrši u pet ravni a pozicioniranje i stezanje po preostaloj šestoj ravni moguće je efikasno sprovesti utiskivanjem steznih elemenata (konusnih kružnih klinova) u površine prethodno urađenih tehnoloških otvora na predmetu obrade.
- Rezultati numeričkih proračuna, koji nisu prikazani u ovom radu, takođe ukazuju da su izložene teorijske pretpostavke osnovane i da se, i pri relativno malim dubinama prodiranja konusnih klinova u površine prethodno urađenih tehnoloških otvora obezbjeđuju visoke vrijednosti sila reakcija koje mogu uravnotežiti spoljašnja opterećenja nastala usljed sila i momenata rezanja.
- Rezultatima izvedenih eksperimantalnih istraživanja potvrđeno je da pomjeranja predmeta obrade nastala u procesu obrade ne prevazilaze vrijednosti najfrekventnijih tolerancija mašinskih delova. Nastala pomjeranja su reda veličine stotog ili desetog dijela milimetra što obezbjeđuje prihvatljive vrijednosti grešaka obrade. Eksperimentalna ispitivanja su takođe potvrdila da se predloženom metodom stezanja, u precesu obrade preporučenim vrijednostima režima rezanja, ostvaruje visok kvalitet obrađene površine.

Pored navedenog, vrlo je važno naglasiti, da u teorijskom i tehničkom smislu faktički ne postoje ograničenja po pitanju mogućnosti podizanja nivoa rezultujućih reakcija na steznim čepovima, odnosno ograničenja veličina efektivnih sila stezanja predmeta obrade. Imajući u vidu prethodno izloženo proizilazi da se predloženom metodom baziranja i stezanja, u opštem slučaju, mogu obezbjediti potrebni nivoi, pravci i smjerovi kao i položaji odnosno zone dejsta sila stezanja.

Predloženi sistem stezanja može naći veliku primjenu u industrijskoj praksi, odnosno u operacijama obrade složenih konfiguracija predmeta obrade. Pri čemu se kompletna obrada izvodi pri jednom baziranju i stezanju, što će imati pozitivne efekte i sa aspekta smanjenja grešaka obrade i sa aspekta mogućnosti podizanja nivoa proizvodnosti i produktivnosti obradnih procesa u savremenim industrijskim uslovima.

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PLATFORM FOR SURFACE ROUGHNESS MONITORING VIA CUTTING TOOL LOAD CONTROL

Uros Zuperl[1]

Abstract: The aim of this paper is to present a surface roughness monitoring platform via an adaptive cutting tool load regulation system. The relations between measured cutting tool loads, cutting conditions and actual surface roughness of machined surface were determined using adaptive neuro-fuzzy inference modeling (ANFIS). The trained ANFIS model predicts on-line the effect of machining parameters and maximal cutting tool loads on surface roughness during machining. End milling machining process of hardened die steel with carbide end mill was used for validation. The developed platform monitors the actual surface roughness and in case of excessive value provides warnings to the operator or stops the machining process for cutting tool change.

Key words: ANFIS, milling, monitoring, adaptive tool load control, surface roughness

1 INTRODUCTION

Despite many research, there are no available method for monitoring surface roughness in high-speed end-milling. In milling the relationship between process characteristics and surface roughness is difficult to capture. This is due to the complexity of the relationship between surface roughness and process characteristics. Therefore, an in-process method based on prediction model is required for the real time process monitoring. We attempt to solve this situation by employing the ANFIS to predict the surface roughness based on measured cutting forces and to CNC controller sent cutting conditions. A new surface roughness prediction model is integrated with the existing cutting tool load control system. The traditional ability of the operator to determine the quality of the machined surface based on his experiences and senses is now the expected role of the predictive model in the upgraded system. Several other models have been proposed to estimate the surface roughness. These include classical statistical approaches as well as fuzzy systems and neural networks. For instance researchers [1,2] developed an approach based on the least-squares regression for estimating surface roughness in machining while [3] have, respectively, used fuzzy pattern recognition for monitoring surface roughness over a limited range of cutting conditions. The capacity of artificial neural networks to capture nonlinear relationships in a relatively efficient manner has motivated a number of researchers to pursue the use

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of these networks in developing surface roughness prediction models. But in these models, the nonlinear relationship between sensor readings and surface roughness embedded in a neural network remains hidden and inaccessible to the user [4]. In this research we attempt to solve this situation by using the ANFIS system to in-process predict the surface roughness. This model offers ability to estimate surface roughness as its neural network based counterpart but provides an additional level of transparency that neural networks fails to provide.

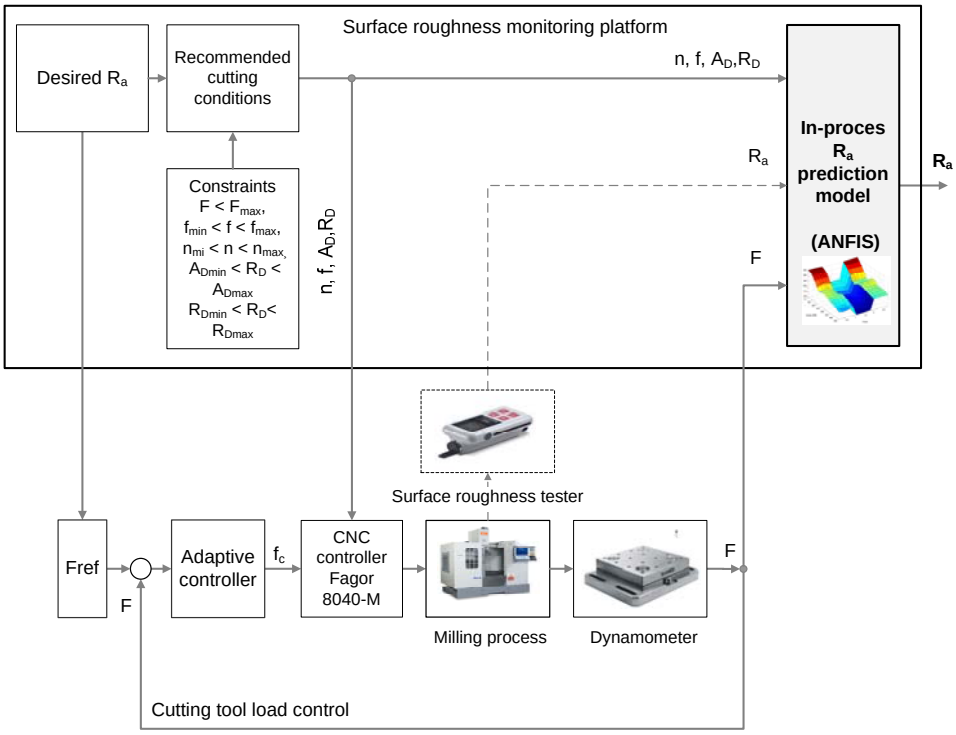


Figure 1. *Inclusion of cutting tool load control system into surface rougness monitoring*

2 ADAPTIVE CUTTING TOOL LOAD CONTROL SCHEME

The adaptive control system shown in Fig. 1 is a cutting tool force feedback loop where the feedrate adjusts itself to the actual cutting tool load, and varies according to the changes in work conditions during machining. The actual maximal cutting tool load is sampled every 0.01 seconds and converted to a digital signal. This signal is immediately compared with a predetermined reference cutting tool load Fref. The maximum measured tool load is a good starting value for the reference load Fref. The difference between the F and Fref is the control error. The control error is used as the input to the system controller. The controller adjusts the federate override percentage and sends the determined federate command signal to the federate routine in the CNC controller. A positive error increases the programmed feedrate and consequently increases the produced actual cutting force. A negative error decreases the programmed feedrate and consequently decreases the actual cutting force. The controller is connected with the CNC controller of a 4-axis machining centre, as shown in Fig. 1.The federate control is achieved through Feed override commands. In order for the controller

to regulate peak load, load information must be available to the control algorithm at every 20 ms. Data acquisition software (LabVIEW) and the algorithm for processing the load signals are used to provide this information. When the adaptive controller is turned on, the feedrates generated by the CNC controller are sent to the feed drive servo-unit and the surface roughness prediction model.

3 SURFACE ROUGHNESS MODEL FOR IN-PROCESS PREDICTIONS

The aim of this study is to develop an accurate and reliable model for predicting surface roughness in-process.

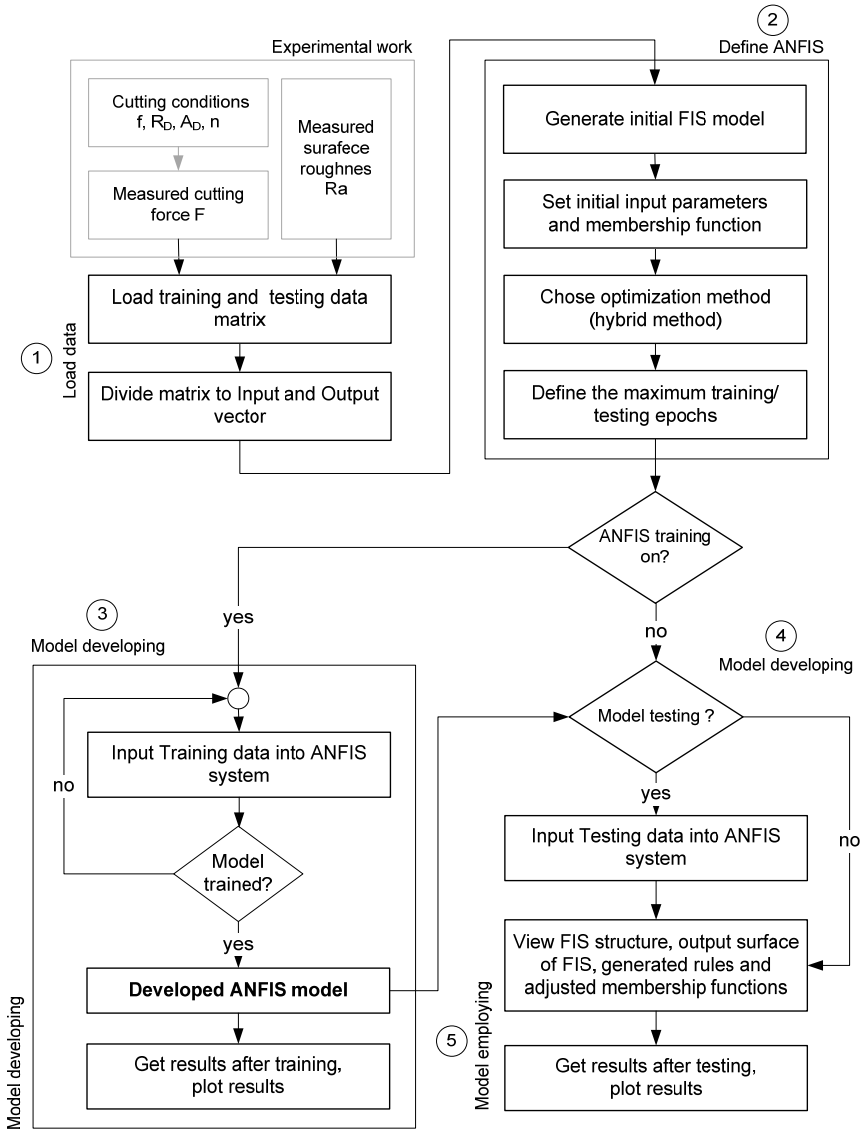


Figure 2. *Algorithm for developing and employing the Ra model*

The surface roughness prediction model is built according to the ANFIS method. The ANFIS method seeks to provide a linguistic model for the prediction of surface roughness from the knowledge embedded in the trained neural network. By given input/output data set, the ANFIS method constructs a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using a backpropagation algorithm. This allows fuzzy systems to learn from the data they are modeling. FIS Structure is a network-type structure similar to that of a neural network, which maps inputs through input membership functions and associated parameters, and then through output membership functions and associated parameters to outputs. Fig. 2 shows the basic flow chart for predicting the surface roughness via ANFIS.

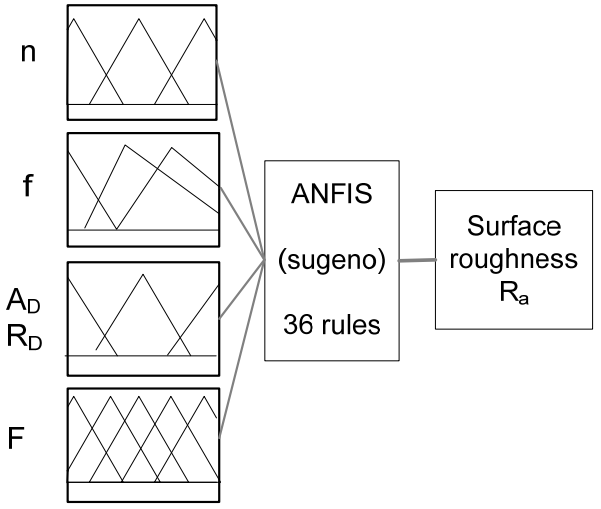


Figure 3. *Structure of developed in-process Ra model*

Five steps are required to develop an ANFIS system. In step 1, the training and testing data are loaded to the system. The process variables are force sensor readings (F), spindle speed (n), feed rate (f), depth of cutting (A_D/R_D), and measured surface roughness. All the data were scaled. The whole data set is divided into the training and the testing set. 350 data points were used in this study. The training data set is used to find the initial premise parameters for the membership functions by equally spacing each of the membership functions. A threshold value for the error between the actual and desired output is determined.

The FIS architecture and training parameters were defined in step 2. The optimization method, the tolerance error, the maximal number of epoch, the number of membership functions and the membership functions types are defined. The ANFIS architecture is explained in detail in [5].

The fuzzy inference system under consideration has 5 inputs and one output. The inputs are cutting force sensor signal, and the cutting conditions. The output is surface roughness provided by the surface roughness tester. In step 3, the training phase is accomplished. With the input–output data, the neuro-fuzzy algorithm is trained, and the unknown parameters are identified.

Fig. 3 shows the inputs, membership functions, and the fuzzy inference system for surface roughness prediction. During the training stage, the ANFIS adjusts its internal

structure to give correct output results according to the input features. The process is terminated when the error becomes less than the threshold value.

During training in ANFIS, 350 sets of experimental data are used to conduct 500 cycles of learning. Finally, in the fourth step the trained ANFIS is used to predict surface roughness. After the training, the inference system could estimate surface roughness from cutting force measurement and cutting conditions in real time.

The developed ANFIS model can guide system or operator in tool change decisions making.

4 EXPERIMENTAL EQUIPMENT

Experiments were performed on a CNC machining platform Heller with FAGOR CNC controller. Material Ck 45 and Ck 45 (XM) with improved machining properties were used for validation tests. The solid end milling cutter (R216.24-16050 IAK32P) with four cutting edges, of 16 mm diameter and 10° helix angle was selected for machining. The corner radius of the cutter is 4 mm. The cutter is made of ultra-fine carbide grade coated with TiN/TiCN coating. The coolant RENUS FFM was used for cooling. The cutting forces were measured with a piezoelectric dynamometer (Kistler 9255) mounted between the workpiece and the machining table. The data acquisition package used was LabVIEW.

The surface roughness was measured by 7061 MarSurf PS1 Surface Roughness Tester. The experiments were carried out for all combinations of the chosen parameters [6], which are radial/axial depth of cut, feedrate, spindle speed and tool wear. Other parameters such as tool diameter, rake angle, etc. are kept constant. Three values for the radial/axial depth of cut have been selected for use in the experiments: R_{D1} = 1d, R_{D2}=0.5d, R_{D3}=0.25d; A_{D1} = 2mm, A_{D2}=4mm, A_{D3}=8mm; d- cutting parameter (16 mm). In the experiments the following values for feedrate and spindle speed were varied in the ranges from 0.05-0.6 mm/tooth and 125 –350 min^{-1}, respectively. In this way two sets of data groups were generated, one for training and other for testing. The cutting tool load signals were monitored by using a fast data acquisition card (National Instruments NI 9215 A) and software written with the National Instruments CVI programming package**.**

5 RESULTS AND DISCUSSION

Predicted surface roughness was found significantly sensitive to the measured cutting tool loads, especially the thrust cutting force component. A total of 250 sets of data were selected from the total of 350 sets obtained in the end milling experiments [5] for the purpose of training in ANFIS. The other 100 sets were then used for testing after the training was completed to verify the accuracy of the predicted values of surface roughness. The best results were obtained when triangular membership functions were chosen for the neuro-fuzzy model. The average error of the prediction of surface roughness is around 2.9% when triangular membership function is used in ANFIS. The accuracy is as high as 96%. The training was very fast, and the error reached a constant value after about 45 epochs. In this case, there were 36 rules in the fuzzy inference system.

The system with incorporated ANFIS model was capable of predicting the surface roughness in real time. The accuracy of the training data was 98.1%, and the accuracy of the testing data was 96 %. Wrong predictions accrued when the feed rate and rotational speed were low. This issue can change the cutting forces and affect the

tool wear estimation via force signals. The force sensor gives a good estimation of the surface roughness.

6 CONCLUSION

The purpose of this research was to integrate cutting load control system into the surface roughness monitoring. The main focus in this paper is on the ANFIS surface roughens prediction model which is a main part of monitoring system. The presented ANFIS model predicts surface roughness with 96% accuracy.

Surface roughness was measured after each cutting test with a Surface roughness tester. Comparison between the actual surface roughness and the simulated results from the neuro-fuzzy method showed good agreement. Once the ANFIS model was trained the surface roughness can be displayed to the operator on the control panel. In this way it provides additional level of process monitoring. The efficiency of the cutting tool load control system with integrated ANFIS model is reflected in improved surface quality.

NOMENCLATURE

A_D axial depth of cutting, mm

F_{ref} reference cutting tool load

F cutting tool load, N

f feed rate, mm/min

f_c feed rate command, mm/min

n spindle speed, N

R_D radial depth of cutting, mm

R_a surface roughness, μm

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OJAČAVANJE MATERIJALA U FUNKCIJI STEPENA DEFORMACIJE KOD HLADNOG VUČENJA ŽICE

Ibrahim Plančić[1], Edin Begović[2], Behar Alić[3]

Rezime: Jedna od ključnih prednosti obrade deformisanjem u hladnom stanju je pojava ojačavanja materijala. Pojava je praćena značajnim promjenama fizičko mehaničkih svojstava metala. Iste se odnose na povećanje pokazatelja osobina otpornosti i smanjenje parametara plastičnosti. Zbog toga se veliki broj proizvoda izrađuje ovim postupkom obrade. Takav je slučaj i sa širokom lepezom proizvoda od nehrđajućih austenitnih čelika, u vidu šipki i žica, koji se oblikuju postupkom vučenja. Značajan uticajni faktor na ojačavanje materijala kod hladnog oblikovanja je ostvareni stepen deformacije. Stoga je jako važno utvrditi uticaj stepena deformacije na izlazne karakteristike proizvoda izražene preko njegovih mehaničkih osobina. To omogućava efikasnije projektovanje tehnologije izrade s ciljem postizanja zahtjevanih mehaničkih osobina proizvoda uz značajne benefite ostvarene prednostima finalnog oblikovanja u hladnom stanju. U radu su, na primjeru vučenja žice, analizirani efekti ojačavanja nehrđajućeg austenitnog čelika X5CrNiMo 18 12 u zavisnosti od ostvarenog stepena deformacije. Dobijeni rezultati omogućavaju uspostavljanje njihove funkcionalne zavisnosti i stvaranje preduslova za postizanje željenih osobina izradaka za određene vrijednosti stepena deformacije.

Keywords: hladna obrada deformisanjem, ojačavanje, stepen deformacije, vučenje žice

STRENGTHENING MATERIALS IN THE FUNCTION OF DEFORMATION DEGREE DURING PROCESS COLD WIRE DRAWING

Abstract: One of the key advantages of deformation processing in cold conditions is the phenomenon of material strengthening. The appearance was followed by significant changes in the physical-mechanical properties of the metal related to increasing the indicators of its mechanical properties and reducing the parameters of plasticity. Therefore, a large number of products are produced by this processing. This

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is the case with a wide aray of wire products made of stainless austenitic steel that are used in modern industrial production and processed by drawing of wire. One of the most important factors influencing the material strengthening in cold forming is the degree of deformation. It is therefore very important to determine the effect of the degree of deformation on the output characteristics of the product expressed through its mechanical properties. This allows for a more efficient design of the production technology with the aim of achieving the required mechanical properties of the product with significant benefits achieved by the advantages of final shaping in a cold state. In the paper, the effects of strengthening of stainless austenitic steel X5CrNiMo 18 12 on the example of wire drawing are analyzed, depending on the degree of deformation. The obtained results enable the establishment of their functional dependence, which creates the preconditions for achieving the desired properties of the workpieces for certain values of the degree of deformation.

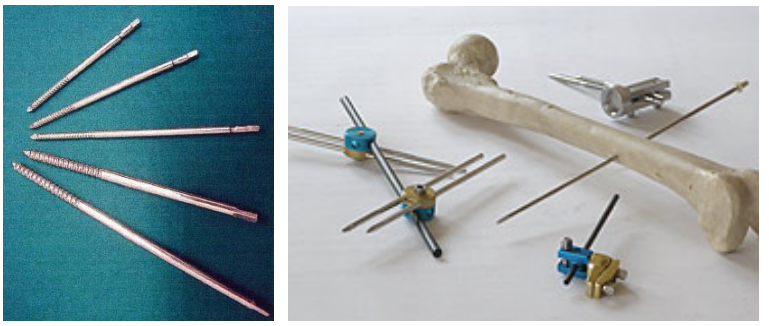
Keywords: cold deformation, material strengthening, degree of deformation, wire drawing

1 UVOD

Nehrđajući austenitni čelici su zbog njihovih izuzetnih karakteristika predmetom mnogobrojnih istraživanja. Ove čelike karakterišu relativno niske vrijednosti napona tečenja, prosječne čvstoćne karakteristike, visoke vrijednosti duktiliteta i visoka sposobnost ojačavanja pri hladnoj plastičnoj preradi.

Stoga je postupkom oblikovanja hladnim vučenjem moguće ostvariti širok spektar mehaničkih i eksploatacionih osobina ovih čelika. Pored poboljšanja mehaničkih osobina koje je rezultat ojačavanja materijala, hladno vučena žica se odlikuje visokom dimenzionom tačnošću i dobrim kvalitetom obrađene površine. Ovo su razlozi intenzivne primjene postupka hladnog vučenja nehrđajućih austenitnih čelika u savremenim industrijskim granama. Istraživanja provedena u ovom radu su inicirana potrebom za cjelovitijim sagledavanjem uticajnih parametara za rješavanje problema efikasnije proizvodnje različitih vrsta fiksatora koji se koriste u traumatologiji, ortopediji i hirurgiji za liječenje preloma kostiju.

Na slici 1. prikazani su Shanz vijci za spoljnu fiksaciju proizvedeni na Institutu u Zenici, postupkom hladnog vučenja žice od nehrđajućeg austenitnog čelika X5CrNiMo 18 12.

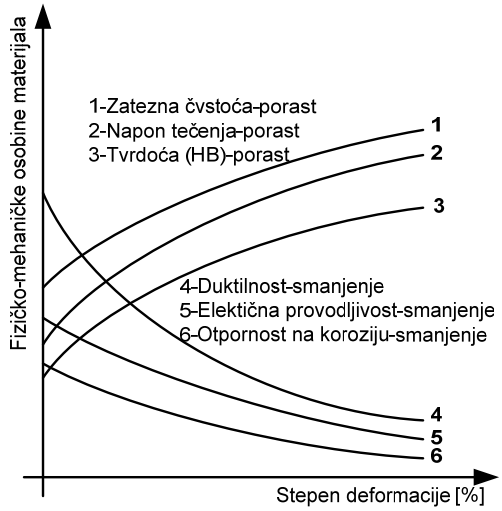


Slika 1. *Izgled i način primjene Shanz vijaka za spoljnu fiksaciju proizvedenih na Metalurškom institutu u Zenici i primjer njihove primjene*

Uobičajeno je da se pod hladnom plastičnom preradom podrazumijeva prerada

metala bez prethodnog zagrijavanja, odnosno na temperaturama ispod $0,3T_{MP}$ (tačke topljenja metala). Posljedica hladne plastične deformacije je povećanje gustine dislokacija koja brzo raste sa intenzitetom deformacije. Usporedbe radi, gustina dislokacija u nedeformisanom žarenom metalu se kreće između 10^6 i 10^8 cm^{-2}, dok se nakon hladne deformacije može povećati na 10^{12} cm^{-2} [1]. Povećanje gustine dislokacija u procesu hladne deformacije metala i interakcija dislokacija međusobno ili sa drugim defektima, koji predstavljaju izvor unutrašnjih naprezanja, uzrokuje znatne promjene mehaničkih i fizičkih osobina metala koje se definišu terminom ojačavanje materijala. Pojava je praćena značajnim promjenama fizičko mehaničkih svojstava metala koje se odnose na povećanje pokazatelja njegovih svcojstava otpornosti, te smanjenje parametara plastičnosti, električne vodljivosti, otpornosti na koroziju i sl., kako je predstavljeno na slici 2.

U radu su, na primjeru hladnog vučenja austenitnog nehrđajućeg čelika X5CrNiMo 18 12 analizirani efekti ojačavanja materijala u zavisnosti od stepena deformacije.



Slika 2. *Uticaj stepena deformacije na mehaničke osobine materijala tokom hladne obrade deformisanjem – ojačavanje materijala [2]*

2 PROVOĐENJE EKPERIMENTA

S ciljem određivanja zavisnosti mehaničkih i strukturnih karakteristika čelika X5CrNiMo 18 12 od stepena deformacije, izvršeno je hladno vučenje šipki sa prečnika d=8 mm na prečnik d_1=5 mm sa različitim parcijalnim, ali približno jednakim ukupnim stepenima deformacije. Na osnovu ovako utvrđenih zavisnosti moguće je projektovanje optimalne tehnologije hladnog vučenja koja će omogućiti dobijanje finalnih izradaka ili polufabrikata sa unaprijed zadanim karakteristikama.

Polufabrikat za eksperimentalno vučenje, prethodno pripremljene šipke kružnog poprečnog presjeka dobijene su tehnološkim postupkom izrade koji uključuje:

- livenje ingota kvadratnog presjeka, dimenzija: a=140 mm do glave ingota, a_1=110 mm do pete ingota i visine ingota H=400 mm; sa hemijskim sastavom

unutar granica propisanih standardom,
- vruću plastičnu preradu ingota postupkom kovanja u gredice stranice a=35 mm i dužine l=400 do 500 mm,
- termički tretman, zagrijavanja na 1150 ºC u trajanju 30 minuta,a potom gašenja u vodi,
- čišćenje i vruće valjanje gredica kroz 11 provlaka na prečnik d=12 mm
- hlađenje na mirnom zraku, zagrijavanje na 1150 ºC, progrijavanje cca 20 minuta i gašenje u vodi s ciljem dobijanja homogene austenitne strukture,
- čišćenje površine brušenjem, a zatim hladno vučenje na prečnik d=8 mm u pet provlaka.

Provedenim ispitivanjima mehaničkih osobina i strukturnih karakteristika dobijenih pripremaka prečnika d=8 mm potvrđena su identična polazna stanja svih šipki namjenjenih za provođenje eksperimentalnih istraživanja koja su predmet ovog rada. Priprema za provođenje hladnog vučenja na konačni prečnik obuhvatala je ponovno zagrijavanje na 1150 ºC, progrijavanje 10 minuta s ciljem dobijanja homogene austenitne strukture, gašenje u vodi i brušenje površine zbog čišćenja od kovarine i površinskih grešaka.

Prethodno hladno vučenje na prečnik d= 8 mm i finalno vučenje na prečnik d_1=5 mm je izvršeno na vučnoj klupi ''Schumag'' sa brzinom vučenja 20 m/s, korištenjem vodene suspenzije praha oznake TKT (Holifa Njemačka) u svojstvu nosača maziva i ulja VP3 kao maziva istog proizvođača.

Broj provlaka za odgovarajuće, ostvarene stepene deformacije dati su u tabeli 1. Stepen deformacije izražen je kontrakcijom presjeka (ψ), odnosno stepenom deformacije II reda ili logaritamskim stepenom deformacije (φ), odnosno stepenom deformacije III reda, kako slijedi:

$$\psi_i = \frac{A_{i-1} - A_i}{A_{i-1}} x100[\%],\ i=1,\ n;\quad \varphi_i = \ln\frac{A_{i-1}}{A_i} \qquad ...(1)$$

U navedenom obrascu je: ψ_i- stepen deformacije II reda, φ_i-stepen deformacije III reda, A_{i-1}-površina poprečnog presjeka žice prije deformacije i A_i-površina poprečnog presjeka žice poslije deformacije, n-broj provlaka, odnosno faza ili operacija vučenja.

Tabela 1. *Stepeni deformacije tokom hladnog vučenje sa d=8 mm na d_1=5 mm [1]*

Planirani	*Ostvareni parcijalni stepeni deformacije nakon i-te provlake (ψi)*									*Ostvareni*
$\psi_{pl.}$[%]	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*$\psi_{uk.}$ [%]*
10	*9,87*	*7,84*	*10,80*	*8,63*	*9,02*	*9,44*	*11,51*	*10,52*	*9,30*	*59,94*
15	*16,94*	*15,97*	*17,35*	*15,97*	*15,69*	*-*	*-*	*-*	*-*	*59,14*
20	*20,75*	*18,26*	*20,09*	*20,82*	*-*	*-*	*-*	*-*	*-*	*59,01*
25	*25,61*	*24,39*	*24,89*	*-*	*-*	*-*	*-*	*-*	*-*	*57,75*

Zbog raspoloživog fonda vučnih matrica došlo je do minimalnih i prihvatljivih odstupanja od planiranih stepena deformacije, te su zahtjevi u pogledu ostvarivanja planiranih parcijalnih stepena deformacije od 10, 15, 20, 25 % i ukupnog stepena deformacije od cca 60% u najvećoj mjeri ostvareni.

3 MEHANIČKA ISPITIVANJA I ANALIZA REZULTATA

Nakon svake provlake, tokom hladnog vučenja sa prečnika d_0=8 mm na prečnik d_n=5 mm vršena su mehanička ispitivanja na uzorcima oznaka A, B, C, i D koji

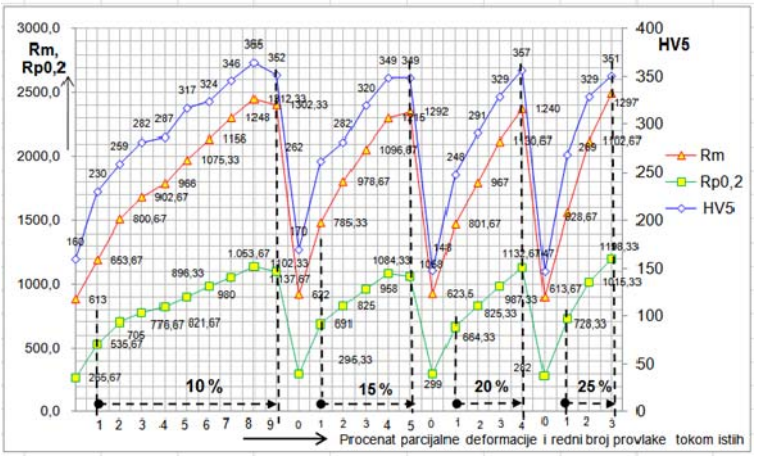
su uzeti iz hladno vučenih šipki sa parcijalnim stepenima deformacije 10, 15, 20 i 25 %. Za svaki parcijalni stepen deformacije mjerenje je vršeno na tri uzorka, a sistematizovani rezultati srednjih vrijednosti mehaničkih osobina izradaka su prikazani u tabeli 2.

Tabela 2. *Promjene mehaničkih osobina tokom vučenja u funkciji step. deformacije [1]*

Uzorak/ parc. step.def.	*Broj prov lake*	*$d_{žice}$ [mm]*	*Parcijalni φ_i [Ukupni $\varphi_{uk.}$]*	*$R_{p0,2}$ [N/mm^2]*	*Rm [N/mm^2]*	*A [%]*	*Z [%]*	*Tvrdoća HV5*
A, 10 %	*0*	*7,90*	*0,00*	*265,67*	*613,00*	*56,53*	*68,90*	*160*
	1	*7,50*	*0,10 [0,10]*	*535,67*	*653,67*	*32,40*	*72,13*	*230*
	2	*7,20*	*0,08 [0,19]*	*705,00*	*800,67*	*19,30*	*67,00*	*259*
	3	*6,80*	*0,11 [0,30]*	*776,67*	*902,67*	*14,50*	*64,10*	*282*
	4	*6,50*	*0,09 [0,39]*	*821,67*	*966,00*	*10,03*	*62,97*	*287*
	5	*6,20*	*0,09 [0,48]*	*896,33*	*1075,33*	*8,80*	*60,50*	*317*
	6	*5,90*	*0,10 [0,58]*	*980,00*	*1156,00*	*7,63*	*59,46*	*324*
	7	*5,55*	*0,12 [0,71]*	*1053,67*	*1248,00*	*7,30*	*58,33*	*346*
	8	*5,25*	*0,11 [0,82]*	*1137,67*	*1312,33*	*6,93*	*55,93*	*365*
	9	*5,00*	*0,10 [0,92]*	*1102,33*	*1302,33*	*7,33*	*55,87*	*352*
B, 15 %	*0*	*7,90*	*0,00*	*295,33*	*622,00*	*54,10*	*71,10*	*170*
	1	*7,20*	*0,18 [0,18]*	*691,00*	*785,33*	*22,33*	*65,70*	*262*
	2	*6,60*	*0,17 [0,36]*	*825,00*	*978,67*	*11,73*	*62,00*	*282*
	3	*6,00*	*0,19 [0,55]*	*958,00*	*1096,67*	*9,47*	*57,83*	*320*
	4	*5,50*	*0,18 [0,72]*	*1084,33*	*1215,00*	*9,27*	*57,00*	*349*
	5	*5,05*	*0,17 [0,89]*	*1058,00*	*1292,00*	*8,40*	*55,40*	*349*
C, 20 %	*0*	*8,20*	*0,00*	*299,00*	*623,50*	*55,28*	*70,90*	*148*
	1	*7,30*	*0,23 [0,23]*	*664,33*	*801,67*	*21,07*	*65,87*	*248*
	2	*6,60*	*0,20 [0,43]*	*825,33*	*9,67*	*10,53*	*62,60*	*291*
	3	*5,90*	*0,22 [0,66]*	*987,33*	*1130,67*	*8,50*	*58,60*	*329*
	4	*5,25*	*0,23 [0,89]*	*1132,67*	*1240,00*	*6,77*	*56,60*	*357*
D, 25 %	*0*	*8,00*	*0,00*	*282,00*	*613,67*	*53,37*	*68,20*	*147*
	1	*6,90*	*0,30 [0,30]*	*728,33*	*828,67*	*20,80*	*65,77*	*269*
	2	*6,00*	*0,28 [0,58]*	*1015,33*	*1102,67*	*10,87*	*58,60*	*329*
	3	*5,20*	*0,29 [0,86]*	*1198,33*	*1297,00*	*6,93*	*58,30*	*351*

Analizom rezultata mjerenja mehaničkih osobina nakon svake provlake može se uočiti da se pri hladnom vučenju sa navedenim parcijalnim stepenima deformacije postižu njihove približno iste vrijednosti na kraju procesa vučenja, odnosno nakon

posljednje provlake. Pokazuje to i sistematizovan grafički prikaz na slici 3.



Slika 3. *Dijagramski prikaz promjena mehaničkih osobina po ostvarenom broju provlaka za ostvarene parcijalne stepene deformacije (po uzorcima A, B, C, D)*

To znači da su pri hladnom vučenju predmetnog austenitnog čelika efekti ojačavanja materijala izraženi kroz promjenu mehaničkih osobina uglavnom u funkciji ukupnog stepena deformacije. Shodno tome, očigledno je da parcijalni stepeni deformacije nemaju znatniji uticaj na efekte ojačavanja materijala. Međutim, adekvatan izbor parcijalnih stepena deformacije omogućava smanjenje sile vučenja po pojedinim provlakama, a time i fleksibilniji izbor alata, odnosno vučnih matrica.

U cilju utvrđivanja zavisnosti mehaničkih osobina od parcijalnog stepena deformacije izvršena je statistička obrada dobijenih rezultata. U obradi je korištena regresiona analiza. Testiran je linearni, kvadratni i kubni regresioni model, a za obradu je korišten statistički paket SPSS 10.0 for windows. Utvrđeno je da najveći koeficijent korelacije i najmanju standardnu grešku daje regresioni kubni model tipa:

$$Y = \text{const} + B_1 \cdot \varphi + B_2 \cdot \varphi^2 + B^3 \cdot \varphi^3 \qquad (2)$$

Pošto je na osnovu rezultata i analize odgovarajućih dijagramskih prikaza utvrđeno da ne postoje statistički značajne razlike u mehaničkim osobinama za različite parcijalne stepene deformacije izvršeno je objedinjavanje podataka u jedinstven skup. Osnovni statistički pokazatelji ovog skupa, regresioni koeficijenti, koeficijenti korelacije i standardna greška regresije su dati u sljedećim tabelama.

Tabela 3. *Osnovni statistički pokazatelji udruženih uzoraka*

Mehaničke osobine	*N*	X_{min}	X_{max}	X_{sr}	σ
$R_{p0,2}$	25	266	1198	812,7	289,2
Rm	25	613	1312	984,8	246,9
A	25	6,8	56,2	19,24	17,15
Z	25	55,4	72,1	62,4	5,25
HV5	25	148	369	287,5	69,8

Tabela 4. *Regresioni koeficijenti, koeficijenti korelacije i standardna greška regresije*

Mehaničke osobine	*Const.*	B_1	B_2	B_3	*Koeficijent korelacije* R^2	*Standardna greška regresije*
$R_{p0,2}$	*300,8*	*2206,4*	*-2468,2*	*1163,8*	*0,980*	*44,1*
Rm	*614,1*	*767,3*	*607,7*	*-694,7*	*0,986*	*31,1*
A	*54,3*	*-224,2*	*362*	*-190,7*	*0,984*	*2,3*
Z	*70,1*	*-12,1*	*-28,2*	*27,6*	*0,947*	*1,3*
HV5	*163,9*	*526,7*	*-566,1*	*253*	*0,977*	*11,4*

Na osnovu provedene statističke analize i proračuna regresionih koeficijenata, koeficijenata korelacije i standardne greške regresije utvrđeno je da se promjena mehaničkih osobina pri hladnom vučenju odvija po kubnom modelu, kako slijedi:

$$R_{p0,2} = 300,8 + 2206,4 \cdot \varphi - 2468,2 \cdot \varphi^2 + 1163,8 \cdot \varphi^3 ; \quad R^2 = 0,980; \quad \sigma_{rez} = 44,1 \quad \ldots(3)$$

$$R_m = 614,1 + 767,3 \cdot \varphi + 607,7 \cdot \varphi^2 - 694,7 \cdot \varphi^3 ; \quad R^2 = 0,986; \quad \sigma_{rez} = 31,1 \quad \ldots(4)$$

$$A = 54,3 - 224,2 \cdot \varphi + 362 \cdot \varphi^2 - 190,7 \cdot \varphi^3 ; \quad R^2 = 0,984; \quad \sigma_{rez} = 2,3 \quad \ldots(5)$$

$$Z = 70,1 - 12,1 \cdot \varphi - 28,2 \cdot \varphi^2 + 27,6 \cdot \varphi^3 ; \quad R^2 = 0,947; \quad \sigma_{rez} = 1,3 \quad \ldots(6)$$

$$HV5 = 163,9 + 526,7 \cdot \varphi - 566,1 \cdot \varphi^2 + 253 \cdot \varphi^3 ; \quad R^2 = 0,977; \quad \sigma_{rez} = 11,4 \quad \ldots(7)$$

4 ZAKLJUČAK

Provedena ispitivanja i analizirani efekti ojačavanja materijala u zavisnosti od stepena deformacije ukazuju da mehaničke osobine hladno vučene žice od austenitnog nehrđajućeg čelika X5CrNiMo 18 12 zavise od ukupnog, a ne od parcijalnog stepena deformacije.

Izvedene regresione jednačine mogu efikasno da posluže za definisanje izlaznih mehaničkih karakteristika u zavisnosti od stepena deformacije.

Međutim, pri konačnom izboru tehnologije vučenja potrebno je voditi računa i o drugim uticajnim faktorima koji su vezani za same troškove proizvodnje. S tim u vezi, manji broj operacija vučenja sa većim stepenima defomacije ne mora nužno značiti manje troškove. Skraćenje vremena izrade i manji broj vučnih matrica može uzrokovati veće troškove proizvodnje zbog većeg opterećenja alata, a time i smanjenje njihovog vijeka trajanja, problema u vođenju procesa i sl.

Stoga je za kompletno projektovanje tehnologije vučenja i izbor optimalne varijante uključujući i broj vučnih matrica neophodno izvršiti detaljnu tehno-ekonomsku analizu.

Rezultati istraživanja i izvedene zakonitosti predstavljeni u ovom radu mogu značajno doprinijeti izboru optimalne varijante izrade i efikasnijem oblikovanju proizvoda zahtjevanog kvaliteta izrade.

NOMENKLATURA

A - relativno izduženje, %
A_i - površina poprečnog presjeka žice poslije deformacije, mm^2
A_{i-1} - površina poprečnog presjeka žice prije deformacije, mm^2
HV5 - tvrdoća po Vikersu

n - broj provlaka, odnosno faza ili operacija vučenja
R_m - zatezna čvrstoća materijala, N/mm^2
$Rp_{0,2}$ - napon tečenja ili tehnička (konvencionalna) granica razvlačenja, N/mm^2
Z - kontrakcija presjeka, %
ψ - *stepen deformacije II reda*
φ - *logaritamski stepen deformacije, stepen deformacije III reda*
R_2 - *koeficijent korelacije*
B_1, B_2, B_3 - *koeficijenti regresije*

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APPLICATION OF EXPLOSIVE ENERGY IN METAL FORMING TECHNOLOGIES

Stipo Buljan [1], Himzo Đukić [2], Darko Šunjić[3]

Abstract: Explosives can be described as chemical compounds in which an external pulse can cause an extremely rapid chemical reaction. This chemical reaction is often followed by the release of a large amount of heat and gaseous. Explosive forming is unconventional technology where final products are produced using an explosive as an energy source. Unlike others, explosives are quite cheaper as energy sources. This technology dates back to 1888. but after WWII it's had a great development, mostly in aerospace industry. There are two system of explosive forming: direct and indirect, and two methods: contact and standoff. Explosive forming is used combined with other technologies such as deep drawing, welding, bulging of tubes etc. This technology can be also used for creating pieces of art.

Key words: explosion, explosive forming, explosives, metalworking

1 INTRODUCTION

Explosion is very fast process of creating heat energy, followed by appearance of gases at a pressure higher than the environment pressure, in which they occurred. Due to the pressure difference, the explosion of the gases created by the explosion process results in a part of the energy being transformed into work. Following this definition, explosives are chemical compounds or homogeneous mixture of chemical compounds that can create a large amount of gases heated to high temperature in short time. Today it is mainly divided into three types of explosion: physical, nuclear and chemical. The most common division of explosives is on low (black powder, gun powder) and high explosives (TNT, dynamite). By detonating explosives it is possible to produce any amount of energy needed for the process of forming. However, it is problematic to have a suddenly freed ability to keep work under control so that the desired shape change is achieved and that the rest of the energy, without any danger to the workpiece, the tool, the machine, and the environment, destroys. The schematic diagram is Fig. 1

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shows usage of explosive in metal forming.

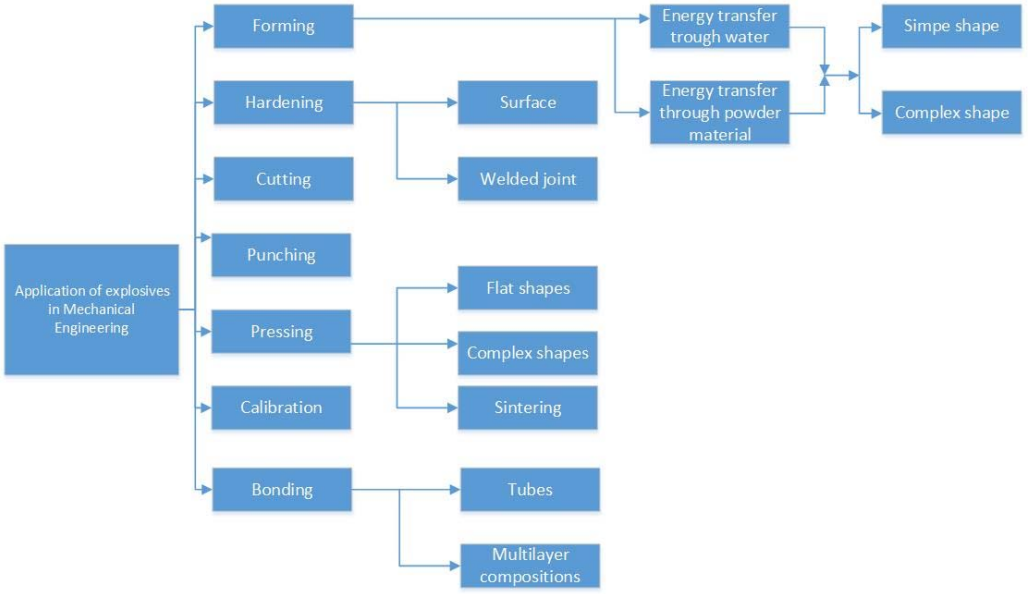


Figure 1. *Schematic diagram of the explosive application in metal forming*

Conventional methods that have been used for many years have reached their peak and have not left much space for technological advancement. Because of this, the engineers found themselves faced with the challenge of getting work items with unconventional technologies because they could not get them conventional. The very beginning of the development of explosive forming is considered to be 1888 when Charles Monroe performed the first experiment using an explosive to form a plate [1-2]. The greater use of explosive energy appeared in the 1960s and at that time experimental researches are mostly done for aerospace industry needs for new workpieces with larger dimensions and complex geometries [3]. By the end of the 1980s, this technology was almost forgotten, but the Dutch research institute, TNO, returned to its popularity, showing that this technology can be used for other purposes, not just in the airline industry. Items can be formed from few kilograms to several tons, with thicknesses from few millimeters to 150 mm and with dimensions to 6000 mm [4]. Today with explosive forming can be processed: steel, aluminum, stainless steel, nickel, titanium, and titanium alloys.

2 METHODS AND SYSTEMS OF EXPLOSIVE FORMING

Conventional metal forming technologies are characterized by forming velocity of up to 10 m/s which means that the energy required to deform the sheet is handover during some period of time. Unconventional or high-velocity forming technologies, which explosive forming belongs, are characterized with fact that potential energy required to perform a process of sheet metal deformation is converted to kinematic energy in a very short period of time [5]. Due to that high-velocity increase plasticity of material, this method can be used for forming sheets with low plasticity on standard forming velocity. This process is based on setting-up of the workpiece on a mold that will define its final shape. In order to evenly shape the workpiece, the energy of deformation must be

transmitted through a medium that is most often water because water is the most accessible and cheapest [6]. Due to the spatial distance between the explosives and workpiece, explosive forming can be divided into contact method and standoff method. In the contact method, the explosive is in direct contact with the workpiece that will be formed. Due to the absence of space between explosive and workpiece, explosives with lower velocity of detonation are used. Proper selection of explosives prevents possible damages on the workpiece. That is the main reason why this method is considerably less in use than the standoff method [7]. In standoff method, the explosive is located at a certain distance from the workpiece. The distance is adjusted to the mass and the type of explosives, the workpiece material and the medium through which the shock wave is transmitted. After detonation, the shock wave progresses and it is followed by expansion of the bubbles. The schematic diagram of the contact and standoff method is shown in Fig. 2 [2-3].

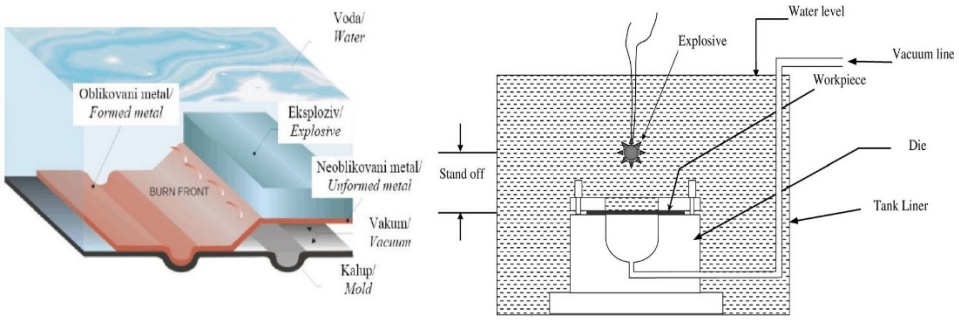


Figure 2. *Contact and standoff method*

According to the system used, explosive forming can be divided into and closed and open forming system. The closed system was named after the manner of setting explosive charge which is located inside a two-part mold. This system is used for molding thin-wall pipes. The advantage of the system is better utilization of explosives energy and the disadvantage is limiting the size of the product because of the mold. When the explosive is detonated in a closed system, the mold is exposed to significant dynamic shocks and therefore needs to be significantly larger than the open system. In case the mold of the closed system is not sufficiently dimensioned, the mold can be crack. Because of this, the closed system is rarely in use. The system has been modified over time and today there are vents on a mold that have the function of safety valves and prevents the possibility of cracking in parts. At open system, the explosive is not blocked on both sides of the mold. Only one side of the mold is by dimensions less than half of the mold of the closed system. Because of the cost-effectiveness of the system, mold represents the most expensive part of production/manufacturing. When an open system is used, a smaller amount of explosive energy is consumed for workpiece worming which is not a disadvantage because the price of explosives in the price of the final product is negligible [8].

Materials used to make dies in explosion processing can be highest quality steels, cast iron, concrete or plastics. Several factors influence the choice of materials, and some of them are the type of processing material as well as the number of work items. Water, oil, salt, sand, air can be used in the explosion forming as a medium. After bringing into the water as a media after the air, the mass of the explosive decreased to 80% [9].

3 APPLIANCE OF EXPLOSIVE FORMING

Among other technologies, explosive forming is combined with deep drawing. The workpiece on which the workpiece clamps are mounted is placed on the die. Above the workpiece, an explosive is placed at a certain height. This workpiece on a die with workpiece clamps is immersed in a water tank where an explosion is being initiated. In this kind of sheet forming it is necessary to ensure that the impact on the die is as small as possible, and this can be ensured if the rubber is placed underneath the die [1]. Fig. 3 presents a part resulted with deep drawing with explosion [10].

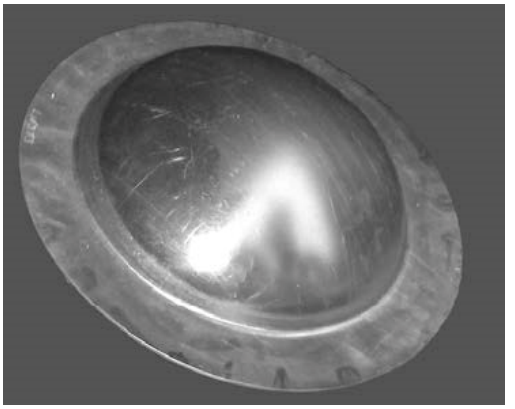


Figure 3. *Deep drawing with explosion manufactured spherical cap*

Another example of explosive forming with contact method is shown in Fig. 5. The tube is, used as a workpiece, is placed in the forming die that has cavities inside it. After initiating the explosion, the tube is plastically deformed and formed to die. This technology is used for bulging of small-sized tubes [7].

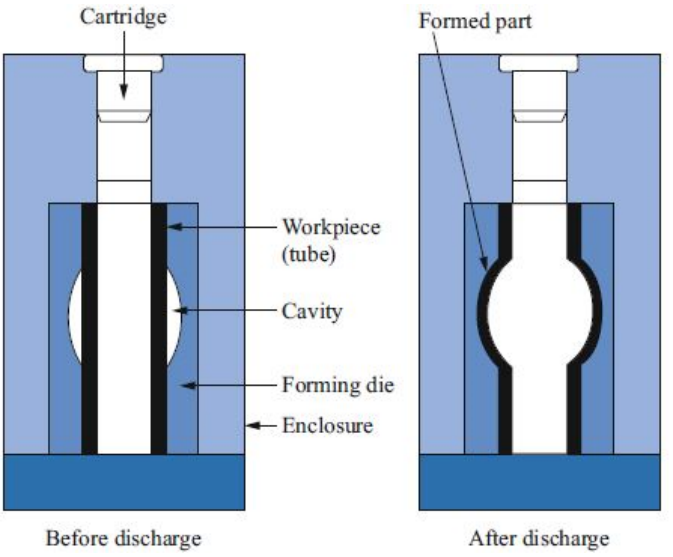


Figure 4. *Bulging of small-sized tubes*

4 CREATING SPHERE WITH EXPLOSIVE FORMING

Free forming is based on the relative displacement of each point of the workpiece when subjected to a shock wave. The main steps of creating the sphere start with preparing the workpiece from several segments of the shell (tapered shell) and welded. The hole is left to allow water to sink and place an explosive in the center of the prepared workpiece. Once all other conditions are ensured, the explosion of explosives with certain characteristics is initiated. In the water, the shock wave spreads equally alike and first transfers the load to the nearest point from the center or from the center of the explosion. The peak shock wave pressure decreases as the distance increases, resulting in the difference in the speed of each point individually, and as a result of that flat workpiece is plastically deformed to the shape of the sphere. By adapting the energy of the explosion, the deformation of the tapered shell ends when it reaches the form of the circumscribed sphere and then the whole process ends. Fig. 6 shows a sketch of explosive forming used to create sphere [11-13].

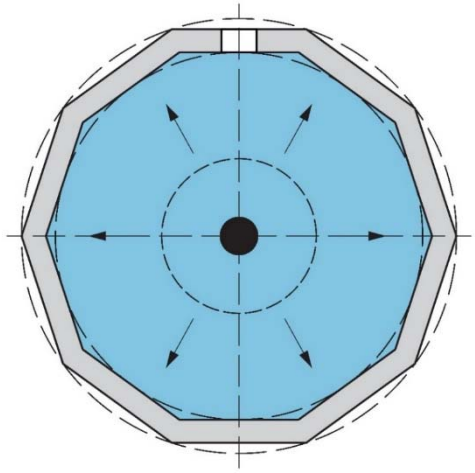


Figure 5. *Free explosive forming sketch*

5 CONCLUSION

Researches on unconventional technologies give us plenty of space for work, progress and introducing new ideas. That is what we need today in an increasingly demanding market. Explosive forming certainly fulfill the requirements of high-energy rate forming for simple and inexpensive forming process. The advantages of explosive forming are the simplicity of the process, explosives price, the ability to form a metal that at conventional deformation velocities is badly formed, almost any amount of energy can be achieved, forming of workpieces with large dimensions and disadvantages are a danger of the process itself and the need for qualified manpower.

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UTICAJ PARAMETARA PLAZMA REZANJA NA PROMJENU STRUKTURE KOD PRIPREME IVICE ZAVARIVAČKOG ŽLIJEBA

Dragoslav Dobraš[1], Milisav Marković[2], Saša Đurić[3]

Rezime: Da bi se primijenila tehnologija spajanja zavarivanjem, kod debljih limova, prethodno je neophodno izvršiti pripremu ivica zavarivačkog žlijeba. Priprema žlijeba primjenom plazma rezanja jeftinija je od metoda odavjanjem čestica, čiji su troškovi često veći od troškova zavarivanja. Međutim, plazma rezanje, zbog unosa toplote, mijenja strukturu u zoni uticaja toplote, čime se mijenjaju mehaničke i tehnološke osobine materijala. Pravilnim izborom parametara plazma rezanja moguće je smanjiti unos toplote, čime je i zona promjene strukure u materijalu manja, te je i zavarljivost bolja. Kroz rad se analizira uticaj parametara plazma rezanja na širinu zone uticaja toplote.

Ključne riječi: plazma rezanje, zavarivački žlijeb, ZUT

INFLUENCE OF PARAMETERS OF PLASMA CUTTING TO CHANGING STRUCTURE FOR PREPARATION EDGE OF THE WELDING GROOVE

Abstract: In order to apply the bonding technology by welding, in the thick sheets, it is necessary to perform the preparation of the edges of the welding groove. Plasma preparation using plasma cutting is cheaper than the particle pickup method, the cost of which is often higher than the cost of welding. However, plasma cutting, because of the heat input, changes the structure of the heat affected zone, thereby changing the mechanical and technological properties of materials. Correct choice of parameters of plasma cutting is possible to reduce heat input, allowing the zones and changes the structure of the material is less, and the weldability is better. Through the work is analyzed the influence of plasma cutting parameters on the width of the heat transfer zone.

Key words: plasma cutting, welding groove, HAZ

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1 UVOD

Zavarivanje je danas nezaobilazna tehnologija spajanja materijala u gotove proizvode koji su nužno potrebni čovjeku. Pred tehnologa zavarivanja postavljeni su različiti zahtjevi kao što su: kvalitet i pouzdanost zavarenog spoja, smanjenje troškova izrade i utroška materijala, kao i energije potrebne za ostvarivanje zavarenog spoja.

Pri ručnom elektrolučnom zavarivanju koriste se niskoenergetski izvori struje. Zavarivanje debljih limova mora se izvesti u više prolaza (slojeva). U cilju pravilnog preklapanja prolaza, prije zavarivanja, mora se pripremiti zavarivački žlijeb čiji oblik i dimenzije zavise od: debljine materijala, vrste spoja, postupka i položaja zavarivanja.

Razvijen je niz postupaka pripreme ivica žlijeba, kako metodama odvajanja čestica, tako i metodama termičkog rezanja. U slučaju kada je ivica stanice žlijeba ravna, daleko je brža i jeftinija priprema ivice žlijeba termičkim rezanjem. Ovo je uslovilo da skoro sva metaloprerađivačka preduzeća pripremu ivice žlijeba izvode termičkim rezanjem.

Međutim, za razliku od metoda odvajanjem čestica, termičkim rezanjem se u materijal unosi veća količina toplote koja znatno mijenja strukturu materijala neposredno uz reznu ivicu i zonu uticaja toplote. Sitnija struktura kristalnog zrna osnovnog materijala omogućava bolju zavarljivost, manju vrijednost zaostalih napona, te bolje mehaničke osobine zavarenog spoja.

Kao što je cilj zavarivanja da se topljenjem ostvari nerazdvojiva veza uz unos što manje količine toplote, tako je i pri termičkom rezanju cilj da se ostvari rezna ivica sa što manjim unosom toplote. Manjim unosom toplote dobija se: manja širina zone uticaja toplote, manja promjena strukture materijala u zoni rezne ivice i manje promjene mehaničkih i tehnoloških osobina materijala u zoni uticaja toplote.

Pored različite širine zone uticaja toplote, pri termičkom rezanju mogu nastati i: različite geometrijske greške rezne ivice, zaostrali naponi i pukotine, te veća ili manja količina troske koja se mora odstranjivati mehaničkim putem. Optimizacijom parametara termičkog rezanja moguće je ostvariti geometrijski tačnu ivicu žlijeba uz minimalnu zonu uticaja toplote i bez ostalih vidova grešaka. Optimizaciju parametara neophodno je vršiti posebno za svaku metodu termičkog rezanja, različit kvalitet i debljinu materijala, pa čak i za različite proizvođače iste vrste opreme.

Kroz rad se analizira širina zone uticaja toplote, nastala pri različitim jačinama struje i brzini plazma rezanja lima kvaliteta S275JR, debljine 10 mm, ostvarenim na plazma rezačici proizvođača Soitaab Linea Red.

2 PLAZMA REZANJE

Plazma rezanje je vid termičkog rezanja kod kojeg se materijal u zoni rezanja topi i kinetičkom energijom plazme izduvava iz zone reza.

Plazma je električno provodljiv, disociran i visokojonizovan gas, te predstavlja četvrto agregatno stanje. Ukupan broj pozitivnih i negativnih naboja jednak je, pa je sa stanoviša električnog naboja plazma kao cjelina, električno neutralna.

U gorioniku za plazma rezanje, kroz posebnu mlaznicu, prolazi plazmeni gas pod pritiskom. Otvor mlaznice ispunjava električni luk kroz koji prolazi gas, usljed čega se gas naglo zagrijava i velikom brzinom izlazi iz mlaznice, povećavajući kinetičku energiju mlaza. Pri toj brzini mlaza, plazma veoma visoke temperature (oko 22000 °C) reže svaki metal debljine do 150 mm. Luk plazme je konusan, te se za dobijanje okomite rezne ivice gorionik mora zakrenuti za polovinu ugla konusa plazmenog luka.

Izvori električne struje za plazma rezanje isti su kao i izvori struje za zavarivanje. Koristi se istosmjerna struja, sa minus polom na elektrodi.

Kada se režu materijali koji nisu provodnici električne struje, električni luk se uspostavlja u gorioniku, tj. koristi se zatvoreni luk. Za rezanje materijala koji su provodnici električne struje može se koristiti i otvoreni luk, koji se uspostavlja između elektrode i radnog komada.

Zbog težnje ka što: boljem kvalitetu rezne ivice, većoj brzini rezanja, manjoj potrošnji energije i smanjenju zagađenja, tehnike plazma rezanja se konstantno unaprjeđuju. Razvijeno je više različitih postupaka plazma rezanja, kao što je korištenje dva nezavisna gasa (jedan kao radni, a drugi kao zaštitni), korištenje vazduha umjesto uobičajenih plazma gasova, ubrizgavanje vode radi efikasnijeg sužavanja mlaza, itd.

3 EKSPERIMENTALNI DIO RADA

Analiza uticaja parametara plazma rezanja na promjenu strukture, kod pripreme ivice zavarivačkog žlijeba, izvedena je sa ciljem optimizacije brzine rezanja i jačine struje plazmenog luka u odnosu na minimalnu širinu zone uticaja.

Priprema uzoraka za ovu analizu izvedena je na ugljeničnom konstrukcionom čeliku kvaliteta S275JR, debljine 10 mm, mehaničkih osobina i hemijskog sastava prema EN 10025-2, datih u tabelama 1 i 2.

Tabela 1. *Mehaničke osobine čelika S275JR*

Zatezna čvrstoća, R_m	*Napon na granici tečenja, R_{eH}*	*Energija udarnog loma pri +20 °C*	*Izduženje*
410 – 560 MPa	*≥ 275 MPa*	*27 J*	*≥ 23 %*

Tabela 2. *Hemijski sastav čelika S275JR (max. sadržaj)*

Hemijski element (%)					
C	*Mn*	*P*	*S*	*N*	*Cu*
0,21	*1,5*	*0,035*	*0,035*	*0,012*	*0,55*

Maksimalan ekvivalent ugljenika računa se prema izrazu 1.

$$C_E = C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15 = 0{,}40\% \quad (1)$$

Termičko rezanje izvedeno je na plazma portalnoj rezačici proizvođača Soitaab Linea Red, uz korištenje komprimiranog vazduha. Rezačica je programski upravljana sa bazom podataka i izborom samo određenih vrijednosti, dok program sam prilagođava ostale parametre. Za promjenljivi parametar usvojena je jačina struje, dok program rezačice za izabranu jačinu struje podešava preporučenu maksimalnu brzinu rezanja. Ručno je moguće smanjiti brzinu rezanja na određeni procenat od programom preporučene maksimalne brzine. U tabeli 3 date su kombinacije izabrane jačine struje i brzine rezanja.

Tabela 3. *Kombinacije brzine rezanja i jačine struje*

Uzorak	*Jačina struje (A)*	*Brzina rezanja*	
		stvarna (mm/min)	*% od maksimalne*
1	*130*	*2680*	*99*
2	*130*	*1340*	*50*
3	*130*	*616*	*23*
4	*80*	*1792*	*99*
5	*80*	*905*	*50*
6	*80*	*615*	*34*

Perema datim kombinacijama brzine rezanja i jačine struje, iz lima su izrezani ispitni uzorci dimenzija 100 x 50 mm. Nakon rezanja ispitnih uzoraka izvršeni su: analiza rezne površine, mehaničko presijecanje uzorka okomito na uzdužnu stranu ispitnog uzorka, analiza grešaka geometrije rezne ivice.

Metalografskom pripremom makrostrukture ispitnih uzoraka, nakon nagrizanja brušene površine, uočena je razlika u strukturi materijala na osnovu čega su izmjerene najveće širine zone uticaja toplote unešene pri plazma rezanju.

Rezultati analize grešaka rezne ivice i širine zone uticaja toplote, za pojedine uzorke, dati su u tabeli 4.

Tabela 4. *Širina zone uticaja toplote i greške rezne ivice*

Uzorak	*Širina zone uticaja toplote (mm)*		*Greške rezene ivice*	
	strana 1	*strana 2*	*strana 1*	*strana 2*
1	*6*	*6*	*konkavnost*	*konveksnost*
2	*7*	*7*	*konveksnost*	*konveksnost, troska na dnu*
3	*8*	*8*	*troska na dnu*	*konveksnost*
4	*3*	*3*	*konveksnost*	*konveksnost, troska na dnu*
5	*4*	*4*	*konveksnost, troska na dnu*	*odstupanje ugla reza*
6	*5*	*5*	*konveksnost*	*odstupanje ugla reza*

4 ZAKLJUČAK

Analizom geometrije rezne ivice uočava se da pri rezanju nije vršena korekcija ugla plazmenog luka, zavisno od smjera rezanja, te su vidljive greške geometrije rezne ivice.

Analogno teoretskom razmatranju, rezultati eksperimentalnog dijela rada potvrđuju da se najuža zona uticaja toplote dobija najmanjim unosom toplote, tj. manjom jačinom struje i većom brzinom rezanja.

Prema ekvivalentu ugljenika, koji za konstrukcioni čelik S275JR iznosi 0,4%, ovaj čelik je dobro zavarljiv. Međutim, za veće debljine lima, kada se pri termičkom rezanju ivice zavarivačkog žlijeba unese veća količina toplote, širina zone uticaja toplote termičkog rezanja je veća. Neposredno uz reznu ivicu, veća je promjena strukture kristalnog zrna pa su mehaničke osobine materijala i zavarljivost lošija.

Termičko rezanje može dovesti do pojave zaostalih napona, koji se pri zavarivanju superponiraju sa termičkim naponima zavarivanja, što može dovesti do gubitka stabilnosti zavarenog spoja, pojave pukotina, a u kritičnom slučaju i do loma.

Do loma konstrukcije, uslovljenog greškama termičkog rezanja, može doći i nakon dužeg upotrebnog vijeka konstrukcije.

Da bi se smanjile greške ivice zavarivačkog žlijeba nastale termičkim rezanjem, povećala zavarljivost materijala, kao i stabilnost, sigurnost i pouzdanost zavarenih spojeva, tehnologiji termičkog rezanja potrebno je posvetiti posebnu pažnu.

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ANALYSIS OF THE APPLICATION OF THE MAG LOW SPATTER CONTROL FUNCTION

Darijo Božičković[1], Dragoslav Dobraš[2], Milisav Marković[3]

Abstract: In the welding technology, the goal is to find the optimal ratio between production costs and productivity, in other words, to produce a product with as little as possible material resources in the shortest possible period of time. In the process of arc welding, it is evident that the molten metal is spraying over the surface of the welding parts. The amount of sprayed metal that does not participate in the deposit represents a direct loss, both the amount of additional material, and the energy required for its melting, as well as the time needed for their removal. At the same time, the sprayed metal changes the structure and mechanical properties of the base material in places where it has fallen. Modern welding current sources, within their control panels, enable the selection of welding parameters in which the spraying of the metal is reduced. Through the work, the application of MAG Low Spatter Control function is analyzed.

Key words: MAG welding, Low Spatter Control Function

1 INTRODUCTION

Welding is an indispensable technology for connecting materials into finished products that are necessary to mankind. Different requirements are set before the welding technologist, such as: the quality and reliability of the welded joint, the reduction in the cost of fabrication and consumption of materials, and the energy required to make the welded joint. Due to the desire to satisfy many of these requirements, a large number of modified MAG welding procedures have been developed that provide high levels of exploitation characteristics of the welded joints, which includes the Low Spatter Control function.

Contamination of the base material by the drops of liquid metal is considered one of the frequent welding errors. Those are the drops that occurred in the welding process as a result of the melting of the additional material, and they did not end at the welded metal, but in the heat-affected zone.

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The appearance of the weld spatter can couse various damege, from aesthetic to mechanical character. In the case of non-alloyed steel, they are considered to be aesthetic error, and extra time, material resources and energy are used to clean the sprayed metal. Weld spatter is a major problem, as it can cause serious technical and mechanical damage, such as changes in the chemical composition and structure at the point where the drops have fallen, the possibility of starting corrosion, which causes a reduction in surface strength and the possibility of failure of the structure.

Apart from possible damage, the formation of weld spatter also causes loss of material, which seems to be not significant, but viewed through serial production, it represents an important value of the price of additional material and energy needed for its melting. By using modern welding machines, with the application of modified MAG welding procedures, this error can be reduced to a minimum with great savings.

2 APPLICATION OF CONVENTIONAL WELDING SOURCES FOR MAG WELDING

For welding with conventional MAG welding sources, constant current sources are used, i.e. springs with a flat or benign characteristic. During the welding process, at the constant speed of the electrode wire delivery, the so-called autoregulation is achieved - the internal regulation of the length of the electric arc, Fig. 1. The changes in the current strength depending on the length of the arc are happening more rapidly, the characteristic of the current source being horizontal. Due to internal regulation, it is not possible to directly select the current level (the operating voltage is chosen on the device), but it is proportional to the amount of additional material supplied, therefore, the speed of the electrode wire.

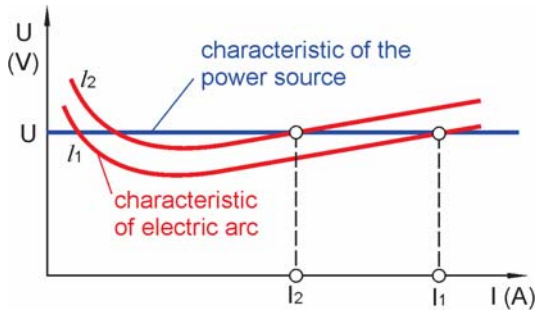


Figure 1. *Static characteristic of classic MAG power sources* [2]

In MAG welding with conventional power sources, the method of transferring additional material through an electric arc is in function of the basic influencing factors: the nominal voltage and current intensity of the electric arc, the rate of delivery of the additional material and the free end of the electrode wire, the type of protective gas, figure 2.

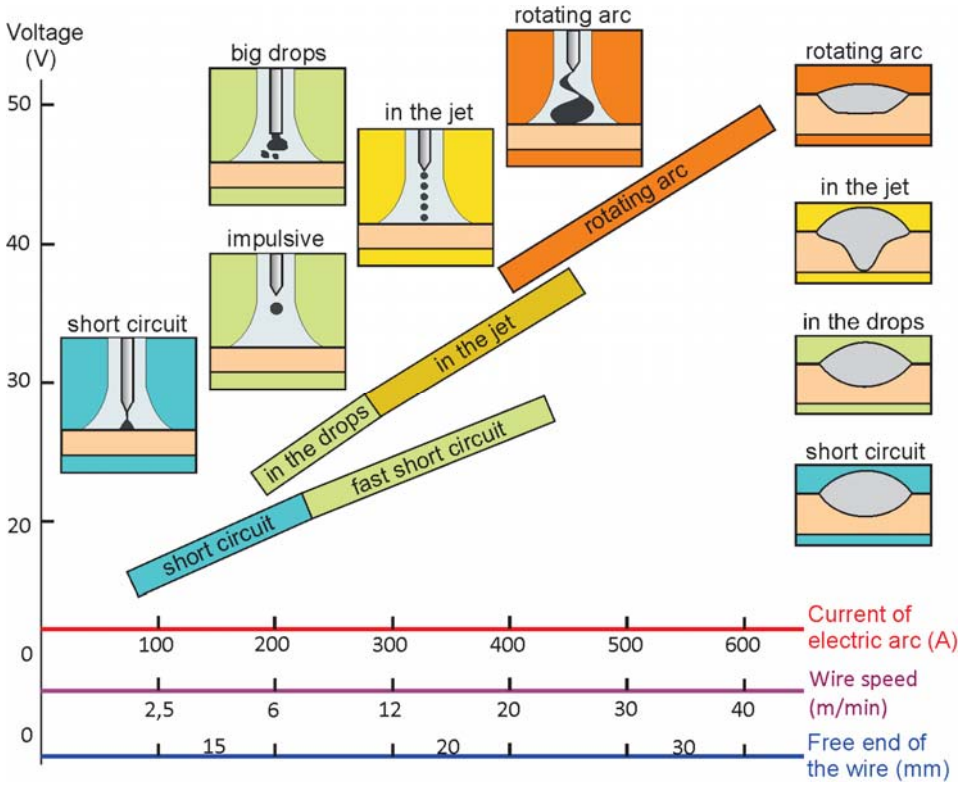


Figure 2. *Characteristic ways of transferring additional material to MAG welding in the function of voltage and current power of the electric arc, speed and length of the free end of the wire* [2]

According to Figure 2, it can be concluded that the smallest amount of heat input is achieved in the welding mode with the transfer of additional material in short circuit. The method of transferring metal to short circuits is most useful for welding thin sheet plates due to low heat input, which is characteristic of this method of metal transfer. This method of transferring additional material is also suitable for welding root pass. The advantages of this method of transferring metals in the electric arc are: the possibility of welding in all positions and less deformation as a result of low heat input. The disadvantages of this method of transmission and the reason why modified MAG processes are formed are: insufficient penetration and excessive spraying.

For welding thick sheet plates, other methods of transferring additional material are used due to higher heat input and higher productivity.

In conventional MAG welding with short circuit, Fig. 3, as soon as short circuit (2) occurs, an increase in current strength occurs which leads to an increase in the force of the pinch effect and the release of the drop (3). The electric arc starts in the case of a relatively strong current short circuit and high pressure of the electric arc (4). This can lead to spatter and instability.

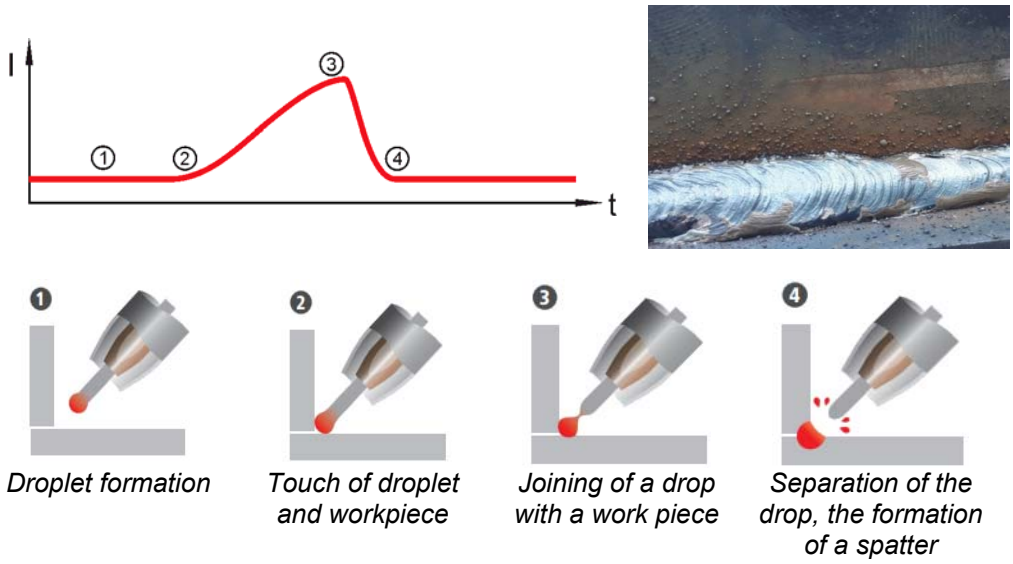


Figure 3. *Dynamic characteristics, weld spatters and short-circuit transfer cycles with conventional MAG welding* [1]

3 APPLICATION OF MODERN SOURCES FOR MAG WELDING

The losses of electricity in the transformation of the network voltage to the voltage of the arc, as well as the inability to manage the dynamic characteristics of the electric arc, have caused the production of new sources of welding current in which voltage transformation is carried out through inverter devices.

Unlike conventional welding machines with a frequency of 50 Hz, inverter welding machines at the output use frequencies in the range of 5 to 25 MHz. By changing the operating frequency, the dynamic characteristics of the arc are also changing.

New sources of welding current have built-in programming, usually microprocessor units which contin data on individual parameters and their conection with material and protective gas. This way of synchronized parameter setting is known as "synergic".

Nowadays, more and more procedures based on the MAG procedure are being developed with certain upgrades. The goal and result are various improvements to classic MAG welding (higher speed, higher productivity, lower energy consumption).

Modern processes of MAG welding their development are based on the modification of conventional metal transfer methods: short-circuit transfer, arc in the spray, and a combination of various metal transfer.

Modification of the method of metal transfer imposes also modification of the welding equipment, ie the possibility of better control of the welding parameters. The characteristic modern MAG welding processes that unify specific metal transfer concepts combining short circuit and impulse, but also modified arc in the spray, are:

- STT, Surface Tension Transfer,
- FastROOT,
- CMT, Cold Metal Transfer,
- RMT, Rapid MIG/MAG Technology,
- MAG Tandem Welding,
- LSC, Low Spatter Control.

4 WELDING OF THIN SHEETS

It can be said that the main aim of the welding is to achieve as much material homogeneity as possible, using as little amount of heat input into the welded joint as possible. Thin sheets are mostly used in automotive, air and military industries. When welding thin sheets (0.6 to 5.00 mm), the amount of heat transferred into the welded joint is the biggest problem.

A small amount of energy input can cause incomplete fusion of additional and base material, while excessive heat input can lead to an increase of the spatter and burning of the base material.

4.1 Problems caused by weld spatter

Apart from the costs, energy and additional materials, labor and equipment, and time needed for making a weld joint, weld spatters can cause various additional problems on the product:

- for a esthetic reasons it is necessary to clean the surface of the basic material after welding, which requires additional resources and time.
- spatter, due to high temperatures, at the point of contact with the basic material, change the structure and the voltage state in the material and can lead to the appearance of initial cracks. After removing the spatters, a thermal treatment is required to normalize the crystal structure.
- spatters affect the emergence of segregations that accelerate the formation of corrosion and aggravate anticorrosive protection.
- agents that are applied to the base material, in order to prevent adhesion of the spatters, require additional passivation and aggravate anti-shock protection.

The tendency of the development of modified MAG welding methods in order to reduce spatters is reflected in the savings of: energy, additional materials, resources and time needed for their removal, better mechanical and technological properties, easier anticorrosion protection.

The key to a successful MAG weld with reduced spattering is reflected in the control of the dynamic characteristics of the arc, the method of metal transfer and stable control of welding parameters, which is enabled by new inverter devices, and faster and more precise control systems.

4.2 Low Spatter Control function

In the conventional procedures of MAG welding, short-circuit transfer is used to reduce heat input and prevent burnout, but there is a higher amount of spattering. Impulse currents are used for less heat input into the work piece and smaller amount of spatters.

In order to eliminate or minimize the spattering problem, the development of invertor welding equipment is an increasingly common use of modified MAG welding processes that combine the advantages of impulse and conventional MAG welding to transfer metals.

This MAG welding method is called: Low Spatter Control (LSC). It lowers the material spattering to a minimum and, with the use of various protective gases, provides a stable electrical arc.

In this process, the power source generates a variable shape of the dynamic characteristics of the arc (pulse), which allows the separation of only one droplet during the impulse, while the amount of material transfer is regulated by the wire diameter and the number of pulses.

The current source should provide two levels of current strength, the basic level representing the minimum value required for the maintenance of an arc and the pulsating level or pulse current, which represents a value that allows the transfer of the metal without establishing a short circuit, Figure 4. This method of metal transfer ensures a stable and quiet electric arc, practically free from spattering.

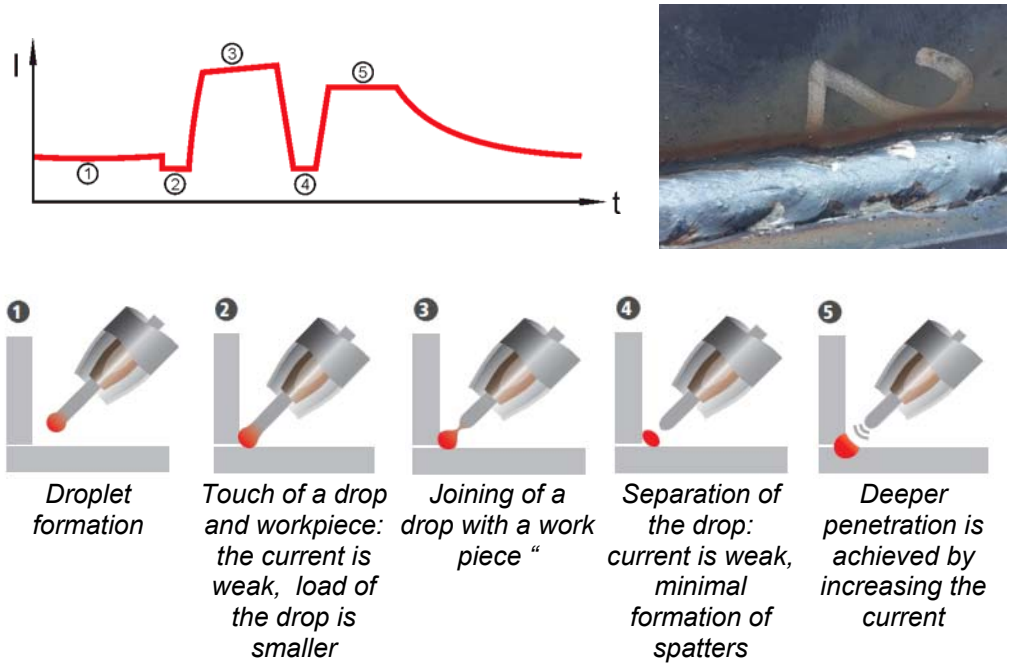


Figure 4. *Dynamic characteristics, weld spatters on workpiece and metal transfer cycles in Low Spatter Control functions* [1]

Depending on the type and device manufacturer, this material transfer option also has additional features: LSC Root, LSC Universal, and options such as stabilization of penetration and stabilization of the electric arc.

An advanced Low Spatter Control function has also been developed, which is used in the field of high-energy metal transfer in the spray.

5 CONCLUSION

The method of metal transfer, which uses a Low Spatter Control function, compared with conventional metal transfer to short circuits, has proved to be much more favorable in terms of: reduced quantities of heat input in welding, stability of welding process and amount of spattering.

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ARMOUR STEEL PLATES OF NEW GENERATION

Jure Bernetic[1], Borut Kosec[2], Mirko Gojic[3], Milan Rimac[4], Zijah Burzic[5], Gorazd Kosec[6], Milan Bizjak[7], Ales Nagode[8]

Abstract: Co-workers of the biggest Slovenian steel producer ACRONI d.o.o. in cooperation with domestic and foreign institutions of science have been designed and developed a new generation of high quality low alloy steel PROTAC 500 in the form of plate for the armour protection. Steel PROTAC 500 represents a high-quality world-class product. Steel PROTAC 500 has excellent mechanical properties, including standard technological characteristics, such as good tensile properties, excellent impact strength at low temperatures, hardness and deflection as well as ballistic testing where the PROTAC 500 armour plate is made according to the NATO standards as it has lower required thickness of protection in comparison to the competition.

Key words: Adiabatic shear band (ASB), Armour Steel, Plate, Protection

1 INTRODUCTION

The selection of the appropriate armour material is crucial to ensure the adequate safety and mobility transport systems [1]. When selecting or developing the appropriate materials for the armour it is necessary to achieve the best possible compromise between the required mechanical properties of materials, minimizing the density and the final price of the product. With the appropriate production technology, which includes synthesis, melting, continuous casting, hot forming, heat treatment, etc. [2]. High strength low alloy (HSLA) steel of good functional properties at affordable prices can be produced [3].

By improving the strength and toughness of the steel the required thickness and the weight of the steel shell is reduced [4]. Such steels are competitive to other materials for the armour [5]. In the context of this study, we carried out a ballistic test of high

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strength low alloy steel PROTAC 500, whose mechanical properties and testing conditions are collected in Table 1.

Table 1. *Mechanical properties of steel PROTAC 500 at testing temperature 20 °C*

Yeald strength $R_{P0,2}$	*1200 MPa*
Tensile strength R_m	*1600 MPa*
Elongation A_5	*8 %*
Impact toughness	*20 J*
Hardness	*480 – 530 HB*

Steel PROTAC 500 belongs to the group of high strength low alloy (HSLA) steels. It is made in Slovenian steelwork ACRONI by the standard industrial procedures, and the relevant mechanical properties are achieved by quenching and tempering. Preliminary tests of the mechanical properties of the steel have indicated the possibility of using steel PROTAC 500 for light armoured vehicles. Ballistic testing was performed by using 7.62 mm armoured piercing bullets of the Swedish manufacturer Nammo (German standard VPAM, level 11, and the American standard STANAG 4569, Level 3), to examine the interaction between a bullet and a steel plate [6]. Armored piercing bullets, containing the rigid core (generally of high strength steel), which results in the conversion of the total kinetic energy of the bullets to the deformation of the target. The peculiarity of this bullet is the core of tungsten carbide (WC-Co) [7]. When the bullet hits its target, first the formation of pressure waves (cyclic stress) are formed, that spread through the target material and shall be deducted from the back side of the target as tensile waves. These waves reinforce the material, at a certain intensity of interaction between the waves of pressure or tension and can lead to the formation of adiabatic shear bands, cracks and crack growth. The material resistance to compressive and tensile waves is improved by increasing the strength and toughness. The deformation mechanisms at low strain rate are relatively homogeneous, while at extremely high speeds they are more complex. Here it comes to the extreme strain localization in narrow bands called adiabatic shear bands (ASB). The belt is during the deformation very hot, whereby there a transformation of the austenite phase originates, after the load it is rapidly cooled, which results in the transformation to martensite, and thus a high hardness and brittleness of the steel in the ASB occurs. The shear zones are therefore weak areas in the steel.

The amount of produced PROTAC brandmark steel increases rapidly. Figure 1 shows the amount of manufactured PROTAC 500 semi-products produced by ACRONI d.o.o.during the period from 2010 to 2017.

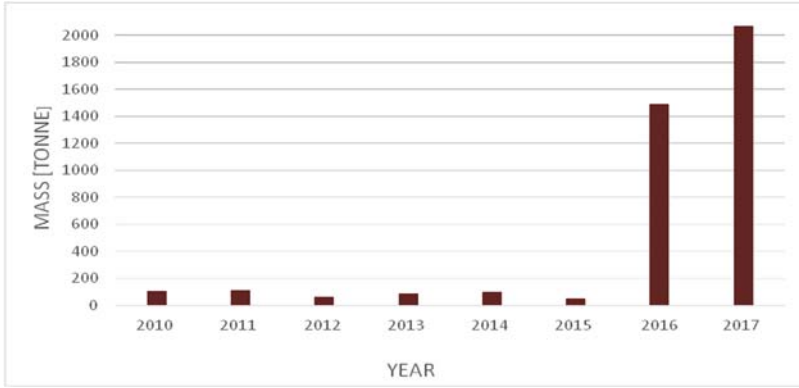


Figure 1.*The amount of PROTAC 500 semi-products, produced by Slovenian biggest steel producer ACRONI d.o.o.*

The quantities of steel plates manufactured in years from 2010, when the industrial production of PROTAC 500 steel started, to 2015 were up to a maximum of 100 tons per year. In 2016, production increased to 1487 tonnes, and in 2017 it already exceeded the 2000 tonnes on an annual level.

2 EXPERIMENTAL WORK

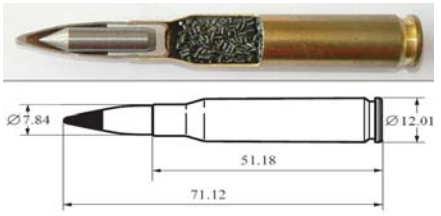
For the ballistics testing a steel PROTAC 500 testing plate with dimensions of 500 x 500 x 20.8 mm was used. Six shots were conducted under the terms of the standard VPAM and STANAG 4569 (Table 2) [7]. Nammo AP8 is the cartridge of an armoured-penetrating bullet caliber 7.62 x 51 mm (.308 Winchester) [7]. American label of the cartridge is the M993. It tends to be used against targets with light armour.

Table 2.*Terms of ballistic test according to the standard VPAM and STANAG 4569 [7]*

Producer	*Nammo AP8*
Standard	*VPAM – level 11*
Caliber	*.308 Win*
Cartridge	*FMJ/PB/WC*
Bullet mass	*8.4 ± 0.,1 g*
Bullet speed	*930 ± 10 m/s*
Distance from target	*10 ± 0.5 m*
Bullet energy	*3633 J*

Bullet is capable of destroying such targets by 2 to 3 times the distance from the armoured piercing of bullets with steel cores. The bullet is made up of a core of tungsten carbide, mounted in an aluminium cup shell is made of steel coated with brass. In Table 3 are collected the properties of the bullet Nammo AP8, and image of transected cartridge and the cartridge sketch with the main dimensions.

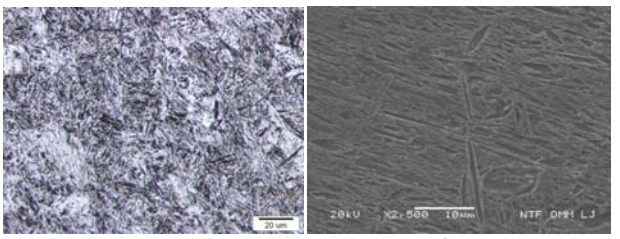
Table 3.*Characteristics of the billet Nammo AP8 [7]*

	*Bullet mass: 8.3 g*
	Core mass: 5.9
	Core diameter 5.5 mm
	Core point: angle 58 °
	Bullet cover material: Steel and brass
	Bullet core material: WC-Co
	Core hardness: 1450 HV

After the ballistics test was excluded from the testing panel three testing samples were cut. The first sample was then cut in several planes perpendicular to the direction of the shot, the other two samples were cut through the penetration of bullets in a plane parallel to the direction of the shot. For the surface metallographic analysis samples were etched with an aqueous solution of ferric chloride. Prepared in this way the surface were examined by metallographic investigation methods. Analysis of macro and microstructure were performed on an optical microscope Olympus BX61. We were interested in particular areas with a different microstructure of the base and the places where the cracks and adiabatic shear bands (ASP) are found. This was followed by analysis with the scanning electron microscope (SEM) JEOL 5610, which allows the observation of microstructure and qualitative and quantitative chemical analysis [8]. The images were recorded at various magnifications, especially the areas where had been ASB, cracks, pores, and where they were traces of melting and mixing of materials. Hardening of the steel plate after penetrating piercing bullets was determined by measuring the Vickers hardness (HV). The fractographic analysis of cracks that have occurred during the ballistic test, for which it was necessary to break down the samples have been done. To determine the mechanism of formation and spreading of the cracks and localized the nature of the fractured surfaces were ignoring and destroying extracts of the errors and faults at liquid nitrogen temperature.

3 RESULTS

In Figure 2 is the microstructure of the steel PROTAC 500 before the ballistic test. The microstructure consists of tempered martensite.



a b

Figure 2. *The microstructure of steel PROTAC 500; tempered martensite (a - (OM), b - (SEM))*

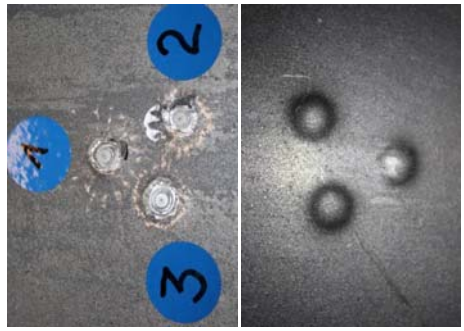


Figure 3. *Front (left) and back (right) side of the steel plate PROTAC 500 after ballistic testing – details of 3 shots*

In Figure 3 (left) there is a front side of the panels PROTAC 500 after ballistics testing with the markings of three samples were have cut and prepared for further analysis. All armoured piercing bullets are stopped in the plate. In interpreting the results of ballistic tests is the most important information if a bullet penetrates the target [9]. In Figure 3 (right) there is the back side of the panel after ballistic test.

In none of the shots no perforation of the panel occurred. The testing results and descriptions of the standard VPAM are in Table 4.

Table 4. *Parameters of the ballistic tests and description of the results*

	Distance (m)	*Shot angle (°)*	*Impact velocity (m/s)*	*Bullet energy (J)*	*Break trough*
Sample A	*10*	*90*	*929*	*3624.77*	*No*
Sample B	*10*	*90*	*931*	*3640.40*	*No*
Sample C	*10*	*90*	*937*	*3687.47*	*No*

By the shot to the sample A the bulge with a crack was formed, that does not transmit light by other shots, but it was smaller bulge without cracks. For a more detailed picture of the interactions between bullets and plate the samples for metallographic analysis were prepared.

In Figure 4 there is a cross-sectional view of the upper level of the sample A, where there are a significant number of cracks, and branched adiabatic shear bands which extend from the border between the envelope bullets (bright narrow band around the circumference of the core) and the base material towards the interior of the target.

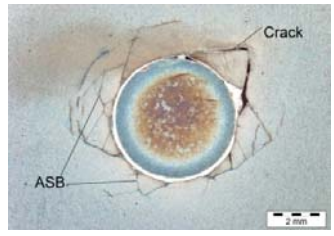


Figure 4. *Macroscopic cross-sectional image of the sample A (upper level)*

Figure 5 shows the macro-picture breakthroughs balls on the analysis of sample C, giving examples of cracks and ASB.

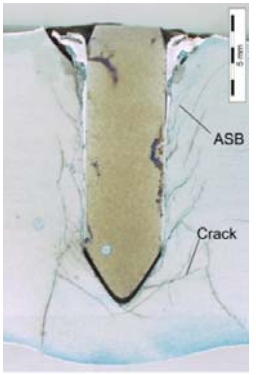


Figure 5. *Macroscopic picture of breakthroughs bullet through the sample C, marked as cracks and ASB*

In the area between the ball and the lower edge of the steel plate they have cracks in the form of a pin. Breakthrough with pin is a common mechanism of penetration through the high strength steels in which the phenomenon of ASB has an important role. The formation of the plug occurs when the thickness of the target is approaching to the diameter of the bullet. Notice also that the bullet after a stoppage due to elastic deformation and the target are slightly separated. For the sample C we have also measured the length of the cracks and ASB. The average length of the cracks on the sample C is 3.9 mm, the average length of the ASB was 4.3 mm, which indicates a very high-speed deformation.

4 CONCLUSIONS

The research analyzed the ballistic properties of armour steel plate PROTAC 500 against armoured piercing bullets caliber 7.62 mm.

The most obvious and significant phenomena in penetrating of the piercing bullets Nammo AP8 in steel plate (target) PROTAC 500 are:

- strain hardening of steels,
- the appearance of cracks and local failure,
- adiabatic shear bands (ASP) and related phase transformations: austenitic, martensitic, melting, solidification, and
- melting and alloying at the border of the bullet /steel of the plate (target).

ACKNOWLEDGMENT

The authors want to thank dr. Slavko Ažman+ (ACRONI d.o.o.), professor Ladislav Kosec (University of Ljubljana), professor Franc Vodopivec (Institute of Metals and Technology), and professor Anton Smolej (University of Ljubljana) for their mentorship at study HSLA steels.

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PROMJENE FIZIKO-METALURŠKIH SVOJSTAVA ČELIKA 16Mo3 i 13CrMo4-5 U ZUT-U ZAVARENIH TIG POSTUPKOM

Belma Fakić[1]

Rezime:*Niskolegirani čelici 16Mo3 i 13CrMo4-5 sa specificiranim svojstvima na povišenim temperaturama imaju veoma široku primjenu u termoenergetskim postrojenjima. Povećani zahtjevi za kvalitet i sigurnost zavarenih spojeva u određenim uslovima eksploatacije, zahtijevaju ostvarivanje niza mehaničkih i strukturnih osobina zavarenog spoja. U ovom radu prikazani su rezultati ispitivanja mikrostrukture, veličine zrna i tvrdoće u ZUT-u sučeono zavarenih uzoraka lima debljine 10 mm koji su zavareni TIG postupkom zavarivanja. Ispitivanje tvrdoće HV10 u zonama zavarenog spoja po standardu BAS EN ISO 9015-1:2012 ukazuje na postojanje korelacije između parametara zavarivanja i dobivenih rezultata ispitivanja.*

Ključne riječi: čelik, mikrostruktura, tvrdoća, zavareni spoj

CHANGES OF PHYSICO-METALIC PROPERTIES OF 16Mo3 and 13CrMo4-5 STEELS IN THE TIG WELDING PROCEDURE

Abstract: Low-alloy steels 16Mo3 and 13CrMo4-5 with specified properties at elevated temperatures are very widely used in thermal power plants. Increased demands on the quality and safety of welded joints under certain conditions of exploitation require the creation of a series of mechanical and structural properties of welded joints. This paper presents the results of the test of microstructure, grain size and hardness in HAZ based on welded samples of 10 mm thick sheets welded by the TIG welding process. Hardness test HV10 in welded joints according to BAS EN ISO 9015-1: 2012 indicates the correlation between the welding parameters and the test results obtained.

Key words: hardness, microstructure, steel, welded joint

1 UVOD

Termički ciklus u toku zavarivanja postupcima topljenjem, kakav je TIG postupak, dovodi do porasta zrna u zoni pod uticajem toplote, što može biti jedan od glavnih degradacionih mehanizama pri zavarivanju. Promjene fiziko-metalurških svojstava zavarenog spoja uslijed unosa toplotne energije tokom zavarivanja se očituju

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u zoni pod uticajem toplote. Unos toplote dovodi do promjene tvrdoće i udarne radnje loma, koje su posljedica promjene mikrostrukture i veličine zrna u odnosu na osnovni materijal. Porast zrna u zoni pod uticajem toplote zavisi od vrste čelika, odnosno njegovog hemijskog sastava i prethodne obrade.

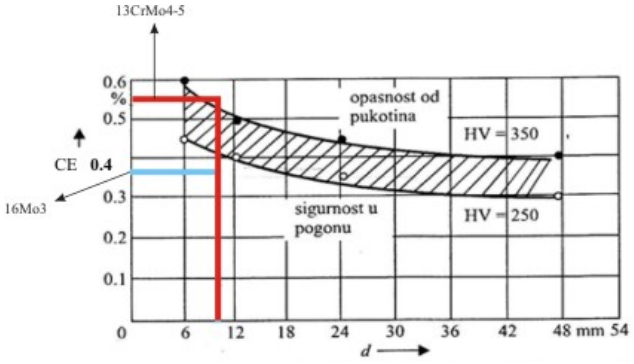
2 PREDMET ISPITIVANJA

Osnovni materijal je lim debljine 10 mm izrađen od niskolegiranog čelika 16Mo3 i 13CrMo4-5, koji imaju specificirana svojstva na povišenim emperaturama, prema standardu BAS EN 10028-2:2004 [1]. Propisani hemijski sastav i hemijski sastav ispitivanih uzoraka dati su u tabeli 1.

Tabela 1. *Propisani hemijski sastav i udarna radnja loma*

	Hemijski sastav, (%)										Udarna radnja loma, (J)
	C	Si	Mn	P	S	Cu	N	Cr	Mo	CE*	
Propisani sastav 13CrMo4-5	0,08 do 0,18	≤ 0,35	0,40 do 1,00	≤ 0,025	≤0,01	≤ 0,30	≤0,012	0,70 do 1,15	0,40 do 0,60	0,57	Min 31
Uzorak 1	0,17	0,30	0,56	0,010	0,005	0,20	0,0060	0,99	0,42	0,56	90
Propisani sastav 16Mo3	0,12 do 0,20	≤ 0,35	0,40 do 0,90	≤ 0,025	≤0,01	≤ 0,30	≤0,012	≤ 0,30	0,25 do 0,35	0,52	Min 31
Uzorak 2	0,17	0,22	0,72	0,010	0,008	0,04	0,0056	0,09	0,28	0,37	117

Prema literaturnim podacima, vrijednost ekvivalenta ugljika od 0,37% za čelik 16Mo3 daje sigurnost u pogonu, dok vrijednost ekvivalenta ugljika od 0,56% za čelik 13CrMo4-5 dovodi materijal u područje opasnosti od pojave pukotina što zahtjeva odgovarajuću temperaturu predgrijavanja. Pravilnim odabirom temperature predgrijavanja sprječava se nastanak hladnih pukotina u zavarenom spoju. Zavisnost tvrdoće od ekvivalenta ugljika i debljine materijala za čelike 16Mo3 i 13CrMo4-5 dat je na slici 1 [2].



Slika 1. *Zavisnost tvrdoće od ekvivalenta ugljika i debljine materijala za čelike 16Mo3 i 13CrMo4-5*

3 EKSPERIMENTALNI DIO

Osnovni cilj ovog rada je istraživanje odnosa između parametara: jačine struje i napona kod TIG postupka zavarivanja sa dobivenim vrijednostima ispitivanja tvrdoće, mikrostrukture i veličine zrna u zoni pod uticajem toplote, kao i utvrđivanje korelacije između dobivenih fiziko-metalurških svojstava – tvrdoće i parametara zavarivanja za niskolegirane čelike 16Mo3 i 13CrMo4-5.

3.1 Parametri TIG postupka zavarivanja

Na ispitnim uzorcima, odnosno limovima debljine 10 mm izvršena je priprema V žlijeba. Zavarivanje je provedeno sa jednim korjenim i dva pokrovna prolaza, na svim uzorcima. Pregled primijenjenih postupaka, uređaja za zavarivanje, elektroda, pripreme međusloja, temperatura predgrijavanja i parametri zavarivanja dati su u tabeli 2 [3].

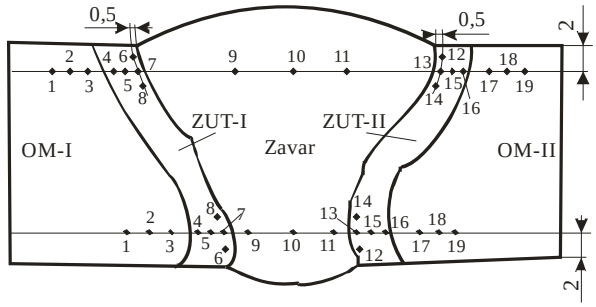
Tabela 2. *Parametri TIG postupka zavarivanja*

Materijal	Elektroda	Uređaj	Predg. °C	Priprema međusloja	Broj prolaza	Parametri zavarivanja	
						Napon (V)	Jačina struje (A)
16Mo3	TIG Mo	Fronius	130 do 150	Četkanje	I	19-20	160-180
					II	14-15,5	160-178
					III	17-20	195-200
13CrMo4-5	TG CrMo	Fronius	200 do 250	Četkanje	I	11,5-12	120-130
					II	12,5-13	135-140
					III	14-14,5	155-160

4 ISPITIVANJE I ANALIZA REZULTATA ISPITIVANJA

4.1 Ispitivanje i analiza rezultata ispitivanja tvrdoće

Ispitivanje tvrdoće zavarenih spojeva izvršeno je prema standardu BAS EN 9015-1:2012 [4], koji specificira ispitivanje tvrdoće na poprečnom presjeku elektrolučno zavarenog spoja metalnih materijala, po metodi Vickers u skladu sa standardom BAS EN ISO 6507-1 [5], opterećenja HV10. Ispitivanje tvrdoće izvodi se u ambijentalnim uslovima, temperatura 23±5°C. Ispitivanje je provedeno na uređaju za ispitivanje tvrdoće i mikrotvrdoće ZWICK. Primijenjena metoda mjerenja tvrdoće je identifikacija u nizu. Shematski prikaz sučeono zavarenog spoja i lokacija ispitivanja tvrdoće dat je na slici 2. Tvrdoća osnovnog materijala u slučaju čelika 16Mo3 je 160HV10, dok je vrijednost tvrdoće osnovmnog materijala čelika 13CrMo4-5 170HV10.
Dobiveni rezultati ispitivanja tvrdoće u ZUT-u kod čelika 16Mo3 i 13CrMo4-5 pokazuju da je tvrdoća u grubozrnatom dijelu ZUT-a veća od tvrdoće u sitnozrnatom i rekristaliziranom dijelu.



Slika 2. *Lokacije ispitivanja tvrdoće [3]*

Rezultati ispitivanja tvrdoće sučeono zavarenih spojeva dati su u tabeli 3.

Tabela 3. *Rezultati ispitivanja tvrdoće sučeono zavarenih spojeva čelika 16Mo3 i 13CrMo4-5*

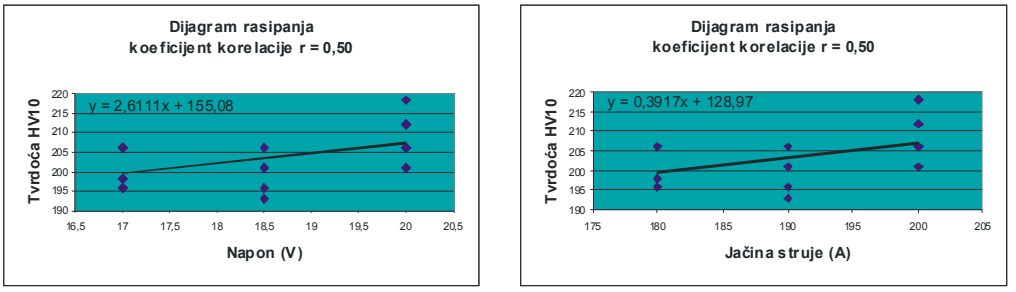
Postupak	*Lokacija*	*ZUT-I*				*ZUT-II*			
		Broj otiska	*GZ*	*SZ*	*R*	*Broj otiska*	*GZ*	*SZ*	*R*
16Mo3	*Lice*	*6*	*198*	*188*	*183*	*12*	*206*	*196*	*183*
		7	*196*			*13*	*196*		
		8	*206*			*14*	*206*		
	Korijen	*6*	*233*	*212*	*191*	*12*	*224*	*218*	*201*
		7	*230*			*13*	*236*		
		8	*236*			*14*	*227*		
13CrMo4-5	*Lice*	*6*	*306*	*266*	*191*	*12*	*297*	*292*	*287*
		7	*312*			*13*	*312*		
		8	*306*			*14*	*292*		
	Korijen	*6*	*297*	*292*	*287*	*12*	*351*	*327*	*297*
		7	*302*			*13*	*333*		
		8	*297*			*14*	*345*		

Prema literaturnim podacima maksimalno dozvoljena vrijednost prema standardu BAS EN 15614-1 [6] za čelike 16Mo3 i 13CrMo4-5 iznosi 320HV. Maksimalno dobivena vrijednost pri zavarivanju TIG postupkom za čelik16Mo3 iznosi 236HV10, dok je za čelik 13CrMo4-izmjerena vrijednost od 351HV10.

Dobivene vrijednosti tvrdoće u grubozrnatom dijelu ZUT-a, kod čelika 16Mo3 su manje od maksimalno dozvoljenih vrijednosti, dok kod čelika 13CrMo4-5 najveća izmjerena tvrdoća (351HV10) prelazi maksimalnu vrijednost po standardu od 320 HV.

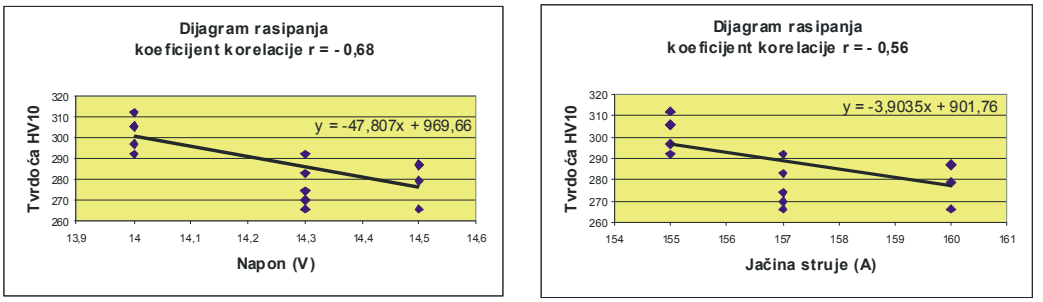
U regresionu analizu uključeni su rezultati ispitivanja tvrdoće u grubozrnatom dijelu ZUT-a, (broj otiska 6,7,8,12,13 i 14) . Dijagrami rasipanja, koeficijent korelacije i jednačine linearnog regresionog modela dati su na slici 3 za čelik 16Mo3 i slici 4 za čelik 13CrMo4-5.

Prema dijagramu rasipanja i koeficijentu korelacije uočava se direktna zavisnost, umjerena korelacija i bitna povezanost tvrdoće čelika 16Mo3 u grubozrnatom dijelu ZUT-a od napona i jačine struje kod zavarivanja TIG postupkom. Znači, ukoliko bi, u završnom prolazu, parametri zavarivanja napon i jačina struje kod TIG postupka bili veći od vrijednosti datih u tabeli 2. došlo bi do povećanja vrijednosti tvrdoće u grubozrnatom dijelu ZUT-a.



Slika 3. *Zavisnost tvrdoće u grubozrnatom dijelu ZUT-a čelika 16Mo3 od parametara napona i jačine struje kod TIG postupka*

Prema dijagramu rasipanja i koeficijentu korelacije uočava se inverzna zavisnost, umjerena korelacija i bitna povezanost tvrdoće čelika 13CrMo4-5 u grubozrnatom dijelu ZUT-a od napona i jačine struje kod zavarivanja TIG postupkom. Znači, ukoliko bi, u završnom prolazu, parametri zavarivanja napon i jačina struje kod TIG postupka bili manji od vrijednosti datih u tabeli 2. došlo bi do povećanja vrijednosti tvrdoće u grubozrnatom dijelu ZUT-a. Obzirom na vrijednost CE od 0,56% i debljinu lima 10 mm, ovako izabrani parametri zavarivanja dovode zavareni spoj u oblast povećane opasnosti od pojave pukotina.



Slika 4. *Zavisnost tvrdoće u grubozrnatom dijelu ZUT-a čelika 13CrMo4-5 od parametara napona i jačine struje kod TIG postupka*

4.2 Ispitivanje i analiza veličine zrna i mikrostrukture

Veličina zrna određena je metodom poređenja prema standardu ASTM E 112 i kod osnovnog materijala čelika 16Mo3 i 13CrMo4-5 je ocijenjena kao G=8,5, dok je veličina zrna u grubozrnatom dijelu ZUT-a kod sučeono zavarenih spojeva čelika 16Mo3 ocijenjena kao G= 6 i čelika 13CrMo4-5 kao G=5,5.
Uslijed termičkog ciklusa zavarivanja u ZUT uz liniju stapanja došlo je do ogrubljenja zrna u odnosu na veličinu zrna u osnovnom materijalu. Veće ogrubljenje zrna u ZUT-u otkriveno je kod čelika 13CrMo4-5 u odnosu na čelik 16Mo3.

Metalografska analiza sučeono zavarenih spojeva lima 10 mm provedena je na optičkom mikroskopu OLYMPUS PMG3. Uzorci za metalografsku analizu su pripremljeni u skladu sa standardom ASTM E 3. Nagrizanje ispitne površine provedeno je u NITAL-u (2%alkoholni rastvor HNO_3) prema standardu ASTM E 407.
Reprezentativni snimci mikrostruktura dati su u prilogu A .

Analiza mikrostruktute rađena je po zonama zavarenog spoja. Tabelarni pregled mikrostruktura osnovnog materijala, ZUT-a i metala zavara dat je u tabeli 4.

Tabela 4. *Pregled mikrostruktura osnovnog materijala, ZUT-a i metala zavara*

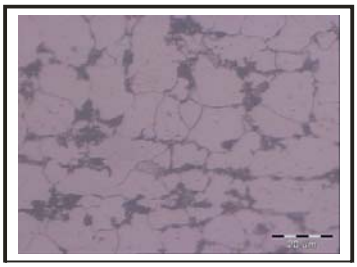
Lokacija			Materijal	
			16Mo3	13CrMo4-5
Osnovni materijal			trakasta, ferit i perlit,	trakasta, ferit i perlit,
ZUT	ZUT između A_{c1} i A_{c3}	R	rekristalizirana, ferit+perlit+bainit	rekristalizirana, ferit, bainit i perlit,
	ZUT iznad A_{c3}	SZ	normalizirana, ferit+bainit,	normalizirana, ferit i bainit,
	ZUT između A_{c3} i linije stapanja	GZ	Widmannstattenski ferit, bainit i martenzit,	bainit i martenzit,
Zavar			livena struktura, ferit i bainit	livena struktura, ferit i bainit

5. ZAKLJUČAK

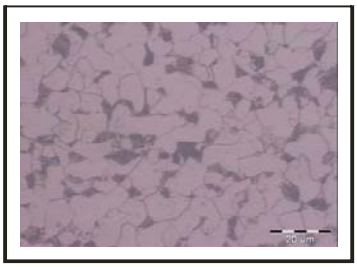
Dobivene vrijednosti tvrdoće u zoni pod uticajem toplote kod TIG postupka zavarivanja čelika *16Mo3* ne prelaze maksimalne vrijednosti tvrdoće prema literaturnim podacima. Analiza mikrostruktura po zonama sučeono zavarenog spoja je pokazala razliku u nastalim mikrokonstituentima u toku zavarivanja. Na osnovu rezultata regresione analize utvrđeno je da bi povećanje vrijednosti parametara zavarivanja napona i jačine struje u odnosu na vrijednosti date u tabeli 2. dovelo do povećanja tvrdoće u grubozrnatom dijelu ZUT-a kod TIG postupka zavarivanja.
Dobivene vrijednosti tvrdoće u zoni pod uticajem toplote kod TIG postupka zavarivanja čelika *13CrMo4-5* prelazi maksimalnu dozvoljenu vrijednost datu u standard. Vrijednost tvrdoće od 351HV10 je blizu vrijednosti maksimalno očekivane vrijednosti. Ovako visoka vrijednost tvrdoće i CE od 0,56% dovode ovaj zavareni spoj u zonu opasnosti od pojave pukotina što je u skladu sa slikom 1. Dobivene vrijednosti tvrdoće u skladu su sa otkrivenim mikrostrukturama. Na osnovu rezultata regresione analize utvrđena je korelacija promjene vrijednosti tvrdoće od parametara zavarivanja napona i jačine struje kod TIG postupka zavarivanja, gdje bi smanjenje napona i jačine struje u toku zavarivanja dovelo do povećanja tvrdoće.

LITERATURA

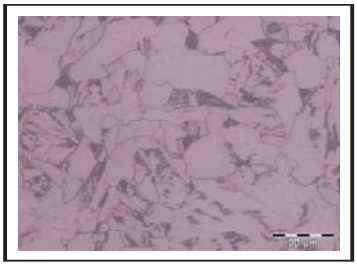
[1] Standard BAS EN 10028-2:2004 – Pljosnati čelični proizvodi za rad pod pritiskom – Dio 2:Nelegirani i niskolegirani čelici sa definisanim osobinama na povišenim temperaturama.
[2] Omer Pašić, (1998), Zavarivanje, IP Svjetlost d.d. Sarajevo.
[3] Belma Fakić (2010), Uticaj postupaka zavarivanja na fiziko-metalurške karakteristike čelika: S355J2G3, 16Mo3 i 13CrMo4-5 u zoni uticaja toplote, *magistarski rad*, UNZE, Zenica.
[4] Standard BAS EN ISO9015-1:2012 Ispitivanje sa razaranjem zavarenih spojeva metalnih materijala - Ispitivanje tvrdoće - Dio 1: Ispitivanje tvrdoće elektrolučno zavarenih spojeva
[5] Standard BAS EN ISO 6507-1: 2007 – Metalni materijali – Ispitivanje tvrdoće
[6] Standard BAS EN 15614-1:05 – Specifikacija i kvalifikacija postupaka zavarivanja metalnih materijala - Ispitivanje postupka zavarivanja- Dio 1: Elektrolučno i plinsko zavarivanje čelika i elektrolučno zavarivanje nikla i legura nikla



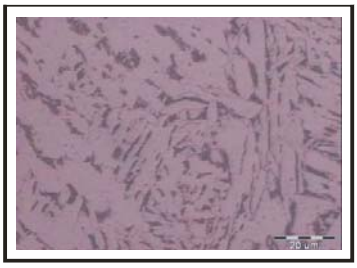
a) Osnovni materijal- OM II
Valjana, ferit+ perlit



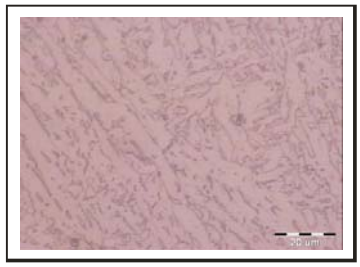
b) Rekristalizirani dio ZUT-I
Rekristalizirana, ferit + perlit+bainit



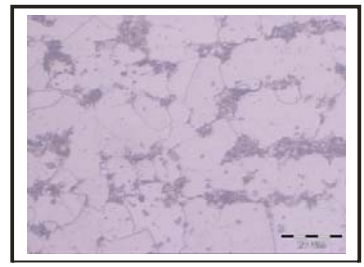
c) Sitnozrnati dio ZUT-I
Normalizovana, ferit + bainit



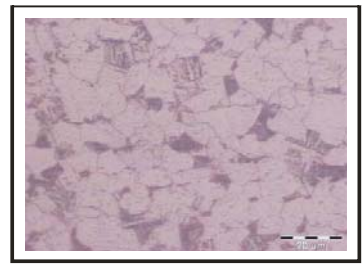
d) Grubozrnati dio ZUT-I
Widmannstatten ferit +
bainit + popuğteni martenzit



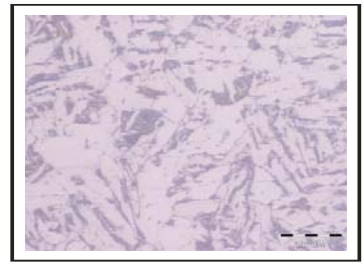
e) Metal zavara
Livena struktura,
ferit + bainit



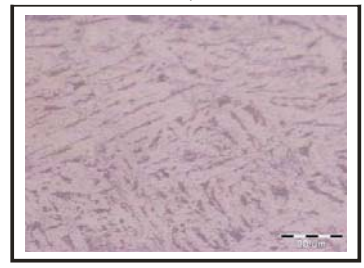
f) Osnovni materijal- OM II
Valjana, ferit+ perlit



g) Rekristalizirani dio ZUT-I
Rekristalizirana, ferit + perlit+bainit

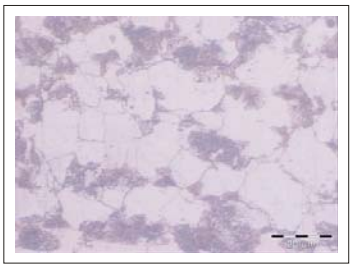


h) Sitnozrnati dio ZUT-II
Normalizovana, ferit +bainit

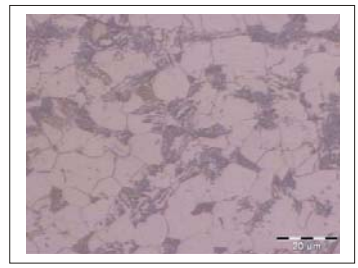


i) Grubozrnati dio ZUT-II
Widmannstatten ferit +
bainit + popuğteni martenzit

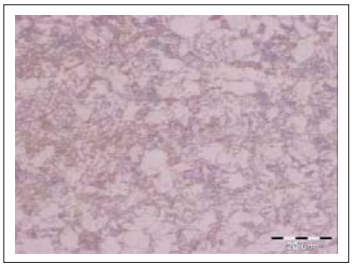
Prilog A- Mikrostrukture po zonama sučeono zavarenog spoja čelika 16Mo3 kod TIG postupka zavarivanja



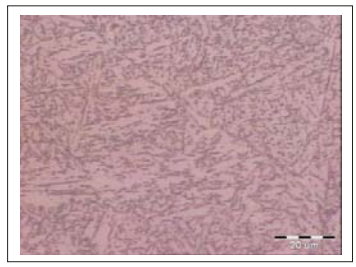
a) Osnovni materijal- OM I
Valjana, ferit+ perlit



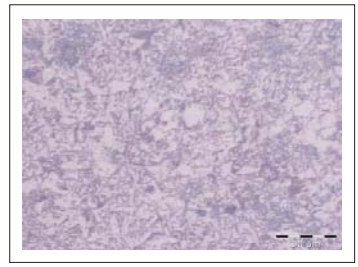
f) Osnovni materijal- OM II
Valjana, ferit+ perlit



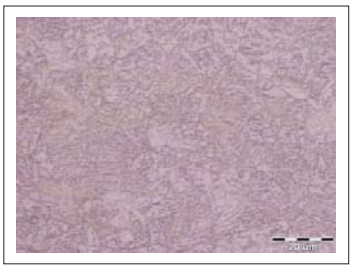
b) Rekristalizirani dio ZUT-I
Rekristalizirana, ferit +bainit+perlt



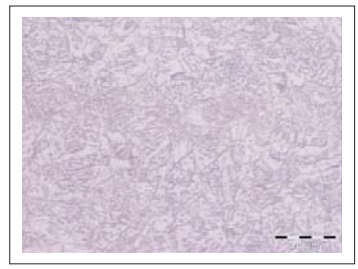
e) Metal zavara
Livena struktura,
ferit po granicama primarnih
austenitnih zrna+ bainit



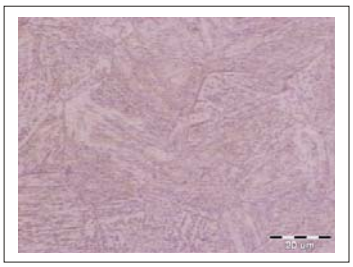
g) Rekristalizirani dio ZUT-I
Rekristalizirana, ferit + bainit+perlit



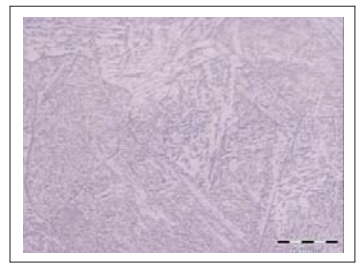
c) Sitnozrnati dio ZUT-I
Normalizovana, ferit +bainit



h) Sitnozrnati dio ZUT-II
Normalizovana, ferit+bainit



d) Grubozrnati dio ZUT-I
Bainit+popušteni martenzit



i) Grubozrnati dio ZUT-II
Bainit+popušteni martenzit

Prilog A - *Mikrostrukture po zonama sučeono zavarenog spoja čelika 13CrMo4-5 kod TIG postupka zavarivanja*

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STUDY OF THE INFLUENCE OF CYCLE FACTORS ON THE THERMAL FATIGUE BEHAVIOR OF ALUMINUM ALLOY 2017A

Lamine Rebhi[1], Branimir Krstic[2], Boudiaf Achraf[3], Aderraouf Zemmoura[4], Dragan Trifkovic[5]

Abstract: The severe operating conditions under cyclic variation in temperature and constraints have exposed many industrial components to the phenomenon of thermal fatigue. In order to study the behavior of the aluminum alloy 2017A in thermal fatigue, the alloy is submitted to a cyclic thermal load. The effect of cycling in temperature on the macroscopic behavior were observed through the changes of the microstructure. Two important parameters of thermal cycles were taken into account; the first is the maximum temperature T_{max} reached in a cycle. The second factor considered is the number of cycles applied. The results show a softening when the number of cycle increases. This evolution is accentuated when T_{max} is high. This fall of hardness is due to the decomposition of the precipitates, which is responsible of the hardening of material.

Key words: 2017A Aluminum alloy, Thermal fatigue, Microstructure, softening

1 INTRODUCTION

Thermal fatigue is an almost ubiquitous phenomenon in our environment both in everyday life and in the industrial field. In fact, fluctuations in temperature, whether seasonal, weekly, daily, or more frequent, have a damaging character because these fluctuations are repeated over time. Let's briefly mention some examples: the peeling of the paint due to coupled effects of variation of humidity and temperature, the cracks that form at the bottom of a coffee cup due to the many fillings of hot liquid in a cup whose walls are significantly colder.

In most cases, the mechanical parts are designed to withstand static mechanical loadings or, at best, mechanical fatigue. It is sometimes found that these parts are

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subject to significant temperature variations that can cause the material to break down by cracking and prematurely ruin these parts. The phenomenon is commonly called thermal fatigue.

An example illustrating the effects of thermal fatigue is given below in the nuclear field, which represents a significant part of the electricity production. However, its exploitation presents a lot of risks, in particular the problem of radioactive fluid leaks. In 1998, on the site of the Civaux nuclear power plant located in the department of Vienne, a leak was observed on the weld seam of the mixing tee of the hot and cold fluids of the secondary cooling circuit. After expertise, a crack opening 180 mm long on the outer skin of the elbow was detected. In addition, cracking networks with cracks limited to 2-3mm in depth were observed. The appearance of the networks of cracking made it possible to conclude that this leak had for origin, the thermal fatigue [1].

In order to enhance understanding of thermal fatigue phenomenon, many studies were conducted. A comparative study on the change of microstructure under thermal loading of two aluminum alloys was presented in details in [2]. The conducted study consists in applying a cyclic thermal loading on the two aluminum alloys 2017A and 4047. A change in the mechanical properties reflected by a drop in hardness as a function of the number of cycles was observed in both alloys due to microstructural changes.

Sasaki in reference [3] reproduced in his thermal fatigue tests on the aluminum alloy 319(according to ASTM designation system), work-conditions under which cylinder head of a diesel motor are subjected. After the thermal fatigue tests, two types of precipitates were observed and categorized into needle-like and ellipsoidal-like. This study led to the conclusion that thermal fatigue life is influenced by temperature range, cycle period, strain range, and mean strain.

The purpose of this work is to give a contribution by an experimental study of the thermal fatigue behavior of the 2017A aluminum alloy. Our main objective is to study the effect of heating and cooling cycles on the microstructure of the chosen alloy. A thermal fatigue device designed at the Laboratory Materials Engineering ensures the temperature cycling. Two parameters are considered, namely: cycle number and maximum heating temperature.

2 PRESENTATION OF THE STUDY MATERIAL

2.1 Chemical composition and mechanical properties

The material used in the study is the aluminum alloy 2017A. The analysis of the chemical composition of the alloy was carried out by means of SPECROLAB spectrometer. The analysis revealed the chemical composition presented in Table 1. which is equivalent to the standard specification for A2017 aluminum alloy taken from [4].

Table 1. Chemical analysis results (wt%)

Element	*Result*
Copper (Cu)	4.339
Manganese (Mn)	0.586
Iron (Fe)	0.700
Silicon (Si)	0.990
Zinc (Zn)	0.211
Magnesium (Mg)	0.931
Aluminum (Al)	*Bal.*

The mechanical properties of the study material are shown in Table 2.

Table 2. *Mechanical properties of the 2017A aluminum alloy [4]*

Mechanical properties	*Result*
Yield strength Re [MPa]	4.339
Tensile strength Rm [MPa]	0.586
Elongation A (%)	0.700
Hardness (HV)	0.990

2.2 Metallographic observation of the study material in the as-received condition

The preparation of a sample of the material for microscopic examination consists of sampling, coating, polishing and finally, chemical etching by the Keller reagent. As the material is delivered in the form of extruded bars, Metallographic preparation of longitudinal and transverse sections to the rolling direction were performed. Figure 1. shows the results of the optical micrographic observation.

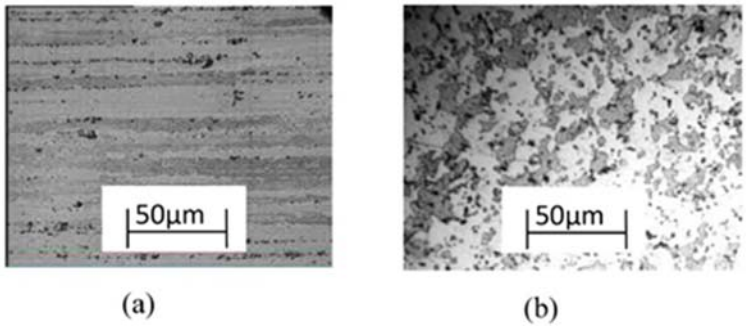


Figure 1. *Micrograph of the alloy 2017A: (a) longitudinal section and (b) transversal section*

3 THERMAL FATIGUE TESTS

3.1 Specimen geometry

The thermal fatigue tests were carried out on tubular cylindrical specimens with a thickness of 2 mm (in the useful zone). The specimens were taken and machined from cylindrical bars of dimensions *Φ*30×130mm. Figure 2. shows the geometry and the dimensions of the test specimen.

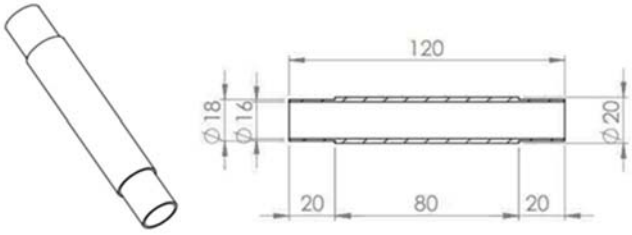


Figure 2. *Geometry and dimensions of the thermal fatigue test specimen*

3.2 Experimental procedure

The thermal fatigue device used exploits the principle of joule heating. An electric furnace with a nominal power of 1000W allowing to reach the temperatures of the order of 500 ° C on the outer surface of the specimen. Cooling is achieved by circulating water inside the specimen (tube) with a constant flow rate of 7.5 l / min, and the face is exposed to the open air and cooling is obtained therefore, by Natural convection. A schematic representation of the device is shown in Figure 3.

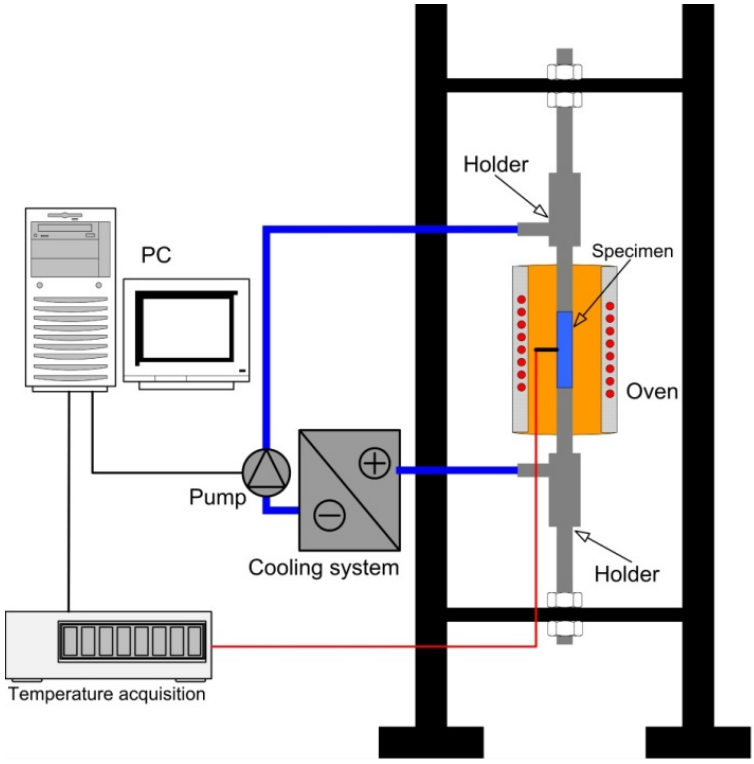


Figure 3. *Schema of the thermal fatigue test device*

Given the time of a cycle; relatively high (more than three minutes), a moderately fast data acquisition system with microcomputer data storage was developed. This microcomputer is linked to a SCXI-1000 signal conditioner that amplifies weak signals, isolates them and filters them to obtain more precise measurements.

An interface for data acquisition was developed with LabView software. It ensures the acquisition and continuous recording, over several channels, the temperature as a function of time. The thermocouple used is of type K, of diameter 0.1 mm, glued on the external surface of the specimen in the middle of the useful part.

In order to follow the evolution of the temperature over time, we glued a thermocouple of type k of diameter 0.1mm on the external surface of the specimen in the middle of the useful part. The thermal cycles obtained on the outer surface of the test piece are shown in Figure 4. The control of the temperature of the furnace is done by another thermocouple.

The cycling in temperature is done without the intervention of the operator.

Simply specify the setpoint values (T_{max} and T_{min}) on the control interface and start the test. As soon as the temperature of the specimen reaches the value T_{max}, the water pump starts automatically to ensure the cooling of the specimen to the temperature T_{min}.

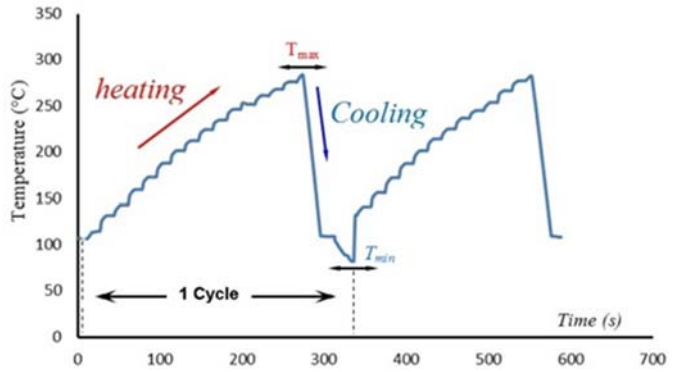


Figure 4. *Thermal cycles applied to the thermal fatigue specimen*

During cooling, the oven remains energized in order to minimize heating time during the next cycle.

Table 3. presents all the thermal cycles adopted in this study. The minimum temperature of the thermal cycle (T_{min}) was kept constant at 80 ° C for all tests, while the maximum temperature (T_{max}) was varied between 200°C and 280°C.

Table 3. *Adopted thermal cycles*

Oven power [W]	*1000*
T_{min} [°C]	80
T_{max} [°C]	200-280
Heating time [s]	210-300
Cooling time [s]	35-45

There are two types of tests, commonly called "interrupted" and "continuous" tests. The interrupted tests are used to follow the evolution of mechanical properties in the surface of the specimens during cycling (oxide layer, hardness, etc.). Continuous tests are destructive and allow the termination of softening and changes in microstructures. In our case, continuous type tests are performed. Table 4. shows the number of cycles at a standstill for the continuous tests considered in this study.

Table 4. *Number of cycles at the end of thermal fatigue tests*

T_{max} [°C]	*Duration of thermal cycle* [s]	*Number of cycles*		
200	210	1000		5000
280	300	10	1000	3000

4 RESULTS AND INTERPRETATIONS

4.1 Influence of thermal cycling factors on hardness

In order to study the influence of thermal fatigue on the mechanical properties of aluminum alloy 2017A, hardness tests on different specimen having undergone different cycling are carried out, in other words, different number of cycles at different maximum temperatures T_{max}. Hardness tests are realised by indentation of a Vickers indenter with a load of 30 kg. The results obtained are shown in Figure 5.

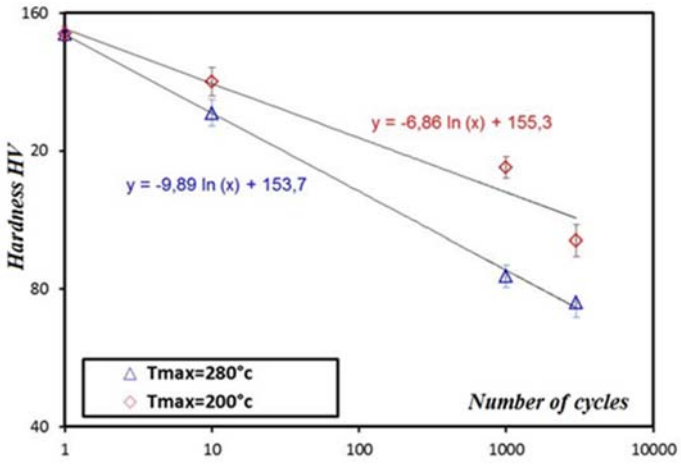


Figure 5. *Evolution of hardness as a function of cycle number and T_{max}*

It can be observed from the results, that the hardness decreases linearly with ln (N), and this evolution is more pronounced for the tests at T_{max} = 280 ° C, the trend curve passes virtually by all points.

It should be noted that the hardness difference between the tests at 200°C and 280°C becomes larger when ln (N) increases. This difference can be seen after 10 cycles only, the hardness goes from 154(HV) in the initial state up to 140(HV) at T_{max} = 200°C, and it reaches 131 (HV) at T_{max} = 280°C

To be able to interpret the results obtained, it is preferable to have a prior idea of probable events.

The hardness drop is probably due to the following:

- Migration of the precipitates towards the core of the part in this case Al_2Cu precipitates which are harder than pure aluminum (α phase),
- Migration of precipitates to grain boundaries,
- Reduction in the total area of the grain boundaries,
- Movement of dislocations,
- Increase in the number of gaps.

The third hypothesis is ignored since the chemical etching done has not allowed us to see grain boundaries for samples with a high number of cycles. As the means of characterization put at our disposal do not allow us to verify hypotheses four and five, the only possibilities that remain are the first and the second.

To identify the exact cause that led to the hardness decrease, an analysis of the microstructure at different stages of thermal fatigue must be performed, which allows a correlation between the micro and macroscopic properties of our alloy.

4.2 Influence of thermal cycling factors on precipitation rate

Samples taken from several specimens in various directions and at different numbers of cycles and different temperatures (T_{max}), are visualized by high- performance scanning electron microscope (SEM), the images obtained are set out below.

The 2017A alloy at the initial state: The SEM micrpgraph of the alloy 2017A Figure 6. indicates that the alloy structure is formed of aluminum crystals in solid solution (white) with Al_2Cu (θ) insertion (light gray) and other types of precipitates in segregations.

The 2017A alloy after 10 cycles at T_{max} = 280°C: As seen previously, the hardness decreased after only 10 cycles. By comparing the cross-sectional and longitudinal section of the sample taken Figure 7.(a) and Figure 7.(b), it is noted that the distribution of the precipitates is the same in both directions, which makes it possible to eliminate the hypothesis of the depletion of the Al_2Cu surface.

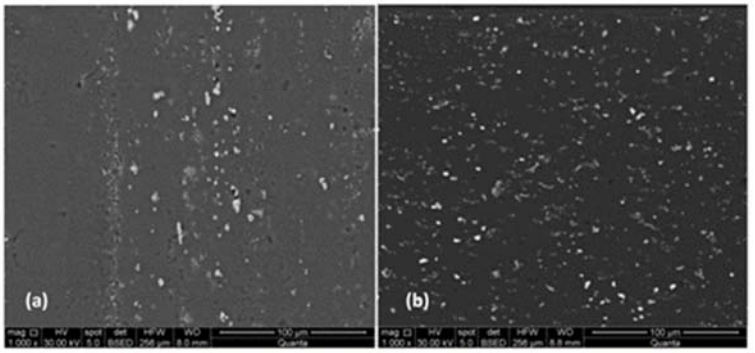


Figure 6. *SEM micrograph indicating the constituent particles of the 2017A alloy at the initial state: (a)longitudinal section and (b) transversal section*

By comparing the microstructure of the alloy at initial state and after 10 cycles, it can be noted that there is no change in the microstructure or in the size of the precipitates; therefore the decrease in the hardness is mainly due to the increase of the number of pores [5]. The increase of the number of pores results from the rise in temperature during the heating phase [6].

The increase in the number of pores as a function of temperature is governed by the following equation:

$$n_L = Ne^{-\frac{E}{KT}}$$

where
n_L- pore concentration per unit volume,
N - number of atoms per unit volume,
E - energy of formation of pores,
K - Boltzmann constant,
T – absolute temperature [K].

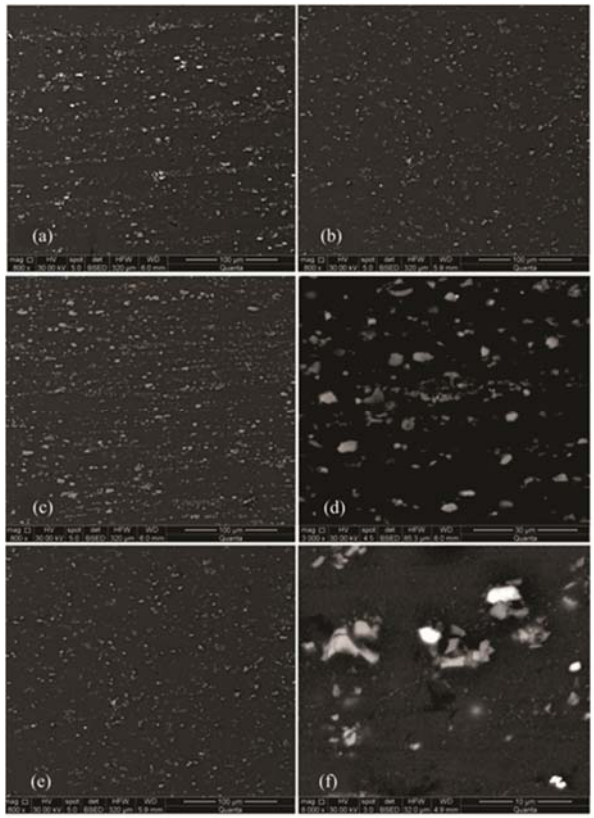


Figure 7. *SEM images of the 2017A alloy after thermal fatigue tests with T_{max}=280°C: (a) longitudinal section after 10 cycles; (b) transversal section after 10 cycles; (c) and (d) after 1000 cycles; (e) and (f) after 3000 cycles*

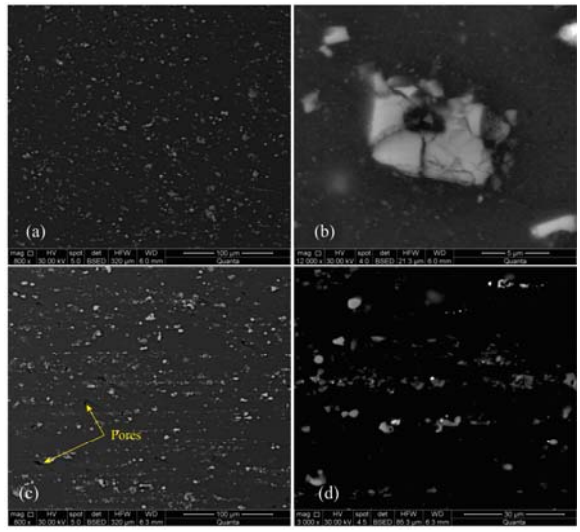


Figure 8. *SEM images of the 2017A alloy after thermal fatigue tests with T_{max}=200°C: (a) and (b) after 1000 cycles; (c) and (d)after 5000 cycles*

The 2017A alloy after 1000 cycles at T_{max} = 280°C: By comparing the alloy after 1000 cycles with the initial state, it can be observed a change in size and in the distribution of precipitates. By carrying out a larger magnification, it is noted that there is a decomposition of the precipitates Al_2Cu (θ). Referring to the Al-Cu binary equilibrium diagram in Figure 9. each time the material is brought to a temperature of 280°C the portion (A) which is shown in Figure 9. dissolves and the percentage of the dissolve portion can be determine by the rule of the inverse segments.

The 2017A alloy after 3000 cycles at T_{max} = 280°C: The findings that can be drawn from Figure 7.(f) is that the decomposition of precipitates Al_2Cu (θ) continues; therefore, their sizes are much finer.

The alloy 2017A after 1000 cycles at T_{max} = 200°C: The decomposition of the precipitates Al2Cu is always noted Figure 8.(a) and Figure 8.(b) , nevertheless As this time the heating temperature is lower than the first, the fraction dissolved at each cycle is less important.

The 2017A alloy after 5000 cycles and T_{max} = 200°C: After 5000 cycles, the appearance of pores, which are the preferred sites for the formation of microcracks Figure8.(c).

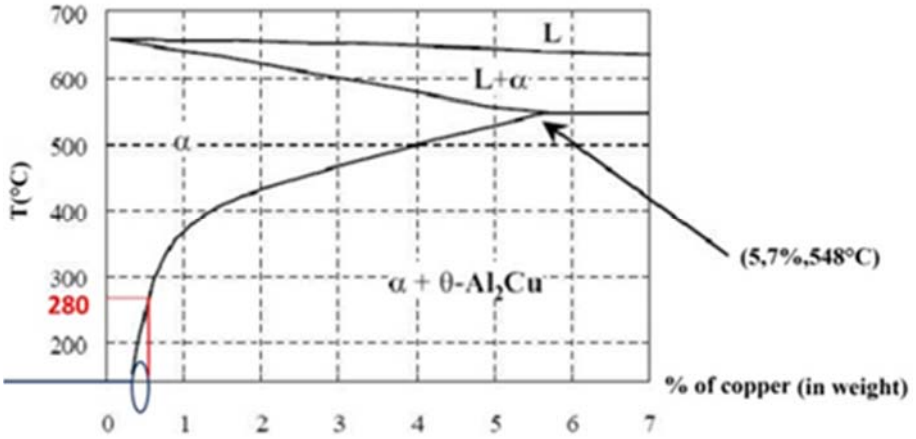


Figure 9. *Aluminum-rich part of the Al-Cu equilibrium diagram [7].*

The micrographs of the samples taken were obtained in (BSE) which means in backscattered electrons, these images in contrast 'Z' make it possible to give a relief in phase contrast, the phases which consist mainly of heavy elements appear in contrast white while the phases formed of light elements appear in dark contrast. This phase contrast allowed us to distinguish four phases in all, a matrix in dark gray as well as three types of precipitates under different color contrast Figure 10. Thanks to these images obtained it was possible to carry out a chemical composition analysis with the help of the EDS analyzer, of the four phases present Figure 11.

In order to determine the nature of the precipitates (1), (2) and (3), a XRD analysis was performed on the different samples Figure 12. We were able to confirm the presence of two precipitates, the precipitate 2 as AlCuMg and the precipitate 3 as Al2Cu. The first precipitate does not appear on the diffractograms, this is probably due to: the coarse scan step, the resemblance of the mesh parameters between the different precipitates and the matrix.

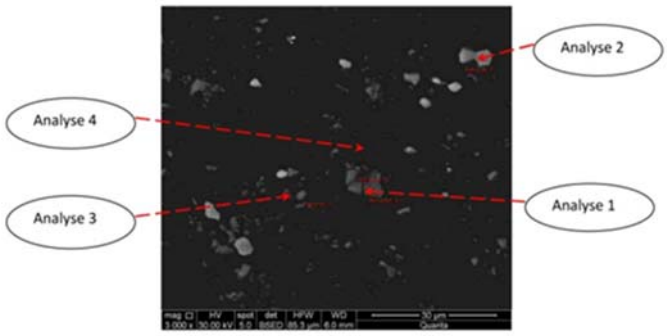
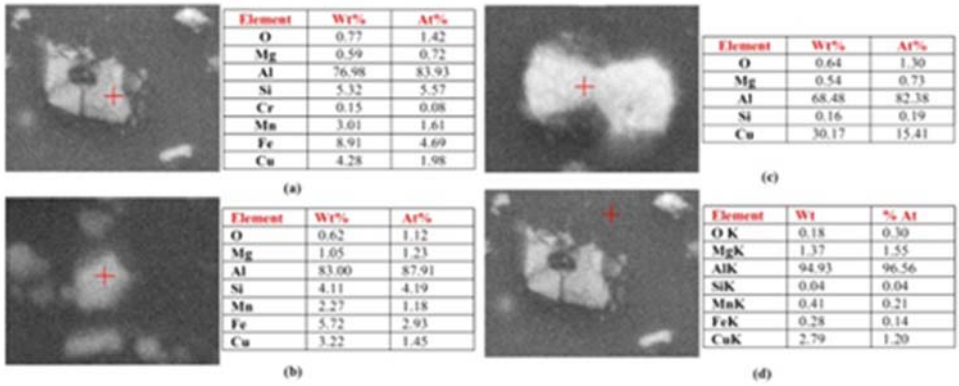


Figure 10. *Phases present in the alloy 2017A*



(a)

Element	Wt%	At%
O	0.77	1.42
Mg	0.59	0.72
Al	76.98	83.93
Si	5.32	5.57
Cr	0.15	0.08
Mn	3.01	1.61
Fe	8.91	4.69
Cu	4.28	1.98

(c)

Element	Wt%	At%
O	0.64	1.30
Mg	0.54	0.73
Al	68.48	82.38
Si	0.16	0.19
Cu	30.17	15.41

(b)

Element	Wt%	At%
O	0.62	1.12
Mg	1.05	1.23
Al	83.00	87.91
Si	4.11	4.19
Mn	2.27	1.18
Fe	5.72	2.93
Cu	3.22	1.45

(d)

Element	Wt	% At
O K	0.18	0.30
MgK	1.37	1.55
AlK	94.93	96.56
SiK	0.04	0.04
MnK	0.41	0.21
FeK	0.28	0.14
CuK	2.79	1.20

Figure 11. *Different phases in the 2017A alloy with EDS microanalysis: (a) Precipitated1. (b) Precipitated2. (c)Precipitated3. (d) Matrix*

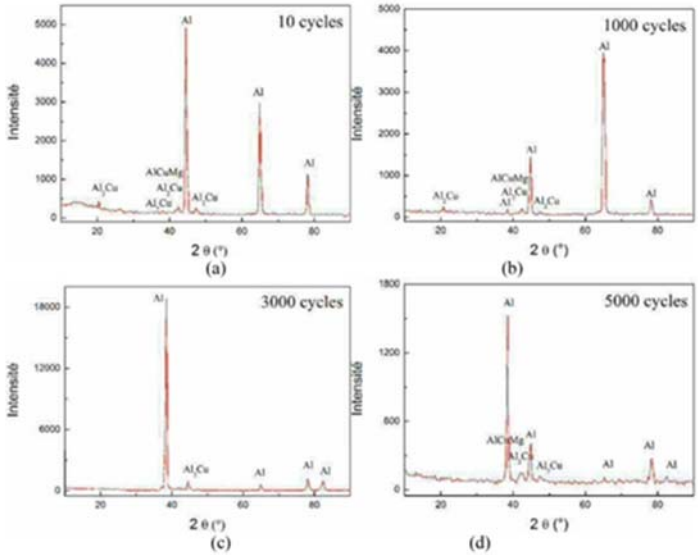


Figure 12. *XRD spectra of the samples taken from the test specimens tested in fatigue thermal*

5 CONCLUSION

The objective of this work is to observe the effects of temperature cycling on the macroscopic behavior through changes in the microstructure. Two important parameters of thermal cycles were taken into consideration; the first is the maximum temperature reached in one cycle. The second factor considered is the number of cycles applied.

For this purpose, thermal fatigue tests on 2017A aluminum alloy specimens were carried out. The results of these tests showed:

- A softening as the number of cycles increases. That evolution is more pronounced when T_{max} is higher,
- Supported by XRD analysis and SEM micrograph, we were able to determine that this drop in hardness is due to the decomposition of precipitates, responsible for hardening of the material, present in the matrix. This decomposition of the precipitates will increase the resistance to fatigue.

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DETERMINATION OF TENSILE STRAIN-HARDENING EXPONENT AND STRENGTH COEFFICIENT FOR HIGH STRENGTH STEEL AT ELEVATED TEMPERATURE

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Abstract: The purpose of this paper is to determine tensile strain-hardening exponent and strength coefficient of the STRENX 700 steel utilizes stress-strain data obtained in a uniaxial tension test at elevated temperature. Tensile data were obtained in continuous and rate-controlled manner via displacement control. Ramberg-Osgood relationship was used to describe the uniaxial tension behaviour of the STRENX 700 steel. The tensile strain-hardening exponent and strength coefficient at elevated temperature are determined from an empirical representation over the relation between the true-stress versus true-strain.

Key words: Tensile properties, elevated temperature, high strength steel, strength hardening coeficient, strength hardening exponent

1 INTRODUCTION

Today steels represent the most used group of mechanical materials. Steels are used in various branches of industry for constructing bridges, buildings, ships, cars, rail vehicles, railways. The development of steel has created an opportunity for manufacturers to produce a wide range of steels with different characteristics to suit the intended use, by combining the small percentage quantity of carbon with other alloying elements. During certain technological processes of production of parts and exploitation in extreme conditions like high temperatures, knowing the behavior of the material and its mechanical characteristics in these conditions is necessary. For ductile materials, reduction in strength and additional increases ductility are coming with increasing temperature. This behavior of the materials is the result of the influence of the temperature on its deformation. In order to determine the characteristics of the material

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in this case, it is necessary to perform material testing at elevated temperature.

It is well known that both the strain-hardening exponent and the strength coefficient are basic mechanical behaviour performance parameters of metallic materials. When the tensile properties of metallic materials are being evaluated, these two parameters must be known. There are many methods for determination strength coefficient and strain-hardening exponent. Theoretical calculation of the strain-hardening exponent and the strength coefficient of metallic materials were presented in [1]. Many authors investigated strain-hardening exponent with some new methods where the tests were performed experimentally and the results were compared with those obtained by the conventional method [2]. Values of strength coefficient and strain-hardening exponent for some engineering alloys at room temperature are given in [3].

This paper presents determination of tensile strain-hardening exponent and strength coefficient of the STRENX 700 steel at elavated temperature utilizes stress-strain data obtained in a uniaxial tension test according to ISO 6892-2 [4], ASTM E21-17 [5].

2 TESTING AT ELEVATED TEMPERATURE

The uniaxial tension test is the most common method for determining the mechanical properties of materials, such as strength, ductility, toughness, elastic modulus, stress-strain behaviour and strain hardening capability. Uniaxial tension stress-strain properties are usually reported in handbooks and are used in many specifications. Stress-strain behaviour is obtained from uniaxial tension test where specimen with circular or rectangular cross section with the uniform gage length is subjected to increasing tensile force until it fractures.

Property of material that the increase of plastic deformation leads to an increase of yield strength is called work hardening. Knowledge of these property is very important to describe the behaviour of metals in the region of plasticity. In the plastic region, a commonly used relation to define the relation between stress and strain is given by equation:

$$\sigma = K(\varepsilon_p)^n, \tag{1}$$

where K is strength coefficient and n strain hardening coefficient.

According to equation (1) and relation that the total strain equals the sum of the elastic and plastic strain and in the region of elasticity Hooke's law is valid, equation for total strain can be derived. Equation (2) represents analytical true stress – true strain relationship, often referred to as the “Ramberg-Osgood relationship” [3], [7], [8], [9].

$$\varepsilon = \frac{\sigma}{E} + \left(\frac{\sigma}{K}\right)^{\frac{1}{n}}, \tag{2}$$

The tests at elevated temperature consist in assessing the behavior and determining the mechanical properties of the material under load. Three basic test methods are distinguished [6]:

- Short-term heating (tensile testing, compressing, bending, impact strength, etc.),
- Long-term heating (creeping, relaxation, etc.),
- Short-term and long-term heating after long-term heating at elevated temperatures.

Tensile testing at elevated temperatures over 35 °C is carried out in accordance with a procedure that basically coincides with the test procedure standard for tensile at room temperature. The methodology for testing of metallic materials at elevated temperatures is defined by the standards ISO 6892-2 [4], ASTM E21-17 [5] and ASTM E646-00 [10].

3 EXPERIMENTAL PROCEDURE OF TENSILE TESTING AT ELEVATED TEMPERATURES

Uniaxial tension at elevated temperature was carried out at the Center for Engineering Software and Dynamic Testing at the Faculty of Engineering Sciences, University of Kragujevac, according to standards ISO 6892-2 [4], ASTM E21-17 [5] and ASTM E646-00 [10]. The testing program includes the testing of mechanical characteristics at five temperatures from 100 °C to 500 °C, including room temperature.

Experimental determination of tensile strain-hardening exponent and strength coefficient of the STRENX 700 steel at room temperature, was done on SHIMADZU Servopulser EV101K3-070-0A (Figure 1.). The shape and dimensions one of tested specimens are shown on Figure 2., in accordance with mentioned standards.

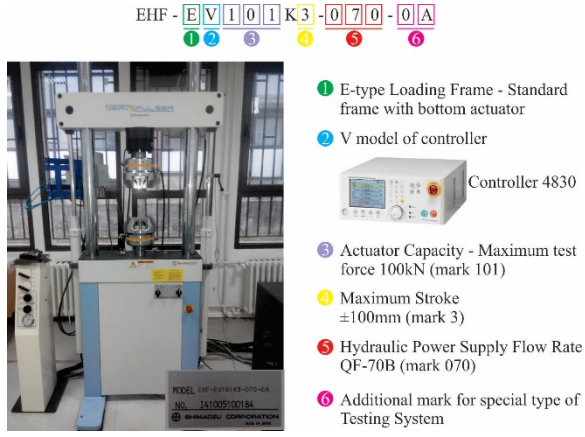


Figure 1. *SHIMADZU Srevopulser EHF-EV101K3-070-0A*

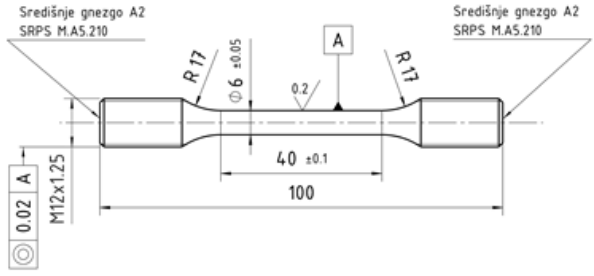


Figure 2. *Specimen for determining Tensile Strain-Hardening Exponent and Strength Coefficient at Elevated Temperature*

For the purpose of measurement of elongation, on gage length (*25 mm*) at high temperature, extensometer EPSILON 3548-025M-050-ST (Figure 3) was used which

was installed in the furnace in a horizontal position. The selected strain rate is $5\ 10^{-4}\ s^{-1}$, which corresponds to the velocity of the cross head of *0.02 mm/s*.

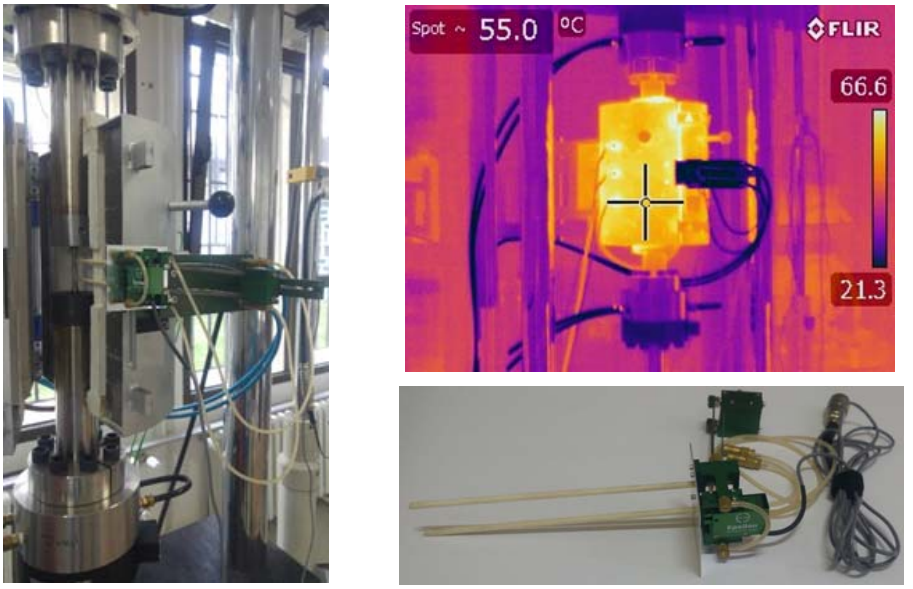


Figure 3. *Extensometer EPSILON 3548-025M-050-ST*

Load-engineering strain diagram, with data-pairs, for determination of tensile strain-hardening exponent and strength coefficient, according to ASTM E646-00 [10] is shown in Figure 4.

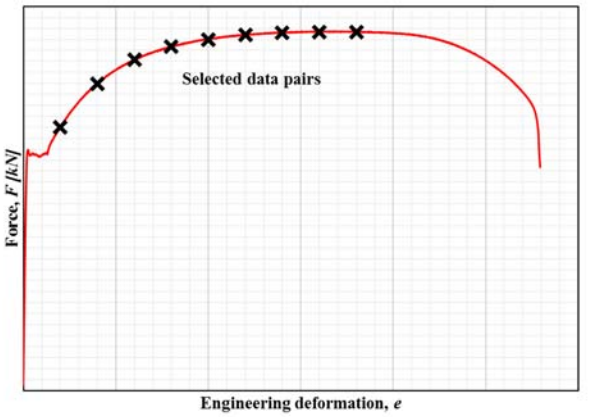


Figure 4. *Load-engineering strain diagram with data-pairs*

All other parameters necessary for the further determination of tensile strain-hardening exponent and strength coefficient could be obtained based on the values of force and elongation. For determination of tensile strain-hardening exponent *n* and strength coefficient *K* it necessary logarithmic form of the equation (1). Logarithmic form of the power curve representation of the true-stress versus true-strain curve within region

of plasticity is given by:

$$\log\sigma = \log K + n\log\varepsilon\,, \tag{3}$$

According to selected data-pairs and calculated logarithm values of true-stress *(logσ)* and true strain *(logε)*, tensile strain-hardening exponent *n and* and strength coefficient *K* can be determined via linear regression analysis in accordance with procedure shown in [10].

4 RESULTS AND DISCUSSION

Specimens after testing and coresponding stress-strain curves from uniaxial tension tests of STRENX 700 steel at room and elevated temperature are shown in Figure 5.

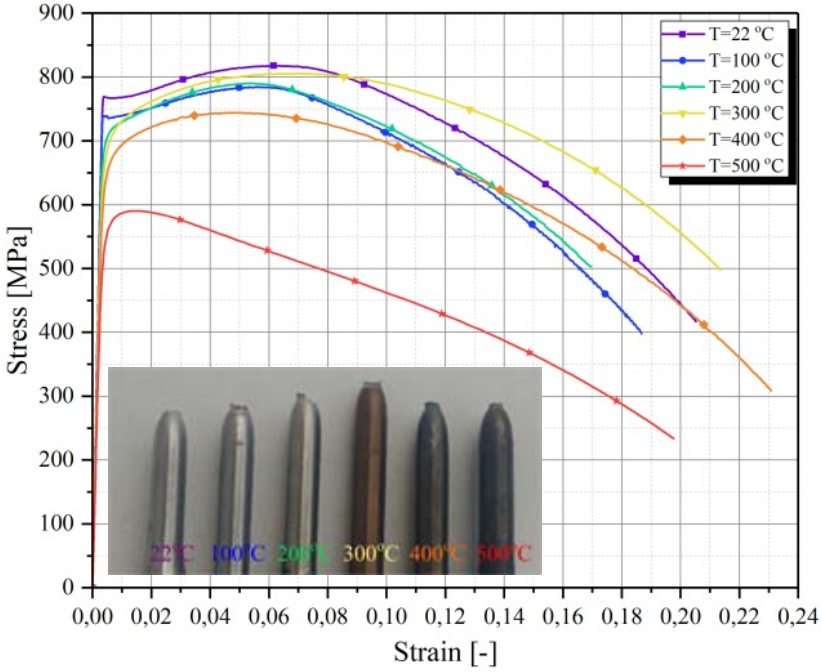


Figure 5. *Specimens after testing and comparative overview of stress-strain curves from uniaxial tension tests of STRENX 700 steel*

It is concluded that at temperatures exceeding *400 °C* there is a sudden drop in the strength of materials for tested specimens. Also, it is noticeable that at temperatures of *200 °C* and *300 °C* the values of the stress are greater than the value corresponding to the room temperature. The temperature range in which this phenomenon occurs is known as the *blue brittle* region.

According to previously derived equations, experimentally obtained results of tests at five temperatures from 100 °C to 500 °C, including room temperature and via linear regression analysis tensile strain-hardening exponent and strength coefficient were determined and shown in Table 1

Table 1. *Experimental determined hardening parameters for STREN X700*

T [°C]	*n*	*K [MPa]*
22	*0.05094*	*992.67*
100	*0.04616*	*936.61*
200	*0.05600*	*975.84*
300	*0.06277*	*1015.74*
400	*0.05008*	*908.64*
500	*0.01893*	*652.04*

5 CONCLUSION

This paper has presented the determination an experimental determination tensile strain-hardening exponent and strength coefficient of the high strength steel STRENX 700 at elevated temperatures exhibiting a continuous stress-strain curve in the plastic region. The stress-strain data was obtained in a uniaxial tension test. The displacement was applied in a continuous and rate-controlled manner while the normal tensile load and strain are monitored. Based on obtained data and test results, true-stress and true-strain were calculated. According to ASTM E646-00 and calculated logarithm values of true-stress and true strain, via linear regression analysis, tensile strain-hardening exponent and strength coefficient were determined for various levels of temperature. Obtained results show changing of material properties (strength and elongation) of the high strength steel STRENX 700 at temperature higher than *400 °C*.

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PERSPEKTIVA UPOTREBE VISOKOPEĆNE TROSKE KAO ZAMJENA PRIRODNIM MINERALNIM AGREGATIMA U TEHNOLOGIJI PROIZVODNJI KAMENE VUNE

Aida Imamović[1], Marina Jovanović[2], Mustafa Hadžalić[3], Mirsada Oruč[4]

Rezime: Među neizbježnim nusproizvodima metalurške industrije, posebno značajno mjesto zauzimaju troske iz proizvodnje gvožđa i čelika. Troska danas nije samo nusproizvod koji nastaje prilikom proizvodnje nego izuzetno vrijedan resurs i dragocjen građevinski agregat koji nalazi sve širu primjenu. Hemijski sastav visokopećne troske je sličan sastavu prirodnih mineralnih stijena te se prepoznaje kao potencijalna sirovina u proizvodnji kamene vune, a kao zamjena prirodnim mineralnim agregatima. U građevinarstvu kamena vuna ima široku primjenu i koristiti za toplotnu, protivpožarnu i zvučnu izolaciju.U ovom radu su predstavljene perspektive u upotrebi visokopećne troske iz zeničke željezare, kao osnovne sirovinske komponente, koja se uz modifikaciju sirovinske mješavine sa prirodnim mineralnim agregatima koji su na raspolaganju u bližem okruženju grada Zenice može koristiti u tehnologiji proizvodnje kamene vune, koja se inače ne proizvodi u BiH.

Ključne riječi: Kamena vuna, Proizvodne tehnologije, Visokopećna troska

THE PERSPECTIVES OF THE USE OF BLASTFURNACE SLAG AS THE REPLACEMENT OF THE NATURAL MINERAL AGREGATES IN TECHNOLOGY OF PRODUCING THE STONE WOOL

Abstract: Among the inevitable by-products of the metallurgical industry, special importance is given to waste from iron and steel production. The slag today are not only the by products that arise in production but rather of a valuable resource and a precious construction aggregate that is widely used. The chemical composition of blast furnace slag is similar to the composition of natural mineral rocks and is recognized as

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a potential raw material in stone wool production and as a substitute for natural mineral aggregates. In the construction of stone wool is widely used and used for thermal, anti-sound and sound insulation.This paper presents the prospects for the use of blast furnace slag from Zenica Iron and steel work as a basic raw material component, which can be used with the modification of a raw mix with natural mineral aggregates available in the immediate vicinity of the city of Zenica in the technology of stone wool production, which is otherwise not products in BiH.

Key words: Production technology, Blast furnace slag,Stone wool

1. UVOD

Zbog sve većih količina proizvodnog otpada koji nastaje u različitim industrijskim procesima, upravljanje otpadom postalo je jedna od najznačajnijih aktivnosti u području zaštite okoliša.Prioritetni cilj u unapređenju održivog razvoja svake razvijene zemlje u svijetu je bezdeponijsko zbrinjavanje otpada, a posebno na način da se nusproizvodi koriste kao alternativne sirovine. Na taj način spriječava se neželjeni uticaj na okoliš uslijed deponovanja nusproizvoda i istovremeno se štite neobnovljivi izvoriprirodnih mineralnih sirovina, te se smanjenju emisije CO_2 i doprinosi uštedi energije.

Među neizbježnim nusproizvodima crne metalurgije, posebno značajno mjesto zauzimaju troske iz proizvodnje gvožđa i čelika, koje se danas smatraju vrijednim resursima sa primjenom u cestogradnji, cementnoj i drugim industrijskim granama, a što je u skladu s evropskim zakonodavstvom iz oblasti očuvanja životne sredine.U novije vrijeme od posebnog interesa je primjena visokopećne troske u procesu proizvodnje mineralne vune, koji inaće u osnovi koristi sirovine koje su mješavina prirodnih mineralnih stjena magmatskog i sedimentnog porijekla.

U ovom radu dat je pregled perspektive upotrebe visokopećne troske iz zeničke željezare kao i ostalih raspoloživih prirodnih mineralnih agregata u bližem okruženju grada Zenice neophodnih u proizvodnji kamene vune, kao i jedan dio preliminarnih istraživanja.

2. KAMENA VUNA

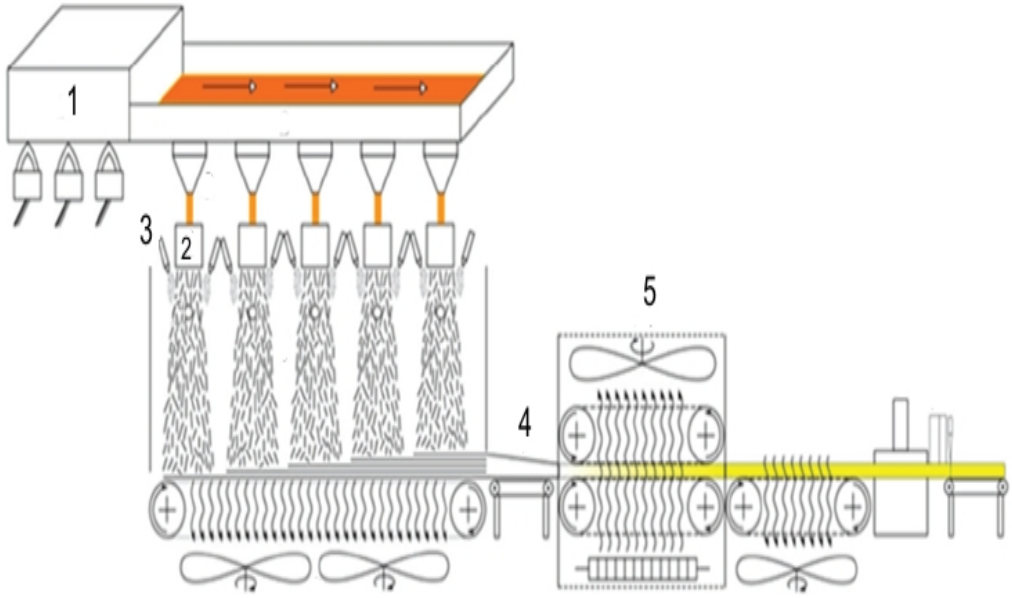
2.1 Primjena kamene vune

Današnja tehnologija pruža mogućnost upotrebe raznih materijala za izvedbu toplotne izolacije zidova, podova i krovova,a u cilju racionalne upotrebe toplotne energije.Na tržištu postoji veliki izbor toplotnih izolacija koji se koriste za vanjsku oblogu zida kao i toplotnoj zaštiti u zgradama. Međutim, najpopularniji su polimerni izolacijski materijali tipa ekspandirani polistiren i kamena mineralna vuna. Kamena vuna je izolacioni materijal koji se upotrebljava za toplotnu, protivpožarnu i zvučnu izolaciju. Nalazi široku primjenu u građevinarstvu, industriji i brodogradnji. Osnovne karakteristike kamene vune su: vatrootpornost (topi se na temperaturi većoj od 1000oC), vodootpornost, paropropusnost, otpornost na hemikalije i mikroorganizme, te dugotrajnost. Također kamena vuna ne mijenja dimenzije s promjenom temperature okoline, omogućava dobru zvučnu izolaciju, te je otporna na starenje i može se reciklirati.

2.2 Način proizvodnje kamene vune

Sirovine koje se koriste za proizvodnju kamene vune su prirodni i umjetni silikatni materijali [1]. Od prirodnih materijala upotrebljavaju se magmatske stijene poput bazalta, dijabaza, gabra i andezita koje u svom sastavu sadrže SiO_2 i to od 40 do 52%. Sedimentne stjene kao što su krečnjak, krečnjak s primjesom dolomita ili gline, dodaju se da bi se pospješio proces topljenja. Od vještačkih materijala koriste se briketi koji se dobijaju preradom otpada iz tehnološkog procesa uz dodatak cementa, pri čemu se postiže zatvoreni proces recikliranja otpada.

Glavni hemijski spojevi koji ulaze u sastav navedenih sirovina su oksidi silicija, aluminija, kalcija, magnezija i željeza. Sirovina koja se koristi kao energent za proces topljenja je koks. Navedene sirovine se tope u kupolnoj peć (1) na temperaturi od 1500 °C (slika 1). Talina. tzv. lava, koja je dobivena procesom topljenja kontrolirano se dovodi na točkove centrifuge (2) i tu pod uticajem visokog pritiska - otpuha dolazi do njenog razvlaknavanja uz istovremeno namakanje s fenol-formaldehidnom smolom (3) koja se koristi kao vezivo vlakana.Razvlaknjena talina pada na transporter gdje dolazi do formiranja plasta (4), koji se dalje transportuje u sušionu komoru (5) u kojoj pod uticajem cirkulacije vrućeg zraka dolazi do polimerizacije fenol-formaldehidne smole [2].



Slika 1.*Tehnologija proizvodnje mineralne vune [2]*

2.3 Hemijske karakteristike troske i poređenje sa prirodnim agregatima

Zahvaljujući masovnosti metalurške proizvodnje u industriji gvožđa i čelika i samim tim velikoj proizvodnji visokopećne troske koja predstavlja sigurnu sirovinsku bazu, a koja je zagarantovana neprekidnim radom visoke peći to se sve više iznalaze šire mogućnosti njenog iskorištenja. Troska se može koristiti kao zamjena i za prirodne građevinske materijale, tabela 1, [3]. U procesu proizvodnje mineralne kamene vune visokopećnu trosku je potrebno neznatno modifikovati tako da zadovoljava dva osnovna uslova u pogledu osiguranja baziciteta od minimalno 1,2 i ukupnom sadržaju oksida SiO_2+Al_2O_3 od minimalno 50%.

Tabela 1. *Prosječni sadržaji oksida u sastavu mineralnog uloška kamene vune, visokopećne troske i bazalta [3]*

Oksid	Hemijski sastav (%)		
	Mineralna vuna –ciljani hemijski sastav	Visokopećna troska	Bazalt
SiO_2	40,3-43,4	35	46,2-51,4
Al_2O_3	17,5-20,3	14	10,4-18,9
TiO_2	0,6-2,6	-	0,8-2,5
Fe_2O_3	6,1-8,4	-	15,8-21,2
CaO+ MgO	23,7-27,7	48	15,6-30,3
$Na_2O+ K_2O$	1,3-4,3	-	1,8-3,7

Proizvodnja mineralne vune iz visokopećne troske vrši se na dva načina: direktno pri ispustu tečne troske iz visoke peći [4] i indirektno kada se hladna troska kao sirovina topi u kupolnoj peći. Hemijski sastav rastopa određuje svojstva vlakana i pri tome su od posebne važnosti viskozitet, zatim kiselost i temperatura topljenja, koji u osnovi određuju sposobnosti razvlaknjavanja rastopa. Viskozitet rastopa ima dominantan uticaj na njegovu sposobnost razvlaknjavanja. Za optimalnu temperaturu rastopa smatra se temperatura oko 1400°C uz zahtjevani viskozitet 1-3 Pa·s. Povećanjem udjela troske u sirovinskoj mješavini dolazi do povećanja viskoziteta rastopa, što je nepovoljno s aspekta formiranja vlakana. S druge strane najefektniji u modifikaciji koeficijenta viskoziteta rastopa je povećanje udjela pepela u sirovinskoj mješavini, jer ova komponenta ima najveći sadržaj SiO_2 i Al_2O_3. Odnos kiselih i baznih oksida u sirovinskoj mješavini određuje dalje i koeficijent kiselosti rastopa, koji u osnovi opisuje hemijsku postojanost kamene vune i uopšteno se kreće u granicama od 1,2 do 1,4. Tako npr. veći koeficijent kiselosti poboljšava hemijsku stabilnost kamene vune i utiče na povećanje dužine vlakana, ali i na povećanje debljine vlakana [5].

2.4 Moduli kvaliteta mineralnog uloška i rastopa

Hemijski sastav mineralnog uloška u najvećoj mjeri definiše kvalitet proizvedene mineralne vune, iako se u praksi često susreće da se iz rastopa različitog hemijskog sastava, ali sličnih fizičko-hemijskih karakteristika dobija mineralna vuna približno istog kvaliteta.

Za utvrđivanje okvirnog hemijskog sastava mineralnog uloška odnosno rastopa koriste se:

- modul kiselosti (MK),
- modul viskoznosti rastopa (MV) i
- koeficijent strukture anjona (KSA).

Modul kiselosti rastopa definiše se kao količnik zbira sadržaja kiselih i baznih oksida u rastopu,a izračunava se prema formuli:

$$MK = (SiO_2 + Al_2O_3) / (CaO + MgO) \quad (1)$$

Modul viskoznosti definiše se kao koeficijent unutrašnjeg trenja rastopa. Vrijednost ovog modula koja se iskazuje u poazima nije konstantna već se mijenja u zavisnosti od temperature na kojoj se rastop nalazi. Orijentaciono se može izračunati iz hemijskog sastava, a iskazati u obliku modula viskoznosti (MV) pri čemu se ovaj modul iskazuje kao odnos molskih sadržaja kiselih oksida u rastopu prema molskom sadržaju ostalih baznih oksida uključujući i sadržaj Fe_2O_3:

$$MV= MSiO_2 + 2MAl_20_3 / 2MFe_2O_3 + M(FeO+CaO+MgO+K_2O+Na_2O) \quad (2)$$

gdje je:
M - molski udio odgovarajućih oksida u rastopu u % .

Mol % oksida predstavlja broj molova posmatranog oksida prema ukupnom broju molova svih komponenti u posmatranoj jedinici zapremine, izraženo u procentima. Izračunavanje molskog viskoziteta vrši se na bazi koeficijenata za preračunavanje masenih na molske procente oksida koji ulaze u sastav rastopa prema trećoj koloni u tabeli2.

Tabela 2.*Koeficijenti za izračunavanje modula viskoznosti*

Oksid	Molska masa	Broj molova u jednom masenom %	Sadržaj kisika u oksidu (%)
SiO_2	60,09	1,67	53,25
Al_2O_3	101,96	0,981	47,08
Fe_2O_3	159,70	0,628	30,06
FeO	71,85	1,390	22,27
CaO	56,08	1,78	28,53
MgO	40,32	2,48	39,68
K_2O	94,20	1,032	16,99
Na_2O	61,98	1,615	40,05

Koeficijent strukture anjona predstavlja broj jona kisika prema broju jona koji obrazuju umreženu strukturu u rastopu sistema SiO_2 - Al_2O_3 – CaO – MgO, a to su joni Si i ¾ prisutnih jona Al. Ovaj koeficijent se izračunava prema obrascu:

$$KSA = O/ Si + 0,75 Al \quad (3)$$

gdje su Si, Al i O broj grama atoma odnosnih oksida koji se obračunavaju prema sljedećim obrascima:
Si = % SiO_2 x %Si u SiO_2/ atomska masa Si

Al = % Al_2O_3 x %Al u Al_2O_3 / atomska masa Al

O = % (svih oksida) / atomska masa O

Na osnovu datih obrazaca za izračunavanje broja gram-atoma u rastopu, procentni sadržaj kisika u oksidima silikatnog rastopa izračunava se na osnovu vrijednosti datih u četvrtoj koloni u tabeli 2. Na osnovu vrijednosti za KSA moguće je dobiti tačniju sliku o viskozitetu jednog rastopa nego na osnovu modula viskoziteta, jer viskozitet ne zavisi samo od hemijskog sastava rastopa već od njegovih fizičko-hemijskih karakteristika, uključujući i površinski napon.

Prema empirijskim podacima vrijednosti modula koji definišu kvalitet mineralnog rastopa treba da se kreću u granicama datim u tabeli 3[7].

Tabela 3. *Vrijednosti modula*

Modul	Vrijednost
Modul kiselosti (MK)	1,20 - 1,60
Modul viskoznosti (MV)	1,05 - 1,20
Vrijednost za KSA	2,90 - 3,30

3. EKSPERIMENTALNA ISPITIVANJA SIROVINSKE OSNOVE ZA DOBIJANJE KAMENE VUNE

U tabeli 4 dat je prosječan hemijski sastav visokopećne troske Željezare Zenica, dobijen na Institutu „Kemal Kapetanović" Zenica.

Tabela 4.*Prosječan hemijski sastav*

Oksidi	Visokopećna troska, %
SiO_2	38,12
CaO	42,3
MgO	5,48
Al_2O_3	8,88
MnO	3,10
Fe_2O_3	0,29

Za modifikaciju hemijskog sastava visokopećne troske iz Željezare Zenica na raspolaganju stoje sirovine koje se ekspolatišu u regiji Žepča, Viteza i Vareša.

Na osnovu dostupnih informacija o eksploataciji i hemijskom sastavu sirovina za proizvodnju kamene mineralne vune, u tabeli 5 date su prosječne vrijednosti oksida prirodnih sirovinana koje su neophodne za formiranje sastava mineralnog uloška za proizvodnju kamene vune iz rudnika: dijabaza "Papratnica" u Žepču, amfibiolita "Stupčići" u Varešu i dolomita "Kalvarija" u Vitezu.

Tabela 5. *Prosječan hemijski sastav potencijalnih sirovina za proizvodnju kamene vune*

Sirovina	Hemijski sastav (%)							
	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	K_2O	Na_2O	G. ž.
Dijabaz Žepče	43,76	22,83	12,26	4,36	10,24	-	-	6,06
Dijabaz Banovići	35,22	14,2	23,5	7,64	9,30	0,25	3,86	4,04
Amfibiolit	44,9	21,67	15,08	12,0	2,48	-	1,14	1,92
Dolomit	0,43	0	30,97	21,04	-	-	-	45,74

U tabeli 6 dat je pregled eksploatacionih rezervi mineralnih sirovina u okruženju grada Zenice, koje bi se mogle koristiti kao osnovne komponente za sastav mineralne smjese za proizvodnju kamene vune uz napomennu da se 400.000 t visokopećne troske odnose na godišnju količine proizvodnje kristalne visokopećne troske u Željezari Zenica, odnosno danas ArcelorMittal Zenica.

Tabela 6.*Rezerve potencijalnih sirovina*

Sirovina	Kristalna visokopećna troska Zenica	Dijabaz "Papratnica" Žepče	Amfibiolit "Stupčići" Vareš	Dolomit "Kalvarija" Vitez
Raspložive količine /Eksploatacione rezerve	400.000t/god	490.000 t	1.150.000 t	Neograničene

Na bazi navedenih potencijalnih sirovina formirani su, za potrebe preliminarnih istraživanja, uzorci mješavina kamene vune i proizvedena vlakna kamene vune sa različitim odnosima visokopećne troske i dijabaza, a na osnovu izračunatih vrijednosti modula kiselosti i viskoznosti i koeficijenta.

Vrijednosti modula kiselosti i viskoznosti i koeficijenta strukture anjona izračunatih za mineralni uložak sastavljen od jednakih dijelova visokopećne troske iz zeničke željezare i dijabaza iz Banovića su date u tabeli 5. Iz tabele 7 se vidi da jedino modul viskoznosti ne ulazi u preporučene granice, ali je jako blizu donje granice. Budući se hemijski sastav sirovina znatno razlikuje od analize do analize ovo ne mora biti ograničavajući faktor za upotrebu ovog omjera sirovinske mješavine što pokazuju i preliminarni rezultati vezani za elastičnost i tvrdoću vlakana dobivenih iz ove mješavine.

Tabela 7. *Vrijednosti izračunatih modula*

Modul	Vrijednost
Modul kiselosti (MK)	1,22
Modul viskoznosti (MV)	0,995
Vrijednost za KSA	3,15

Uzorci vlakana kamene vune se sa različitim odnosima visokopećne troske i dijabaza. mehanički ispituju na uređaju tipa Nanoindenter AG200 pomoću DCMII mjerne glave [6]. Na slici 2 dati su prikazi preliminarnih ispitivanja vlakana kamene vune na nanometarskom nivou sačinjenih od 50% visokopećne troske i 50% dijabaza. Rezultat ispitivanja su vrijednosti modula elastičnosti 70,6 GPa i tvrdoće7,8 GPa vlakana na dubini između 100 nm i 200 nm.



Slika 2. *Prikaz debljeg vlakna (lijevo) i tanjeg vlakna(desno) kamene vune sačinjenog od 50% visokopećne troske i 50% dijabaza, povećanje 1000x*

Dosadašnja ispitivanja pokazuju pozitivan trend po pitanju upotrebe visokopećne troske, te ukazuju da je moguće dobiti kamenu vunu zadovoljavajućih karakteristika na bazi supstitucije prirodnih sirovina sa visokopećnom troskom.

4. ZAKLJUČAK

- Masovnost proizvodnje u industriji crne metalurgije i samim tim i velikoj proizvodnji visokopećne troske predstavljaju sigurnu sirovinsku bazu za proizvodnju kamene vune, a koja je zagarantovana neprekidnim radom visoke peći.
- Korištenjem visokopećne troske u proizvodnji kamene vune smanjuje se potrošnja prirodnih minerala.

- U bližem okruženju grada Zenice na raspolaganju su pored velikih količina visokopećne troske također sirovinske komponente za modifikaciju mineralne mješavine za dobijanje kamene vune, kao što su dijabaz, dolomit i amfibiolit.
- Upotreba visokopećne troske kao dominantne komponente u proizvodnji kamene vune zahtijeva sveobuhvatnu analizu s aspekta kvaliteta, kao i ekološke i ekonomske opravdanosti.

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ON NANOMECHANICAL PROPERTIES IDENTIFICATION BY OPTICAL TWEEZERS

Svetomir Simonović[1]

Abstract: This paper contains a short overview of the principles of trapping and manipulation of nanoparticles by optical tweezers. Also, some methods of force and displacement measurement by optical tweezers, as well as their different calibration methods are presented. As an example, a short insight into the application of optical tweezers to DNA mechanical properties measurement is exposed.

Key words: Optical, Nanomechanical, Trapping

1 INTRODUCTION

In 1970, Ashkin, in the course of working at the Bell Telephone Laboratories, observed that freely suspended particles are accelerated by the forces of radiation pressure from visible laser light [1]. In 1986, Ashkin et al. published a paper entitled Observation of a single-beam gradient force optical trap for dielectric particles, therein describing a technique that is nowadays known as optical tweezers. With the invention of optical tweezers in the 1980s, it became possible to generate and measure forces in the unprecedented range of pico- and nanonewtons. For the first time, microscopic particles such as living cells or bacteria could be individually manipulated [2].

Today, optical tweezers are the most common type of optical traps, and due to their simplicity, they are used in a wide range of different applications. There is increasingly more investment in this technology due to promising applications in biotechnology and medicine. Capabilities have evolved from simple manipulation to the application of calibrated forces on– and the measurement of nanometer-level displacements of – optically trapped objects. The ability to apply forces in the piconewton range to micrometer-sized particles while simultaneously measuring displacement with nanometer resolution is now routinely adopted for the measuring of the force-generating properties of various molecular motors at the single-molecule level [3–6] and to obtain force–extension profiles of single DNA or protein molecules [7,8].

In parallel with the widespread use of optical tweezers theoretical and experimental work on fundamental aspects of optical trapping is being actively

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performed [9].

2 THEORETICAL PRINCIPLES

In optical tweezers, small dielectric particles (beads) are manipulated by electromagnetic traps. Three-dimensional light intensity gradients of a focused laser beam are used to pull or push particles with nanometer positional accuracy. Using this technique, forces in the range of 10^{-13}–10^{-10} N can be measured accurately [10,11].

The optical tweezers technique is based on the trapping of dielectric particles at the center of a focused laser beam by restoring forces arising from radiation pressure and light-intensity gradients [12,13].

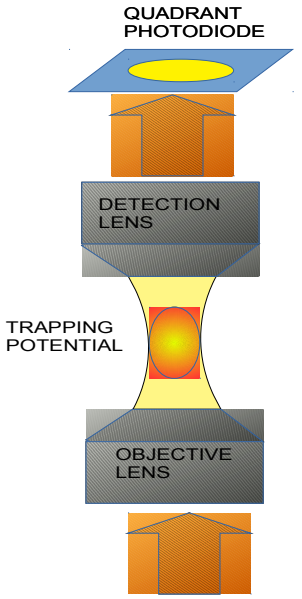


Figure1. *Basic design of an optical tweezer*

Basically an optical tweezer consists of a trapping laser (with wavelength λ), an objective lens with high numerical aperture (NA) to focus the laser beam, a detection lens, and a quadrant photodiode for detecting the scattered and unscattered light (Fig. 1.). Due to the high NA of the objective, high-intensity gradients arise in three dimensions. A dielectric particle near the focus experiences a force in the direction of the light gradient, called the gradient force (Fig. 2.), as well as one in the direction of light propagation, called the scattering force. Both forces originate from the change of momentum of the photons, which causes, according to Newton's third law, also a change of momentum of the bead. In Fig. 2. the optical path of exemplary beams and the resulting gradient forces are shown for two different bead positions. The scattering force F_{scat} arises from absorption and reflection of the incident photons (the so-called radiation pres-sure) and is the dominant force in most conventional cases. Only if there is a steep intensity gradient in the beam can the gradient force F_{grad} compensate for F_{scat}. The arrows that cross the sphere show the refraction of light at each surface, indicating how the net sideways force on the particle is zero in the middle of the focused spot. The momentum imparted to the sphere by scattering of photons tends to push it along the y-axis, but scattering of the refracted rays can give rise to a

compensating force that keeps the sphere at the point of highest intensity along the y-axis (i.e., at the focus).

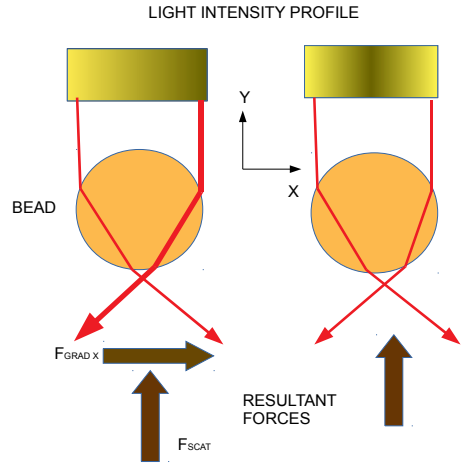


Figure 2. *Optical path of exemplary beams and the resulting gradient forces for two different light intensity profiles*

The balance between the scattering force and the gradient force in the axial direction results in stable trapping slightly behind the focus. For small displacements of the particle (≤ λ /2 in the axial and λ/4 in the lateral direction) the resulting, restoring optical force

$$F_{opt} = F_{scat} + F_{grad} \tag{1}$$

is linear and the trap acts like a Hookean spring in three dimensions. For the x-, y- and z-directions it follows that

$$F_x = k_x \Delta x, \quad F_y = k_y \Delta y, \quad F_z = k_z \Delta z \tag{2}$$

where Δx, Δy,and Δz are the displacements and k_x, k_y, and k_z are the characteristic trap stiffnesses in each direction. The trap stiffness grows linearly with laser intensity.

As the stiffness in the axial (z-) direction is maller than in the xy-plane the trapping volume forms an ellipsoid.

Clearly, these forces are a minimum at the center of the beam where the gradient of intensity is the same on each side of the sphere. What is not so obvious is that the net force on the bead from scattering of the incident light is also a zero along the y-axis when the bead is at the point of highest intensity, that is, the focal point. This is because the focusing action of the bead itself results in a backward push that can balance the forward momentum imparted by scattering. Therefore, the particle becomes trapped at the focal point of the laser beam provided that it is large enough and has a large enough dielectric constant. Typically, plastic or glass beads of a diameter on the order of a micron are used. Typical laser sources for this application emit tens of mW or less, resulting in effective spring constants in the xz plane that range from 10−10 to 10−3 N/m, a 1000-fold or more less than the spring constants of levers used in the AFM. This greatly enhances force sensitivity (at the expense of spatial resolution). The lowered spatial resolution relative to the AFM comes as a consequence of the larger thermal fluctuations in the “softer” spring driven by k_BT = 4.2 pN·nm [14].

3 ON POSITION AND FORCE MEASUREMENT AND CALIBRATION

A frequently used technique to calibrate the position detector is the so-called attached-bead method. Following this method the position detector response is recorded while a bead fixed to the surface is moved through the laser focus by a known length within the linear response of the detector. Unfortunately this method is affected by significant bias caused by surface-proximity effects and spherical aberrations. Another drawback is caused by the axial dependence of the lateral position signals. So it is necessary to match the axial position of the tethered bead precisely to that of the trapped bead, which is not that easy.

Another possibility is position calibration based on thermal motion, for example, using the power-spectral density as described for force calibration below. Another problem using oil-immersion objectives is that the calibration factor for position detection de-creases as the focal plane penetrates the sample, due to spherical aberrations mainly caused by refractive-index mismatch. Using water-immersed objectives this effect was not noticed [15].

Once the optical trap is calibrated, measurement of the displacement of the bead in the trap provides a direct readout of the force on the bead. This displacement is commonly measured by one of the two techniques. The first technique relies on the measurement of the interference pattern between transmitted and scattered laser light from the bead. It is illustrated in Fig. 3.

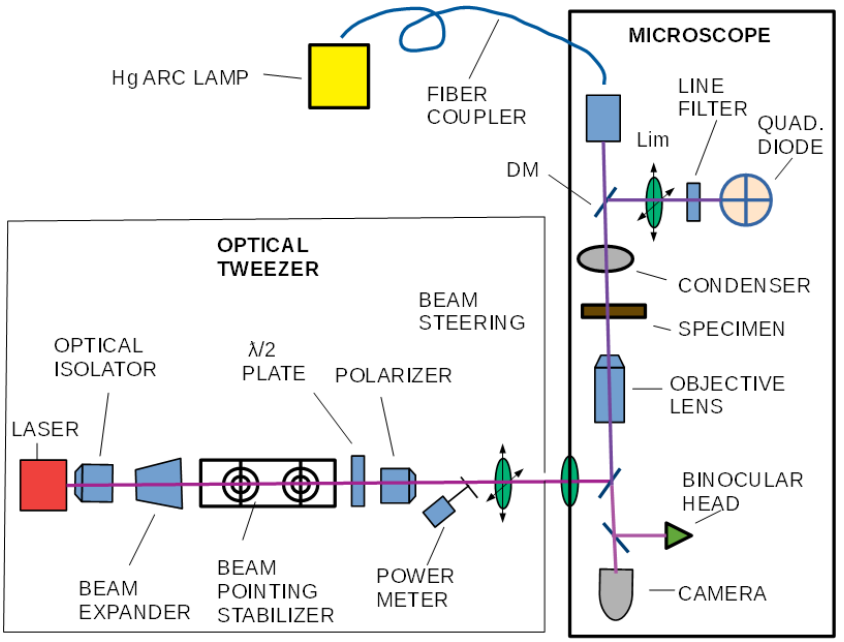


Figure 3. *Layout of an optical tweezers experiment incorporating backscatter detection of the position of the bead [16]*

DM indicates the location of a dichroic mirror that directs transmitted and scattered laser light onto a four quadrant photodiode (Quad Diode). The interference pattern between the transmitted and scattered light is used to determine the position of the bead [16].

An instrument like this can resolve displacements as small as 3 nm, sampling data at kilohertz rates [16]. Displacement is calibrated by moving a bead fixed to a glass slide a known distance through the laser beam using a piezoelectric translation system. Force can be calibrated by a number of means. One method is to flow a solvent of known viscosity past a bead tethered to the surface by a flexible tether. The viscous drag on the bead will cause a displacement of the bead relative to its equilibrium position before the flow was started. Stokes' law can be utilized to calculate the viscous force (taking into consideration correction for the hydrodynamic effects of a nearby surface [17])

The Langevin equation for a free particle reads

$$m\ddot{x} = -\alpha\dot{x} + F(t) \tag{3}$$

where α is a friction coefficient (given by $\alpha = 6\pi\eta a$ for a sphere of radius a in a medium of viscosity η). F(t) is a random force that obeys the following constraints

$$\langle F(t) \rangle = 0 \tag{4}$$

$$\langle F(t)F(t') \rangle = F\delta(t - t') \tag{5}$$

These equations state that the time average of the force is zero (as it must be for a randomly directed force) and that the force is finite only over the duration of a single "effective" collision (corresponding to many atomic collisions in reality). By adding a restoring force proportional to the displacement of the particle from the center of the trap to describe the case of a particle in an optical trap, (3) turns into

$$m\ddot{x} = -\alpha\dot{x} - kx + F(t) \tag{6}$$

In this equation, κ is the spring constant of the optical trap. In the limit of heavy viscous damping, the inertial term $m\ddot{x}$ can be ignored. The equation of motion then becomes

$$\dot{x} + 2\pi f_c x = \frac{F(t)}{\alpha} \tag{7}$$

where

$$f_c = \frac{k}{2\pi\alpha} \tag{8}$$

Thus, the response of the particle falls off for frequencies above this "corner frequency," fc. Fourier analysis of the response to a random driving force yields the following result for the power spectrum (proportional to $|x(f)|^2$ of the random motions of the particle in the trap

$$P(f) = \frac{C}{f_c^2 + f^2} \tag{9}$$

where C is a constant. Thus, by recording the displacement of the particle as a function of time over some interval, calculating the power spectrum by Fourier transforming the displacement vs. time data, and fitting the resulting distribution by Equation (9), the

corner frequency, fc, is determined. The spring constant of the trap, κ, can then be obtained with Equation (8) (with α calculated from Stokes' law) [17].

4 ON DNA MECHANICAL PROPERTIES MEASUREMENT

Here is demonstrated one of optical tweezers first applications, which was measurement of the elastic properties of a single DNA molecule. Using an experimental set-up like that illustrated in Fig. 4., Bustamante and coworkers have measured the force vs. extension curves for various different single- and double-stranded DNA molecules [18].

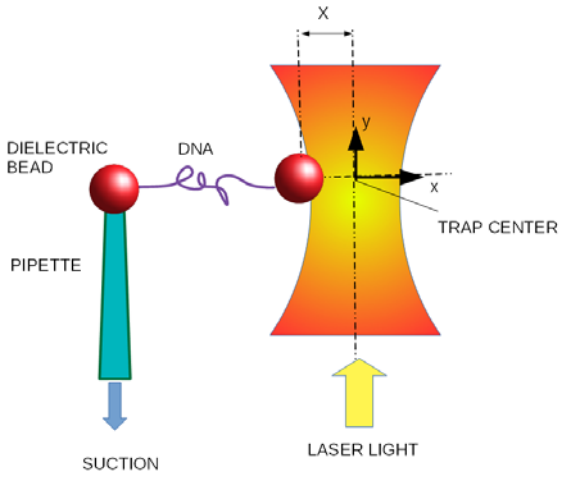


Figure 4. Optical *tweezers setup for strectching force and DNA extension measurement*

The focused laser beam acts as a trap, drawing the small transparent sphere into the point of highest light intensity. Fig. 4. shows a molecule (DNA) attached at one end to a small sphere that is trapped in the laser beam and at the other end to a small sphere that is attached to the end of a suction pipette. Moving the pipette away from the laser trap generates a stretching force on the DNA. DNA is not visible in the optical image.

A summary of some of these data is given in Fig. 5. The entropic force produced by extending a polymer dominates the force extension curve of both single- and double-stranded DNA at low extensions. The entropy of a given length of a double-stranded DNA is much smaller than that of the single-stranded DNA because of the constraint that the two polymers wrap around one another in a double helix. This gives rise to an effective flexible link that is quite long for double-stranded DNA. This effective flexible link length is called the persistence length, and it is ~50 nm for double-stranded DNA. It is <1 nm for single-stranded DNA. Consequently, at low extensions, a force of only 0.1 pN will extend double-stranded DNA significantly, whereas ~6 pN is required to extend single-stranded DNA a similar amount. The double helical structure of double-stranded DNA causes it to be relatively inextensible when pulled to its full length (fractional extension = 1) until, that is, the force applied to the double helix is large enough to disrupt the double helical structure, causing a transition to a new overstretched form of DNA. In contrast, single-stranded DNA continues to extend in a

smooth way. This behavior is important for the biological processing of DNA because the molecular motors that process DNA impose forces of a few pN. The solid lines are theoretical fits. Double-stranded DNA gives less entropic restoring force at low extensions because its persistence length is longer than that of ssDNA [18].

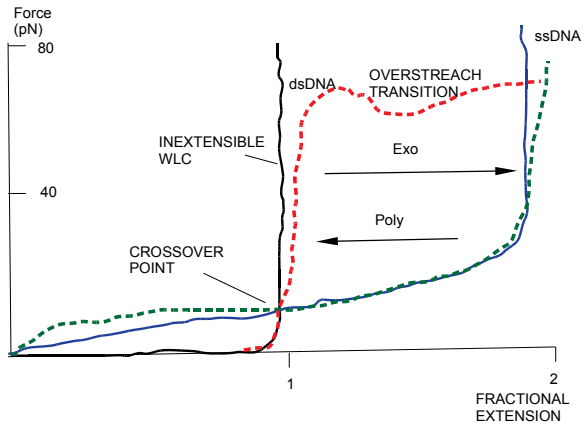


Figure 5. *Force vs. fractional extension for double stranded DNA (dsDNA, red dashed line) and single stranded DNA (ssDNA, green dashed line) obtained with optical tweezers measurements [18]*

5 CONCLUSION

An optical tweezer is a scientific instrument that uses a focused laser beam to provide an attractive or repulsive force, depending on the index mismatch, to physically hold and move microscopic dielectric objects. Optical tweezers have emerged as a powerful tool with broad-reaching applications in biology and physics. Optical tweezers have been used extensively to measure the force-generating properties of various molecular motors at the single-molecule level and to obtain force–extension profiles of single DNA or protein molecules.

The optical tweezer acts as an elastic spring with a tunable spring constant, so the force applied to the bead can also be controlled with high precision. Another advantage of the optical trap system is that multiple beads can be inde-pendently controlled by splitting the laser beam, so that cells can, for example, be stretched between two beads that are slowly moved apart.

The biggest limitation of using optical tweezers in cell mechanics experiments is that the maximal force level is limited to <1 nN, as larger forces would require higher laser power that could excessively heat the cell.

Optical tweezers are ideally suited to holding and manipulating cells since inherently dielectric biological matter is drawn into a trap in a self-adjusting manner, with cell viability widely conserved. An exponentially increasing demand for high-throughput and high-content cell-based studies makes the use of optical traps in the development of new techniques increasingly important. Optical trapping has several primary inherent advantages. Optical tweezers can be readily combined with optical microscopy and spectroscopy as well as integrated into microfluidic setups. Moreover, the momentum of light can be used as the best solution to probe cells mechanically, since it is difficult and often destructive to touch them physically.

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RAZVOJ OPTIČKOG SISTEMA ZA ON-MACHINE INSPEKCIJU DELOVA DOBIJENIH MAŠINSKOM OBRADOM

Dragan Lazarević[1], Bogdan Nedić[2], Živče Šarkoćević[3], Ivica Čamagić[4], Jasmina Dedić[5]

Rezime: Iako su još uvek manje tačnosti od koordinatnih mernih mašina, optički uređaji za skeniranje (skeneri) sve se više koriste u industrijskom merenju iz razloga brzog merenja, mogućnosti merenja složenih oblika, nezavisnošću rezultata od tvrdoće delova i sl. U sistemima On-Machine inspekcije odnedavno se koriste taktilne i optičke sonde, dok se skeneri uglavnom koriste za Off-line inspekciju. Cilj ovog rada je integrisanje opitčkih skenera u savremeni On-Machine sistem inspekcije. Rad daje opis elemenata navedenog sistema i problema koji se javljaju, počev od postupka akvizicije podataka tačaka, preko preprocesiranja i procesiranja površina do inspekcije u adekvatnom softveru i dobijanja izveštaja merenja. U eksperimentalnom delu prikazani su rezultati inspekcije dela obrađenog glodanjem sa različitim parametrima rezanja i skeniranim optičkim skenerom ATOS.

Ključne riječi: Merenje, On-Machine inspekcija, Skener

THE DEVELOPMENT OF OPTICAL SYSTEMS FOR ON-MACHINE INSPECTION OF PARTS MADE WITH MACHINING PROCESS

Abstract: Although the accuracy of coordinate measurement machines, optical scanning devices (scanners) are used more and more in industrial measurement because of fast measuring, the possibility of measuring complex objects, the independence of part hardness results and similar. In On-Machine systems of inspection tactile and optical probes are recently used, while scanners are mostly used for Off-line inspection. The goal of this paper is the integration of optical scanners in contemporary On-Machine systems of inspection. The paper gives the description of the elements of the mentioned system and problems that are occurring, starting from the procedure of point data acquisition, over preprocessing and processing of surfaces

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to inspection in adequate software and obtainment of the measuring report. In the experimental part the results of part inspection processed by milling with different parameters of cutting and scanning using ATOS optical scanner are shown.

Key words: Measurement, On-Machine inspection, Scanner

1. UVOD

Mesto i uloga merenja i inspekcije u industriji menja se saglasno razvoju i uvođenju novih tehnologija u tehnološke sisteme. Sa porastom složenosti oblika proizvoda i povećanjem zahteva za tačnošću, delovi postaju sve komplikovaniji za merenje i kontrolu. Zbog toga je potrebno u kontroli i merenju (inspekciji) primenjivati takve merne uređaje koji su precizni, brzo izvršavaju veliki broj operacija merenja, a pri tom je njihova primena ekonomski opravdana.

U primeni su kontaktni i beskontaktni uređaji za inspekciju. Koordinatna merna mašina (CMM), najznačajniji predstavnik nekontakntih uređaja, već dugo se smatra standardom u metrologiji. S druge strane, optički, bezkontaktni uređaji za inspekciju (skeneri) su revolucija u inspekcijskim aplikacijama u poslednjoj deceniji. U mnogim oblastima proizvodnih procesa srednjih i velikih obima, uređaji za skeniranje u kombinaciji sa inspekcijskim softverom postaju glavno sredstvo za inspekciju u industriji [1] iako su još uvek manje tačnosti u poređenju sa koordinatnim mernim mašinama (CMM). Njihovim usavršavanjem i integrisanjem u proizvodnju omogućava se merenje direktno na mašini (*on-machine*), bez potrebe da se deo skida sa mašine alatke. S druge strane, CMM meri tačku po tačku, što dovodi do relativno niske efikasnosti u poređenju sa drugim metodama optičke inspekcije. Ovaj inherentni nedostatak ograničava primenu CMM u nekim slučajevima sa visokim zahtevima u brzini merenja [2].

Ova studija daje kratak osvrt na probleme koji se javljaju pri dobijanju oblaka tačaka, njegovog preprocesiranja i procesiranje tj. generisanja površine, kao i na postojeće softverske aplikacije za inspekciju. Eksperimentalnim istraživanjima izvršena je analiza pogodnosti (verifikacija) optičkih uređaja za skeniranje kod dimenzionalne i geometrijske inspekcije delova dobijenih obradom glodanjem sa različitim parametrima rezanja. Da bi se postigao ovaj cilj, izvršeno je poređenje rezultata merenja odstupanja prizmatičnih izdanaka obrađenog dela. Delovi su mereni off-line postupkom, najpre na CMM, a zatim skenirani korišćenjem tri različita ATOS skenera. Rezultati skeniranja obrađeni su u GOM Inspect softveru. Vrednosti dobijene pomoću CMM su izabrane kao referentne iz razloga što kontaktna tehnologija pruža bolju preciznost i ponovljivost [3]. Predložen je MIPP sistem, kompletne integracije postupaka CAD/CAM/CAI.

2. PRINCIP INSPEKCIJE 3D SKENIRANJEM I MIPP

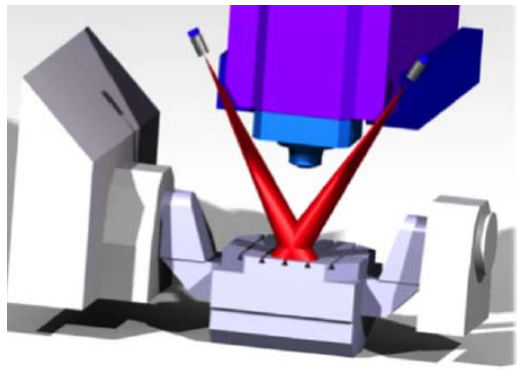
Računarom podržano merenje (Computer Aided Inspection - CAI) predstavlja novu tehnologiju koja omogućava merenje poređenjem odstupanja fizičkog dela od njegovog nominalnog (idealnog) 3D CAD modela. Proces CAI počinje od generisanog CAD modela i fizičkog dela koji je potrebno meriti. Deo se najpre nekim od uređaja za 3D digitalizaciju skenira. Dobijena datoteka oblaka tačaka (STL, TXT i sl.) se po potrebi primenom CAD ili CAI softvera pre-procesira, procesira tj. generiše se površinski model dela i takav koristi za inspekciju. CAI softver vrši poređenje nominalnog modela sa površinskim modelom i izračunava željena odstupanja elemenata realnog dela u odnosu na idealni CAD model.

U nepravilnosti (greške) oblaka tačaka, koje nastaju prilikom skeniranja i koje je

postupcima preprocesiranja potrebno ispraviti spadaju: gustina uzorkovanja (sampling density), šum (noise), tačke van opsega (outliers), neusklađenost (misalignment) i nedostatak podataka (missing data) [4]. Podfaze u okviru preprocesiranja su filtriranje oblaka tačaka i redukovanje podataka-tačaka [5]. Segmentacija oblaka tačaka je proces koji se takođe javlja u pojedinim sistemima za inspekciju. Segmentacija se može opisati kao proces deljenja rezultata 3D skeniranja (oblaka tačaka) na smislene regione ili proces ekstrakcije važnih elemenata iz oblaka tačaka [6]. Cilj faze procesiranja površina predstavlja generisanje površinskog (surface) modela iz preprocesiranog oblaka tačaka [7]. U geometrijskom modeliranju, površine se generišu ili preko postupaka aproksimacije na osnovu podataka-tačaka ili preko poligonalne aproksimacije.

Skeneri snimaju „oblik“ dela tako da merenja ne mogu biti analizirana bez korišćenja mernog softvera. Komercijalno dostupni softverski proizvodi uključuju: Geomagic Qualify, Rapidform XOV, Innovmetric Polyworks kao i GOM Inspect. GOM Inspect sadrži osnovne alate za preprocesiranje i procesiranje oblaka tačaka, dok omogućava korisnicima inspekciju uz kreiranje mernih izvještaja koji sadrže snimke, slike, tabele, dijagrame, tekst i grafiku, ili su u PDF formatu.

Kako postoji direktna veza između CAD, CAM i CAI, javila se potreba za potpunim integrisanjem opitčkih skenera u savremeni On-Machine sistem inspekcije, odnosno izradnju kompletno integrisanog proizvodnog procesa koji odnedavno nosi akronim MIPP (Machining and Inspection Process Planning - planiranje procesa proizvodnje i inspekcije) [8]. Primer ovakvog sistema podrazumeva implementiran optički uređaj za skeniranje u nosač alata, dok se deo nalazi na rotirajućem stolu kod 4-osnog, odnosno 5-osnog obradnog centra (slika 1).



Slika 1. *Optički uređaj za inspekciju inplementiran na 5-osnom obradnom centru*

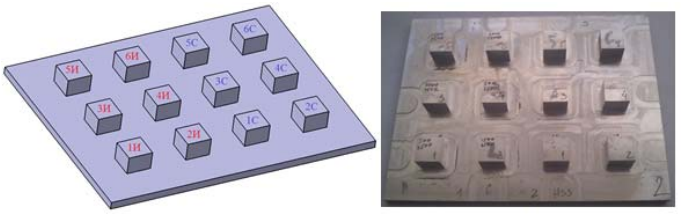
3. EXPERIMENT

U okviru eksperimenta izvršena je obrada dela glodanjem uz primenu različitih paramatara rezanja (brzina rezanja i pomoćno kretanje - korak), a obrađivana je legura aluminijuma. Primenjene su strategije istosmerno i suprotnosmerno glodanje sa alatom vretenastim glodalom prečnika ϕ6 mm od brzoreznog čelika (HSS). Ovako izrađeni izdanci delova mereni su off-line postupkom na CMM, a zatim primenom tri različita optička skenera. Softveri koji su korišćeni za obradu izmerenih podataka i izračunavanje dimenzionalnih odstupanja su PC DMIS (za CMM) i Gom Inspect (za skenere).

3.1. Materijal i oprema

Mašina na kojoj je vršena obrada je vertikalna glodalica Haas VF-3SS sa tri CNC kontrolisane ose. Kao rezni alat korišćeno je vretenasto glodalo 15112 Orion od brzoreznog čelika (HSS) prečnika 6 mm, ugla spirale 45o, dužene reznog dela 13 mm, ukupne dužine 57 mm i broja zuba 3. 3D Model dela (Slika 2-a) kao i sve staze (putanje kretanja) alata i simulacija obrade, dobijene su korišćenjem softvera CATIA P3 V5-R62014. Generisane putanje alata simulirane su u softveru CIMCO Edit v7.0.7. Materijal obrađivanih delova je legura aluminijuma 6005A-T6 Al (AlSiMg(A) 3.3210).

Obrađeni deo (Slika 2-b) je meren na koordinatnoj CNC mernoj mašini (CMM) DEA GLOBAL Silver Performance. Rezultati merenja u vidu koordinata tačaka obrađeni su pomoću softvera PC DMIS.



Slika 2. *CAD model i deo nakon obrade*

Deo je skeniran sa tri različita optička skenera i to skenerom: ATOS II, ATOS IIe i ATOS Compact Scen M5. Geometrijske konfiguracije senzora ATOS II i ATOS IIe su identične, dok razlika postoji u hardverskim verzijama kontrolera, kamera i projektora. Prah kojim je posut deo kako bi se mogle skenirati reflektujuće površine dela je NORD-TEST, Endringprufsystem, Entwickler U 89.

Rezultati merenja sa skenera, u vidu oblaka tačaka (stl formata), uvezeni su i obrađeni korišćenjem softvera Gom Inspect i dobijena su dimenzionalna i geometrijska odstupanja bočnih površina izdanaka.

3.2. Plan eksperimenta

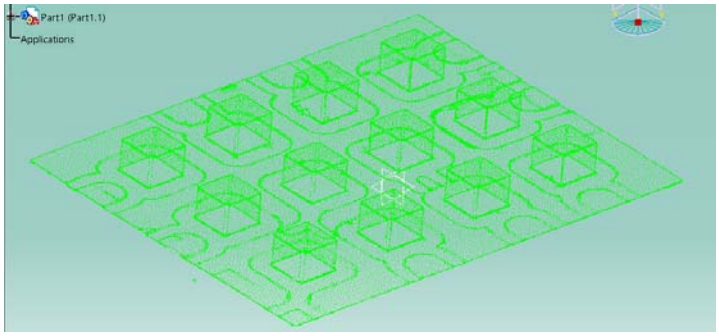
Radni komad (pripremak) je dobijen iz ploče dimenzija 180x140x20 mm, iz koje su prethodnom obradom dobijeni prizmatični izdanci (Slika 2-b). Prvo grubom, a zatim finom obradom vretenastim glodalom ϕ16 mm, dobijen je finalni deo sa izdancima dimenzija 20x20x12 mm. Izdanci dela obrađivani su zatim vretenastim glodalom (ϕ6 HSS) uz primenu različitih parametara rezanja po izdanku i to korak (f, mm/min), broj obrrtaja (n, o/min), dubina a (mm) i širina b (mm) rezanja, istosmernom (IS) i suprotnosmernom (SS) strategijom obrade. Parametri rezanja i plan eksperimenta prikazani su u tabeli I. Obrada je vršena sa dva prolaza sa dubinom rezanja od 0,875 mm i završnim prolazom od 0,25 mm.

Tabela 1. *Parametri eksperimentalnih ispitivanja*

Parametri rezanja	*Izdanci*					
	1	*2*	*3*	*4*	*5*	*6*
f (mm/min)	*500*	*1500*	*2000*	*500*	*1500*	*2000*
n (o/min)	*3500*			*5500*		
a (mm)	*0,875/0,875/0,25*					
b (mm)	*12*					

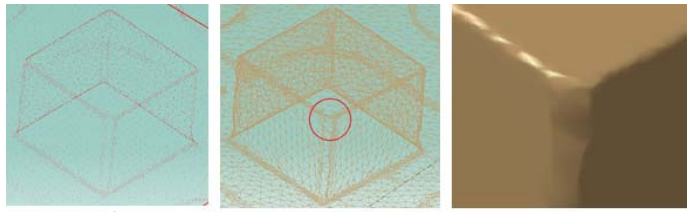
3.3. Inspekcija 3D skenerima

Za razliku od obrade podataka kod CMM, koja za rezultat daje koordinate određenog broja korisnički definisanih tačaka na uniformnom rastojanju, skeneri generišu stl fajl oblaka tačaka, koji sadrži veliki broj neravnomerno raspoređenih tačaka po celokupnoj površini dela. Dobijeni oblak tačaka (stl fajl) je uvezen u softver za inspekciju Gom Inspect. Na slici 3 prikazan je oblak tačaka dela dobijen pomoću skenera modela ATOS II.



Slika 3. *Oblak tačaka dela dobijen pomoću skenera ATOS II*

Kao što je ranije rečeno, dobijeni oblak tačaka najčešće sadrži brojne nepravilnosti koje je postupkom preprocesiranja potrebno pročistiti. Na oblaku nije bilo tačaka van opsega, a greške na mreži se nalaze uglavnom na ivicama izdanaka. Na celokupnoj mreži primećeno je jedno non-manifold (koje koje deli dve nepovezane mreže) teme i jedna šupljina, nalazili su se na graničnim površinama, pa nisu uzeti u razmatranje. Jedan od nedostataka skeniranja optičkim skenerom predstavlja nedostatak skeniranih tačaka na ivicama i prelaznim površinama dela. Na slici 4-a jasno se vide ovi nedostaci. Ovaj nedostatak se dalje komplikuje triangulacijom, koja preko algoritma spaja postojeće tačke (Slika 4-b). Na ovaj način dobio bi se deo bez jasno definisanih ivica (Slika 4-c), odnosno nameće se potreba za naknadnim izvlačenjem ivica.



Slika 4. *Triangulisanje oblaka tačaka i karakteristične nepravilnosti na ivicama*

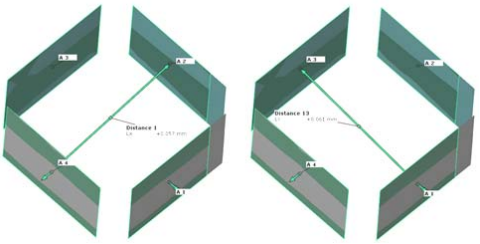
Površine od intresa za inspekciju su bočne površine izdanaka, pa su samo one posmatrane. Tako su kreirane aproksimativne ravni (Plane 1 na slici 5) i provučene kroz određene oblasti oblaka tačaka. Oblasti oblaka tačaka ne uzimaju u obzir tačke na graničnim prelazima površina pa nije bilo potrebe za preprocesiranjem.

GOM Inspect nudi mogućnost izbora između dve metode aproksimacije najmanjeg kvadrata i to Gausovu (koja je korišćena u eksperimentu) i Čebašijevu. Ponavljanjem navedenog postupka na bočnim površinama svih izdanaka, postupak generisanja površina je završen i pristupilo se merenju dimenzionalnih i geometrisjkih

odstupanja. Kod merenja odstupanja od dužinske mere izabrana su rastojanja između srednjih tačaka aproksimativnih ravni. Zadavanjem nominalne mere program izračunava i ispisuje odstupanje (Distance X/Y) u okvir (Slika 6).



Slika 5. *Aproksimirana ravan*



Slika 6. *Izmerena odstupanja (ΔX i ΔY)*

Na sličan način izmerene su vrednosti geometrijskog odstupanja bočnih površina izdanka od upravnosti, upravnosti i paralelnosti.

3.4. Rezultati i analiza rezultata

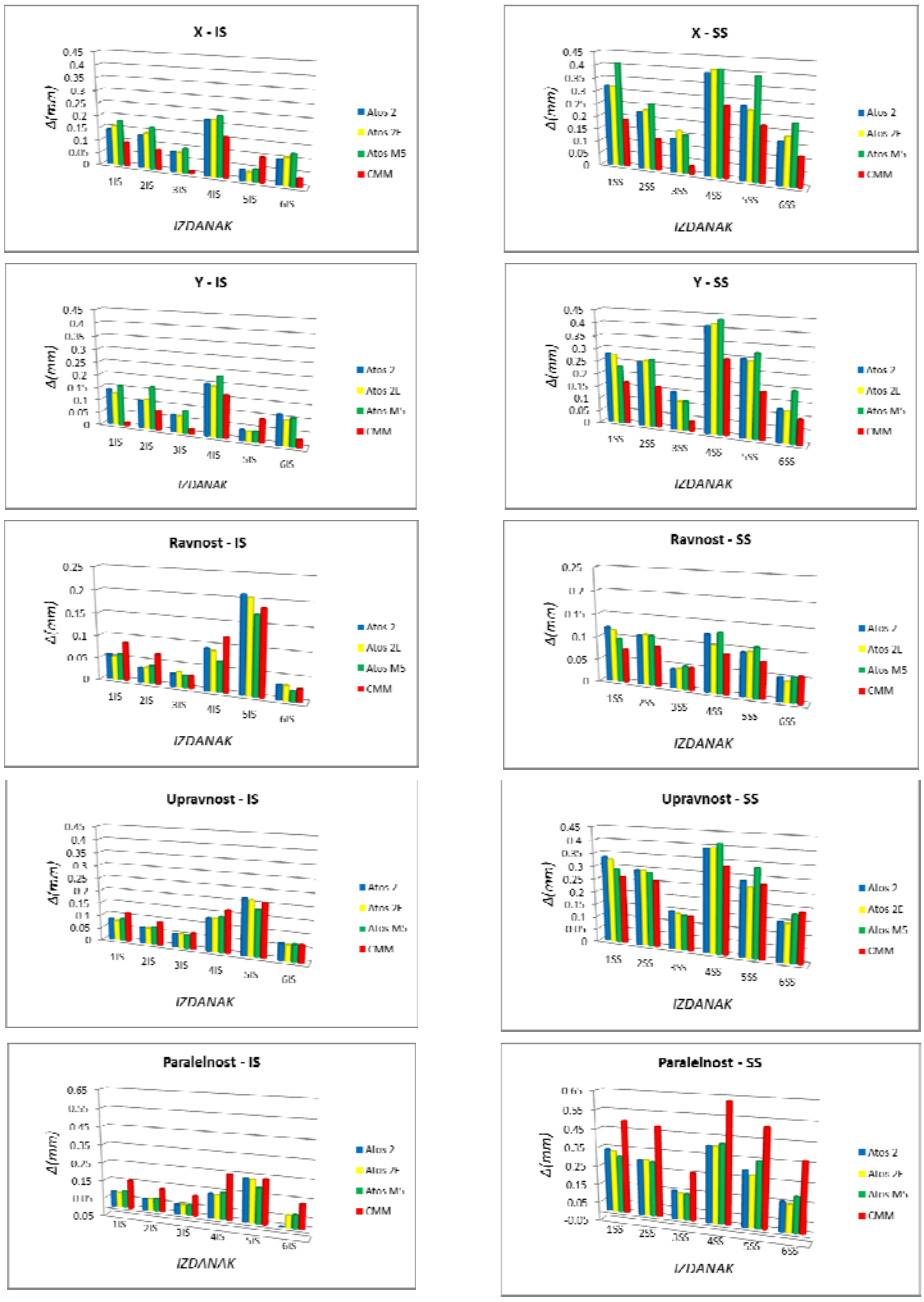
Rezultati izmerenih prosečnih vrednosti dimenzionalnih odstupanja u X i Y pravcu (ΔX, ΔY, mm) i prosečnih geometrijskih odstupanja (⏥ - od ravnosti, ⊥ - od upravnosti i // - od paralelnosti, sve u mm) po izdanku, dati su u tabeli II.

Tabela 2. *Rezultati merenja dimenzionalnih i geometrijskih odstupanja*

Odstupanje	Skener	Izdanci – Istosmerno glodanje						Izdanci – Suprotnosmerno glodanje					
		1	2	3	4	5	6	1	2	3	4	5	6
ΔX	*CMM*	0,095	0,079	0,010	0,158	0,097	0,035	0,188	0,123	0,030	0,277	0,217	0,117
	A II	0,141	0,131	0,079	0,218	0,041	0,097	0,317	0,224	0,132	0,393	0,282	0,165
	A IIe	0,157	0,141	0,078	0,219	0,035	0,108	0,316	0,235	0,167	0,404	0,269	0,186
	A M5	0,179	0,166	0,096	0,236	0,048	0,123	0,407	0,259	0,150	0,409	0,393	0,236
ΔY	*CMM*	0,012	0,074	0,018	0,165	0,089	0,029	0,168	0,162	0,039	0,292	0,183	0,096
	A II	0,140	0,107	0,068	0,200	0,040	0,115	0,277	0,255	0,147	0,411	0,298	0,125
	A IIe	0,127	0,113	0,065	0,193	0,037	0,096	0,276	0,262	0,114	0,417	0,293	0,122
	A M5	0,158	0,166	0,087	0,231	0,040	0,107	0,229	0,267	0,115	0,435	0,324	0,198
⏥	*CMM*	0,085	0,067	0,028	0,120	0,185	0,028	0,074	0,087	0,049	0,086	0,079	0,057
	A II	0,055	0,034	0,029	0,093	0,210	0,032	0,120	0,108	0,042	0,124	0,094	0,051
	A IIe	0,051	0,036	0,034	0,088	0,205	0,032	0,114	0,111	0,044	0,102	0,097	0,044
	A M5	0,059	0,041	0,028	0,067	0,171	0,022	0,096	0,110	0,050	0,130	0,107	0,054
⊥	*CMM*	0,113	0,091	0,062	0,166	0,207	0,067	0,263	0,256	0,133	0,332	0,276	0,190
	A II	0,083	0,061	0,051	0,129	0,218	0,065	0,334	0,293	0,147	0,393	0,285	0,150
	A IIe	0,077	0,061	0,055	0,129	0,214	0,062	0,327	0,293	0,140	0,396	0,264	0,145
	A M5	0,087	0,067	0,053	0,138	0,180	0,067	0,289	0,287	0,134	0,412	0,335	0,181
//	*CMM*	0,157	0,129	0,111	0,247	0,241	0,133	0,498	0,480	0,253	0,631	0,515	0,367
	A II	0,088	0,064	0,054	0,132	0,234	0,068	0,338	0,296	0,150	0,402	0,295	0,155
	A IIe	0,082	0,064	0,057	0,131	0,232	0,065	0,331	0,299	0,142	0,402	0,272	0,146
	A M5	0,094	0,072	0,056	0,147	0,192	0,071	0,305	0,290	0,138	0,416	0,344	0,187

Polazna hipoteza je da su rezultati dobijeni na CMM tačniji, pa su isti izabrani za referentne, i na osnovu njih izvedeni komentari u vezi tačnosti korišćenih skenera.

Na osnovu dijagrama prikazanih na slici 7 može se zaključiti da razlike u odstupanju izmerenih vrednosti, dobijenih na različitim skenerima, odnosno dobijenih merenjem na koordinatnoj mernoj mašini postoje.



Slika 7. *Poređenje dimenzionalnih i geometrijskih odstupanja*

Određivanjem srednje vrednosti odstupanja skenera u odnosu na odstupanja izmerena na mernoj mašini konstatovano je da je model skenera ATOS M5 pokazao najveće odstupanje, njega sledi skener tipa ATOS II, dok je najmanje ukupno odstupanje u odnosu na CMM postignuto skenerom tipa ATOS IIe.

4. ZAKLJUČAK

Iako se koordinatna merna mašina (CMM) smatra standardom u metrologiji, optički, bezkontaktni uređaji za inspekciju (skeneri) su revolucija u inspekcijskim aplikacijama iz razloga bržeg merenja, većeg broja mernih tačaka, mogućnosti merenja fleksibilnih materijala kao i mogućnosti merenja direktno na mašini (On machine). Pa je za očekivati da će, sa dodatnim povećanjem preciznosti i razvojem softvera, postati glavno sredstvo za inspekciju u industriji.

Navedeni eksperimenti su pokazali da razlike između izmerenih odstupanja postoje (iako su neznatne) i da putem daljih istraživanja treba raditi na preciznijem definisanju i praćenju uslova u mernom okruženju, izboru metode aproksimacije i procesiranja površina, kako bi se povećala tačnost uređaja za inspekciju 3D skeniranjem. Kako su delovi mereni off-line postupkom, potrebno je fokusirati se na kompletnom integrisanju optičkih skenera, odnosno integrisati CAD, CAM i CAI u jedinstven On-machine proizvodni proces (MIPP).

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FLEKSIBILNOST PROIZVODNIH PROCESA U AUTOMOBILSKOJ INDUSTRIJI PRIMJENOM KOLABORATIVNIH ROBOTA

Isak Karabegović[1]

Rezime: Najveći broj instaliranih industrijskih robota je u proizvodnim procesima automobilske industrije, a radi se o industrijskim robotima prve generacije koji su odvojeni ogradama od radnika radi njihove sigurnosti. Razvoj novih tehnologija doprinio je razvoju industrijskih robota druge generacije odnosno kolaborativnih robota. Kolaborativni roboti imaju niz prednosti u odnosu na industrijske robote prve generacije, što im daje velike šanse u primjeni u automobilskoj industriji za različite nivoe automatizacije u proizvodnim procesima. Sa kolaborativnim robotima možemo izvršiti automatizaciju u slučajevima kada je automatizacija suviše kompleksna ili nije ekonomična.Na globalnom tržištu kada je automobilska industrija u pitanju kontinuirano se povećava raznovrsnost proizvoda, smanjuje se životni ciklus proizvoda što zahtjeva fleksibilnu automatizaciju koju možemo ostvariti primijenom kolaborativnih robota. Motiva za primijenu kolaborativnih robota u automobilskoj industriji ima mnogo nabrojimo samo dio: smanjenje operativnih troškova, smanjienje kapitalnih troškova, poboljšanje kvaliteta proizvoda i konzistentnosti, poboljšati kvalitet rada za radnike, poštujući pravila o zdravlju i bezbednosti, itd.U radu je napravljena uporedna analiza primijene industrijskih robota u automobilskoj industriji u svijetu, kao i u tehnološki razvijenim zemljama u kojima je najrazvijenija automobilska industrija. Date su mogućnosti primijene kolaborativnih robota u automobilskoj industriji sa trendom njihove primjene u budućnosti.

Ključne riječi: Automatizacija, Automobilska industrija, Fleksibilna automatizacija, Kolaborativni robot, Proizvodni procesi.

FLEXIBILITY OF PRODUCTION PROCESSES IN THE AUTOMOTIVE INDUSTRY BY APPLICATION OF COLLABORATIVE ROBOTS

Abstract: The largest number of industrial robots is installed in the production processes of the automotive industry, and these are the first-generation industrial robots that are separated from workersby fences for their safety. The development of new technologies has contributed to the development of second-generation industrial robots or collaborative robots. Collaborative robots have a number of advantages over industrial robots of the first generation, which gives them great chances for application in the automotive industry for different levels of automation in production processes.

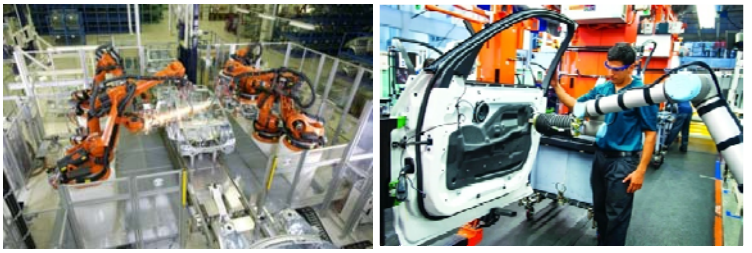
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With collaborative robots, automation can be implemented in cases where automation is too complex or not economical. In the global market when the automotive industry is case,product diversityis continuallyincreased; the life cycle of products is reduced, which requires flexible automation that can be achieved by using collaborative robots. The motive for the application of collaborative robots in the automotive industry has a lot: a reduction in operating costs, a reduction in capital costs, improving product quality and consistency, improving work quality for operators, respecting health and safety rules, etc. A comparative analysis of the application of industrial robots in the automotive industry in the world, as well as in the technologically developed countries where is the most developed automotive industry have been carried out. The possibilities of applying collaborative robots in the automotive industry with the trend of their application in the future are given.

Key words: Automation, Automotive industry, Collaborative robot, Flexible automation, Production processes

1 UVOD

Poznato je da su prvi industrijskih roboti instalirani 60.godina prošlog vijeka u proizvodnim procesima automobilske industrije, a kontinuirano se povećava njihova zastupljenost u proizvodnim procesima ove industrijske grane. Primjenom industrijskih robota u automobilskoj industriji kompanije su povećavale kvalitet, zamjenjivale radnike gdje je izvođenje zadataka za radnike bilo monotono, teško, dosadno i opasno po zdravlje kao što je zavarivanji i bojanje konstrukcija vozila. Automatizacija proizvodnih procesa u automobilskoj industrije je izvedena sa indsutrijskim robotima prve generacij, što predstavlja krutu automatizaciju, a razloga je što sam prostor industrijskog robota mora biti ograđen pregradama da pri radu robota nebi došlo do ozljede radnika koji rade u proizvodnom procesu. Industrijski roboti se programiraju za izvođenje jedne operacije, odnosno izvođenje određenog projektovanog zadatka. Tako na primjer kada niz robota zavaruju automobilsku karoseriju (tačkasto zavarivanje) svaki robot je programiran za izvođenje svog zadatka u procesu zavarivanja. U koliko želimo zavarivati drugu vrstu karoserije za drugo vozilo tada moramo reprogramirati sve robote koji su u liniji procesa zavarivanja karoserije automobila, a to traje vrlo dugo što predstavlja nedostatak jer to povećanja vreme izrade karoserije. Da bismo izbjegli postavljanje ograda između robota i radnika u proizvodnom procesu, razvoj novih tehnologija prije svega informaciono-komunikacione tehnologije, digitalne tehnologije, senzorske tehnologije doprinio je napredku robotske tehnologije tako da su razvijeni roboti druge generacije i napredni sistemi u industrijskoj robotici što pokazuje slika 1.



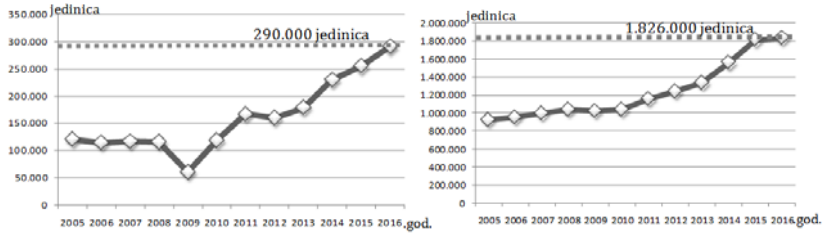
a – roboti prve genercije b – roboti druge generacije

Slika 1. *Industrijski roboti prve i druge generacije-kolaborativni roboti*

Industrijski roboti druge generacije-kolaborativni roboti vrlo jenostavno se integriraju u postojeći sistem proizvodnje, zauzimaju manje prostora od industrijskih robota prve generacije, jeftiniji su, laki za programiranje, mogu se koristiti efikasno za automatizaciju u području automobilske industrije kao što su dijelovi za zavarivanje, sječenje, fleksibilnu montažu, pakovanje i palatiziranje [1,2,3,]. Pogodni su za mogućnost raznih nivoa automatizacije u proizvodnom procesu, tako da možemo zadatke djelimično automatizirati u onim slučajevima kada je potpuna automatizacija suviše kompleksna ili nije ekonomična. S obzirom da se trenutno nalazimo u četvrtoj industrijskoj revoluciji kolaborativni roboti imaju najznačajniju ulogu u „Industrija 4.0“, koja povezuje fabriku realnog života sa virtuelnom stvarnošću, što otvara buduće perspektive u globalnoj proizvodnji, a posebno u automobilskoj industriji. Da bi smo vidjeli zašto izvršimo analizu zastupljenosti industrijskih robota u automobilskoj industriji u svijetu i u zemljama gdje je najrazvijenija automobilska industrija.

2 ZASTUPLJENOST INDUSTRIJSKIH ROBOTA U AUTOMOBILSKOJ INDUSTRIJI

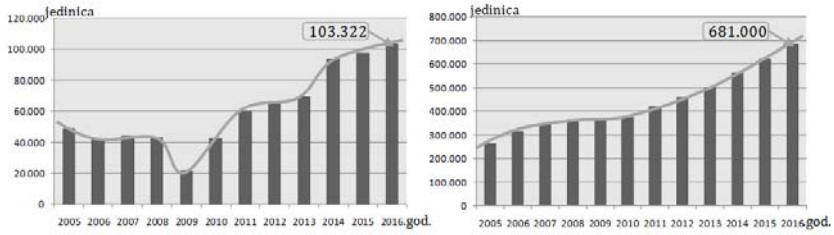
Da bismo napravili analizu trenda zastupljenosti industrijskih robota u automobilskoj industriji u svijetu svijetu statističke podatke smo preuzeti od International Federation of Robotics (IFR), the UN Economic Commission for Europe (UNECE) and the Organization for Economic Cooperation and Development (OECD) [1,2,3,4-7], a sami trend je prikazan na slici 2.



a – godišnje b- ukupno

Slika 2. *Zastupljenost industrijskih robota u svijetu u periodu 2005-2016. godina[4-7]*

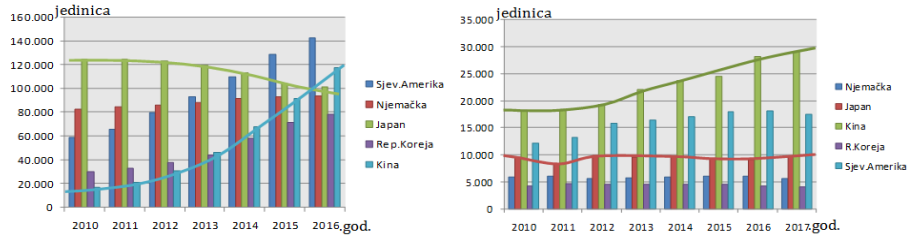
Dijagrami na slici 2. a) i b) nam pokazuju da zastupljenost industrijskih robota u svijetu u svim proizvodnim procesima imaju trend povećanja. Na godišnjem nivou zastupljenost industrijskih robota je u 2016.godini dostigla je zastupljenost oko 290.000 jedinica robota.



a – godišnje b- ukupno

Slika 3. *Zastupljenost industrijskih robota u automobilskoj industriji u svijetu u periodu 2005-2016. godina [6-9]*

Isto tako ukupna zastupljenost također rastućeg trenda i u 2016.godini ukupna zastupljenost u svijetu je dostigla vrijednost oko 1.826.000 jedinica robota. Na osnovu slike 2.a) vidimo da je godišnja primjena industrijskih robota u automobilskoj industriji od 2009.godine stalno u porastu u svijetu.Trend primjenje industrijskih robota u svijetu u automobilskoj industriji u 2016.godini dostigao je vrijednost oko 103.322 jedinica robota, što predstavlja oko 35,5 % ukupne godišnje zastuplenosti industrijskih robota u svijetu i prestavlja industriju broj jedan po zastupljenosti industrijski robota. Ukupna zastupljenost industrijskih robota u automobilskoj industriji u svijetu je u zadnjih jedanaest godina stalno u porastu slika 2.b), a u 2016.godini dostigao je vrijednost oko 681.000 jedinica robota, što u odnosu na (sliku 1.b)) ukupnu zastupljenost robota u svijetu predstavlja oko 37,2% jedinica robota, predstavlja prvu industriju u svijetu po zastupljenosti industrijskih robota. Imajući u vidu da se danas nalazimo u četvrtoj industijskoj revoluciji »Industrija 4.0« čiji je cilj potpuno inteligentni proizvodni procesi, odnosno implementacije novih tehnologija (digitalne tehnologije, IK-tehnologie, robotske tehnologije, senzorske tehnologije itd.) u proizvodne procese vode nas u pravcu stvaranja potpuno »inteligentnih fabrika«. Mislimo da će se to pored ostalih upravo dogoditi u automobilskoj industriji gdje je ostvarena velika automatizacija proizvodnih procesa. Da bismo vidjeli u kojim zemljama je najveća zastupljenost industrijskih robota u automobilskoj industriji i kakva je vozila u tim zemljama napravljena je statistička analiza i prikazana na slici 4. U analizu su uzete tehnološki razvijene zemlje i u kojima je razvijena automobilska industrija u svijetu, a te zemlje su: Sjeverna Amerika (USA, Kanada, Meksiko), Njemačka, Japan, Rep.Koreja i Kina.



a – zastupljenost robota b- proizvodnja vozila

Slika 4. *Ukupna zastupljenost industrijskih robota u automobilskoj industriji u zemljama Sjeverna Amerika(USA,Kanada,Meksiko), Njemačka,Japan, Rep.Koreja i Kina, i proizvodnja vozila u navedenim zemljama [4-7]*

Dolazimo do zaključka na osnovu slike 4.a) da je Japan bio prva zemlja u svijetu po broju zastupljenih robota u automobilskoj industriji sve do 2014.godine, a trend je u padu u zadnjim godinama. Od 2014.godine na prvom mjestu po zastupljenosti industrijski robota je Sjeverna Amerika (USA,Kanada,Meksiko). Ovdje moramo izdvojiti Kinu koja je 2010.godine bila posljednja u odnosu na navedene zemlje po zastupljenosti industrijskih robota u automobilskoj industriji, a trend primjene u posljednjih šest godina kreće se po eksponencijalnoj funkciji i u 2016.godini dolazi na prvo mjesto sa zastupljenosti oko 117.400 jedinica robota. Ovaj trend je logičan ako analiziramo proizvodnju vozila u ovim zemljama slika 4.b) , gdje je Kina ostalno na prvom mjestu. Na drugom mjestu po proizvodnji vozila je Sjeverna Amerika (USA,Kanada,Meksiko), a na trećem mjestu je Japan. U automobilskoj industriji instalirani su industrijski roboti prve generacije koji su ogradama odvojeni od radnika u proizvodnom procesu. Kao što smo već vidjeli razvijeni su roboti druge generacije koji mogu da izvode radne zadatke skupa sa radnicima, a u narednom periodu će

komunicirati sa radnicima [10-14] . Prednosti kolaborativnih robota u odnosu na industrijske robote prve generacije su mnogobrojene a neke su:

- prilikom podjele zadataka između robota i radnika imamo poboljšanje performansi,
- moguće je automatizirati proizvodni proces gdje se do sada to nije moglo izvesti, kada je automatizacija kompleksna, ili nije ekonomična za instaliranje industrijski roboti prve generacije,
- uloga kolaborativnih robota je jako značajna kod povezivanja realnog proizvodnog procesa sa virtualnom stvarnošću, drugim rječima imaju najznačajniju ulogu u primjeni i realizaciji »Industrije 4.0«.
- primjenom kolaborativnih robota krutu automatizacije pretvaramo u fleksibilnu, što je cilj svake kompanije iz razloga što se smanjuje životni ciklus proizvoda, a isto tako se povećava raznovrsnost proizvoda,
- smanjenje operativnih troškova,
- smanjenje kapitalnih troškova,
- poboljšanje kvaliteta proizvoda i konzistentnosti,
- poboljšati kvalitet rada za radnike, poštujući pravila o zdravlju i bezbednosti,
- povećanje stope proizvodnje,
- povećanje fleksibilnosti u proizvodnji proizvoda,
- ušteda radnog prostora, itd.

Imajući u vidu sve prednosti kolaborativnih robota automobilska industrija je ta koja će prva realizirati primjenu u svojim proizvodnim procesima jer svakoj kompaniji koja proizvodi vozila donosi niz prednosti koje smo već nabrojali.Vodeći računa o cijeni i jenostavnom programiranju i reprogramiranju kolaborativnih robota za izvođenje različitih operacija, mogućnost dobijaju male i srednje kompanije za implementirati ovih robota. U budućnosti je očekivati za povećanjem zastupljenosti kolaborativnih robota u proizvodnim procesima u automobilskoj industriji prije svega, a također i u ostalim industrijskim granama.

3 ZAKLJUČCI

Na osnovu izvedene analize možemo da zaključimo da je trend primjene robota u svijetu rastući svake godine. Isto tako trend primjene industrijskih robota u automobilskoj industriji je rastući svake godine, sa očekivanjem da će se zastupljenost robota povećavati jer se povećava proizvodnja vozila u svijetu i zemljama u kojima je razvijena automobilska industrija. Razvoj naprednih tehnologija doprinio je razvoju kolaborativnog robota koji ima veliki broj prednosti u odnosu na industrijskig robota prve generacije. U radu su navedene prednosti kolaborativnih robota, a zbog niza prednosti doći će do veće zastupljenosti kolaborativnih robota u prizvodnim procesima u automobilskoj industriji, bilo u izvođenju novih zadataka, gdje se nisu mogli primjeniti roboti prve generacije, bilo da se vrši zamjena industrijskih robota prve generacije sa kolaborativnim robotima. Trend primjene kolaboratinih robota u budućnosti se očekuje rastući u svim industrijskim granama, a na prvom jestu je automobilska industrija.

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AN APPLICATION OF FOUR ROBOTS AND AN INTELLIGENT CONVEYER SYSTEM FOR AUTOMATED FIXTURING IN MACHINING

Uros Zuperl[1]

Abstract: This paper presents an application of four industrial robots and an intelligent logistic transport system for assembling and transporting fixtures during the realization of the fully automated fixture system. By using hand terminals and vision system, the machine tool operator can communicate with robots and order the appropriate fixture with clamped workpiece. The fully automated fixture system includes a clever transport system Montrac with the new Chaos technology that ensures that the right assembled fixture is delivered to the right machine tool. The automated fixture system demonstrates how efficient and safe the applications of industrial robots and logistic without centralized control system can be.

Key words: Chaos technology, Fixtures, Industrial robots, Machining, Transport system

1 INTRODUCTION

In this contribution a fully automated fixturing system developed for machining operations is presented. The fixturing system consists of two robot cells, an intelligent transport system for delivering assembled fixtures with the clamped workpiece to the machine tools, four order terminals and main control unit [1]. The schematic structure of the whole system is shown on Fig. 1. The robots in the first cell are used for assembling the fixtures on the machine tool operator demand while the robots in second cell are used for inserting and clamping workpiece in the assembled fixture. A clever transport system based on Chaos Technology ensures that the right fixture is transported to the right machine tool. By using four order touch screen terminals, the machine tool user can order the appropriate modular fixture, and required workpiece. The order is sent to the main computer (soft PLC) via Profibus. The main computer ensures the optimal coordination and communication between all units. The transport system is connected to main PLC via serial communication.

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2 FIXTURE ASSEMBLY CELL

The fixture assembly cell consists of two Epson E2S551S scara-robots, controller RC 420, grippers GPL-40-1 and the rack storage system with modular fixturing components. The modular fixtures are assembled by two Epson robots. The modular fixture components are taken from the automated storage system. As soon as the fixture component is in the griper, it is placed on a fixture base plate. The next step is to add the other components from the storage system and to integrate then to the fixture. As soon as the fixture is assembled the storage system calls and waits for the transport shuttle to pass in order to place the assembled fixture into the steel fitting. The fixture assembly cell and the pneumatic cylinders from the storage system are controlled by the main computer. The pneumatic valves, sensors and the robots are wired to a Profibus I/O block. The capacity of this cell is to assemble 4 modular fixtures per hour.

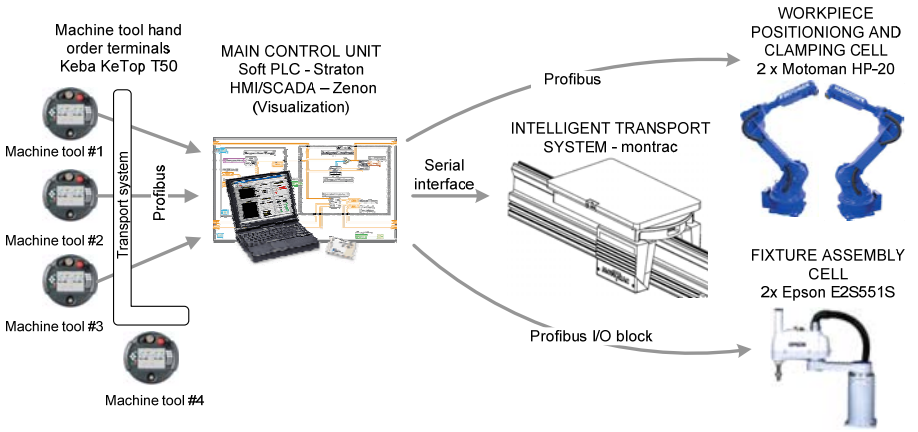


Figure 1. *Schematic structure of the fully automated fixturing system for machining operations*

3 THE WORKPIECE POSITIONING AND CLAMPING CELL

The workpiece positioning and clamping cell consists of two industrial robots Motoman HP-20 6 controlled by Nx-100 controller with direct connection to the pneumatic valves and sensors. Communication with the main control unit is achieved by Profibus. Based on the order of the machine tool user, the first robot picks the workpiece from the second storage system. The second storage system stores the raw material for machining and semi-finished workpieces. Then the first robot passes the workpiece to the other robot, so the first robot is able to hold the clamping element of the assembled fixture. Then the second robot positions the workpiece and inserts it into the fixture. The inductive sensors check if the workpiece has been inserted properly. If the workpiece was not positioned in the first attempt, the robot tries to position it again. During this operation the first robot cleans the fixture with the compressed air. As soon as the workpice is properly inserted into the fixture, the first robot engages the pneumatic clamping elements according to the defined plan. The assembled fixture with the clamped workpieces is then placed into the steel fitting on the shuttle. Next, the workpiece stability is mechanically checked and the cell transports the shuttle to the appropriate machine tool. Finally the shuttle is released, so it can deliver the completed fixture to the terminal where the order was made [2]. The capacity of this cell is 20 fixtures per hour.

4 INTELLIGENT TRANSPORT SYSTEM

The assembled fixture is transported to the right machine tool user by an intelligent conveyer system Montrac. This system is linked to the main control unit by a serial interface. It works without any controls thanks to the new Chaos Technology. It has the following advantages over traditional classical conveyor systems [3]:

- Simplicity; It is comprised of very few components, making design and assembly easy. The components are quick to assemble. The exclusive use of electronic components eliminates the need for pneumatic connections and complicated wiring. Chaos Technology greatly reduces the cabling and programming. The greatest benefit of this simplicity is not only during assembly but also when changing or expanding the whole system.
- Flexibility; The conveyer system is especially well suited for chaotic manufacturing, planned expansion, phased integration, short product life, and many other applications that are not generally considered suitable for transport systems. The transport system is flexible and it can be expanded, modified or adapted to different system configurations almost effortlessly. It has modular construction with very few interchangeable mechanical parts, so it can easily be reconfigured. Curves have a tight radius so that system can fit in small spaces and manoeuvre around obstacles.
- Reliability; A shuttle can always be removed and additional shuttles can be added. The Trac itself is a passive element and not subject to failure. The shuttle was designed to be maintenance free.
- No Maintenance; The transport system requires absolutely no maintenance! Mechanical components constitute a tiny portion of the overall system and are very robust. The track itself is a passive element and is not subject to wear. The shuttle is self-propelled by a brushless DC motor. All bearings are sealed and lubricated for life. Modular design means that the unlikely minor repair can be made easily.
- Efficiency; System consumes 95% less electricity and no compressed air when compared to traditional systems. The simplicity of conveyer system means considerably less time spent designing, installing, and programming.
- Travel time becomes production time; Montrac system can be upgraded with an additional current collector on the shuttle that can supply 3 A at 24 VDC to the product. This opens up the possibility of processing the product while it is in transit [5].

Montrac virtually excludes the possibility of a system failure [4]. Montrac is an efficient solution for complex and expandable machining systems, but it is also competitive in smaller/simpler layouts.

When machining a variety of products, some process may be common to all products while other processes are dedicated to a specific product. It may also be that different products require processes in different order. This makes writing a centralized control program nearly impossible. With Chaos Technology, products can easily navigate through chaotic production processes without a centralized control system. This is the main reason why the Montrac transport system is used for this project. Chaos Technology is based on the simple principal that, upon completing a process, that process station (Fixture assembly cell and Workpiece positioning and clamping cell) communicates to the shuttle what the next process station will be. At each place that a routing decision needs to be made, the Trac asks the shuttle where it is headed and directs it accordingly to pneumatically controlled turnouts. In addition to providing chaotic

routing capability, Chaos Technology reduces the need for I/O hardware, programming, and cabling; and localized controls make the system easy to reconfigure**.**

5 MAIN CONTROL UNIT AND ORDER TERMINALS

The task of the main control unit is to manage the orders from the machine tool users, to control the valves of the both cells and to visualize the error codes from both cells and the conveyor system [6]. The main control unit is a Windows based PC with installed Zenon and Straton software. The Straton works as a soft PLC, while the Zenon 6.2 SP3 is used for process visualization. Zenon is a HMI/SCADA (Human-Machine-Interface/ Supervisory Control and Data Acquisition) software.

The fixture order can be performed on four touch-screen terminals KeTop T50. They are used as order terminals. The order is then sent to main control unit via Profibus.

6 CONCLUSION

In this paper the fully automated fixturing system developed for milling operations is presented. The automated fixturing system was successfully tested in industrial environment, where it has shown that the industrial robots with an intelligent transport system can be successfully, efficiently and safely used in automated fixture assembling and transporting process. The robots were assembling and transporting the fixtures to the 4 machine tools with 22 different kinds of fixtures. Extensive testing confirms that the automated fixturing system has a capacity of 4 fixtures per hour. The main effort during realization of the project was how to achieve efficient and reliable communication between the two robot cells, transport system and order/hand terminals. The innovation of this project is also the design and optimization of fixture transport logistic.

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APPLICATION OF MODERN TECHNOLOGY FOR INCREASING EXPERTISE OF EMPLOYEES IN MECHANICAL INDUSTRY

Ivan Palinkas[1], Jasmina Pekez[2], Eleonora Desnica[3], Ljiljana Radovanovic[4]

Abstract: In this paper it is shown the possibility of CAD/CAM application in order to educate employees in area of machining and design of mechanical parts. Practical example is done in order to show the way of usage and path for further development.

Key words: CAD/CAM tools, education, machining, design

1 INTRODUCTION

The process of creating goods and/or services through a combination of material, work, and capital is called production.[1]

Production system is often used as synonymous with manufacturing system and assembly system. Other notions used to describe different types and sizes of production systems are line, factory, plant and workshop.[1]

In hierarchy perspective production system is part of manufacturing system and parts production and assembly systems are part of production system. Basic elements in production systems are humans, machines and equipment. Software and procedures might be added to the list. [2,3]

Today, computers are integral component of almost every system. Modern production can`t function without them. The vast types of software are beeing used to make production better, cheaper, simpler and more effective in every aspect – from organization to technical aspects of making parts and assemblies.

In order to be competitive on market, besides improving technology, we need to improve knowledge of employees.

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2 CAD/CAM TECHNOLOGIES AND APPLICATION

Computer-aided design (CAD) and Computer-aided manufacturing (CAM) are two disciplines, of many, that are used by engineers and designers in wide variety of applications. CAD activities are a part of integrated management of development activities in the product lifecycle, and as such it is used with other parts, such as CAM, that can be as integrated modules or stand-alone products.[4]

In production, CAD softwares are used to model parts, to make technical documentation and to make assembly of parts for better understanding of machine design. CAM softwares are used for connecting design and production of workpiece. That is one of the application. They can also be used to assist in all operations of manufacturing plant (management, transportation, etc). [5]

Today, successful companies are using integrated CAD/CAM systems to quickly place the product in market and reduce costs.

The interest of this paper are CAM softwares for manufacturing workpiece, from CAD 3D model using CNC machines and that interest will be explain in further text.

Nevertheless, CAD design must be mentioned here in order to complete the process. It is not possible to use CAM software without created 3D model of part. The software used here is Inventor and InventorCAM. Autodesk Inventor and InventorCAM represent CAD/CAM software tools used in:

1. parametric modeling, animation assemblies created from individual parts, creating technical documentation (Inventor).

Parametric modeling helps designers to present their idea as a 3D model. The model is created based on the geometrical design features that can change at any time for necessary corrections in the design process.

2. Implementation of 3D models into production (software prepares 3D models for physical processing, generating G code used for programming CNC machines) (InventorCAM).

InventorCAM is a certified integrated CAM engine for Inventor that has full connectivity with the model in Inventor. InventorCAM is used in the mechanical manufacturing, electronic, medical and consumer products, machine design, automotive and aerospace industries, as well as workshops for the manufacture of molds, tools and rapid prototyping.

3 APPLICATON OF CAD/CAM TECHNOLOGIES IN EDUCATION OF ENGINEERS

Today there are numerous methods for learning how to work in CAD/CAM softwares. One of the example are functions embeded in Autodesk Inventor (Fig. 1):

- Online Support – represents online material in order do learn how to use Autodesk Inventor. Some of online material can be downloaded for offline usage.
- Interactive Learning – is series of video tutorial made for learning basics of Autodesk Inventor. Using this tutorials, users can view step-by-step examples for part modeling, creating assemblies, creating technical documentation and sheet metal working.

Using this principles, and CAD/CAM software, tutorial has been made in order to present machining of pump gasket. The purpose of this tutorial is to show a different way for exchange of knowledge between mechanical engineers for machining process.

In order to increase knowledge of engineer, tutorial of this type can be used to show them step-by-step machining of specific part that is needed in production. In that way the production technology of machine part can be presented and explained in detail. The goal is improwing engineers expertise, transfer of knowledge and, in the end better usage of available resources in production. The parts of tutorial are shown in figures 2-10.

Similar tutorial has been used to show faculty students what are the steps in machining of one part, and different machining technologies in order to improve the quality of education [6,7].



Figure 1. *Different methods for learning functionality of Autodesk Inventor software*

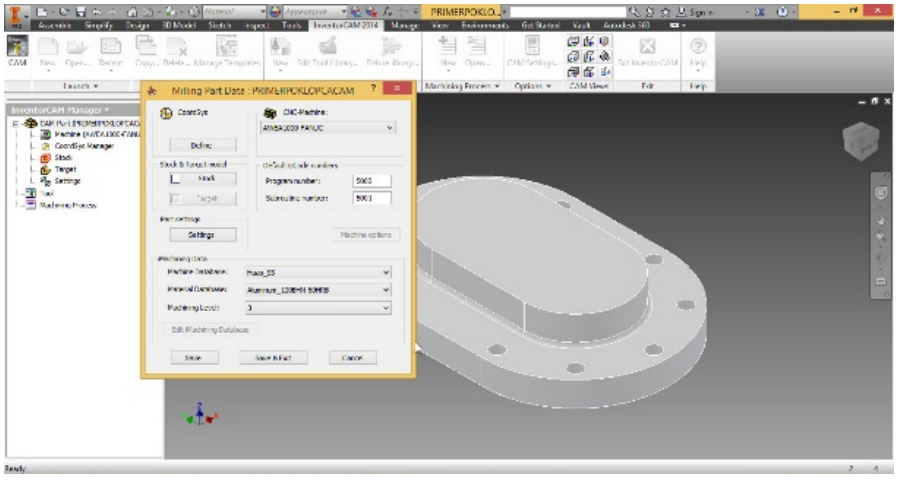


Figure 2. *Settings of machining initial parameters*

Figure 2. represents the begining of part production. The first step is, after modeling the required part, importing the model in InventorCAM module and definining the appropriate CNC machine and adjusting the coordinating system and part orientation.

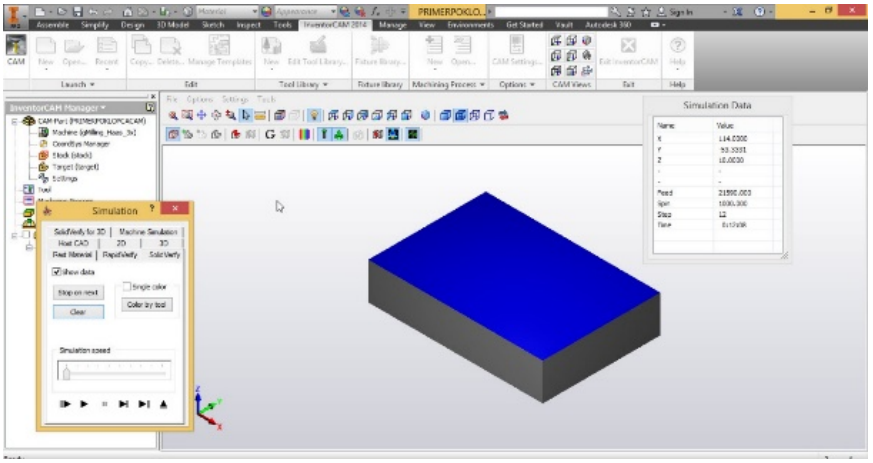


Figure 3. *Face Mill simulation of upper surface*

Figure 3. shows the next operation in machining of pump gasket, and that is the face miling of outside surface. The figure shows the animation of operation after the settings of operational parameters (the beginning position of tool, the type of tool and its characteristics, the tool path). After those settings, software have the possibility to animate the operation in which can be determined the errors of settings and visualy see the operation (without direct operation on CNC machine).

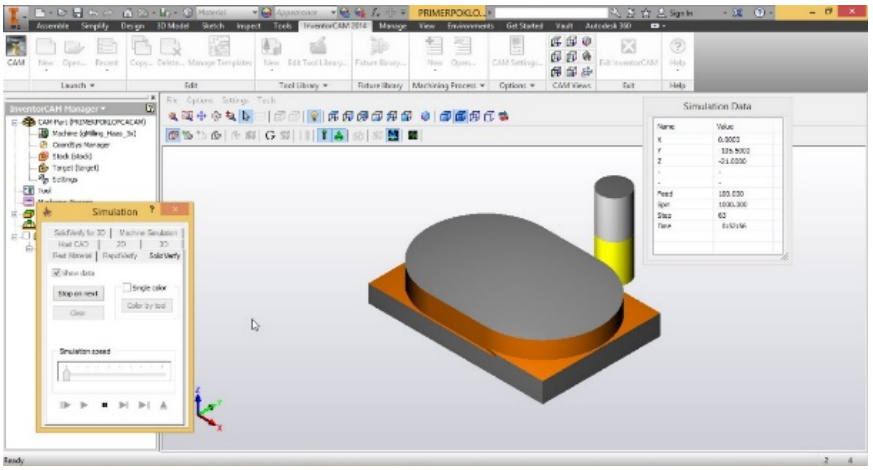


Figure 4. *Simulation of profile milling of outer side*

The next operation is profile milling of outer side (fig. 4). Like the operation of face milling in this operation we also need to set operational parameters. The difference between these two operations, from the software point of view, is that it needs to be defined what is the type of milling (or machining operation) that is applying

on part. The same procedure is used for milling of upper part in order to achieve the shape op gasket (fig. 5).

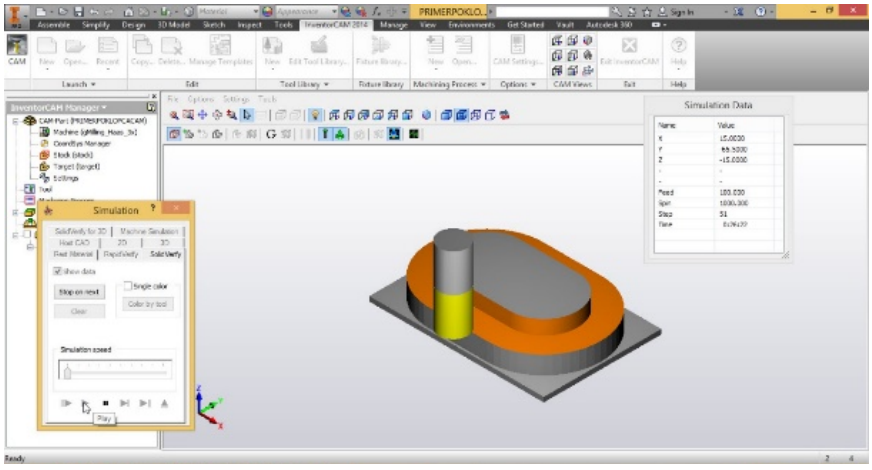


Figure 5. *Simulation of profile milling of outer, upper side*

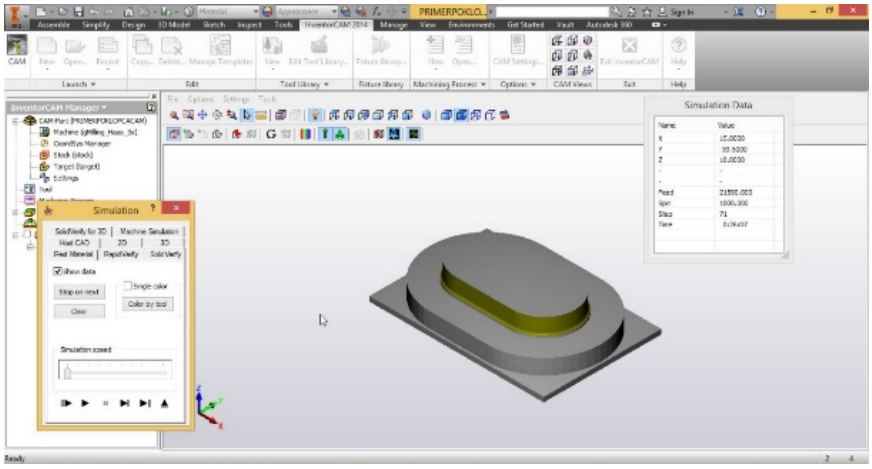


Figure 6. *Simulation of milling of upper curve between two surface*

In order to produce the curve between two oval shapes, the operation of profile milling is applied to get the fine surface and required shape (fig 6.).

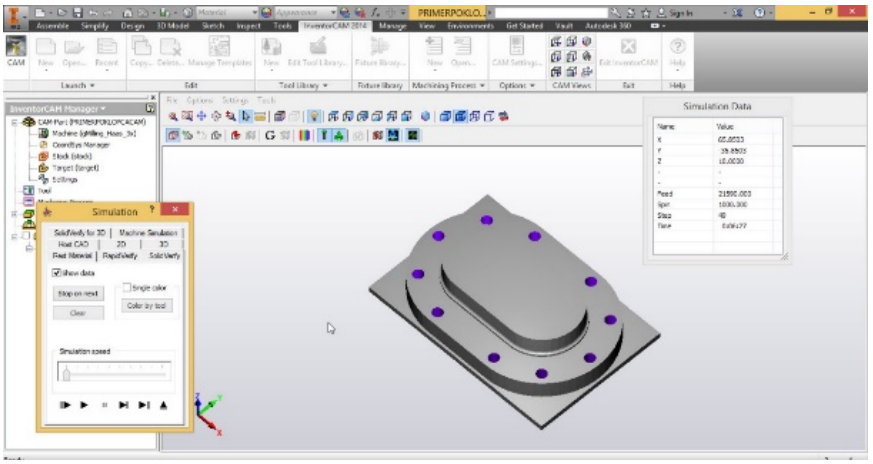


Figure 7. *Simulation of drilling through workpiece*

On figure 7. is the last operation that needs to be done from that side of part, the drilling of holes used to connect the gasket to the pump using screws. For this it needs to be defined the charactersitics of tool and the order of holes. When the drilling is finished the part needs to be repositioned (in this case turned over) and new coordinate system needs to be defined for the definition of space (fig. 8.).

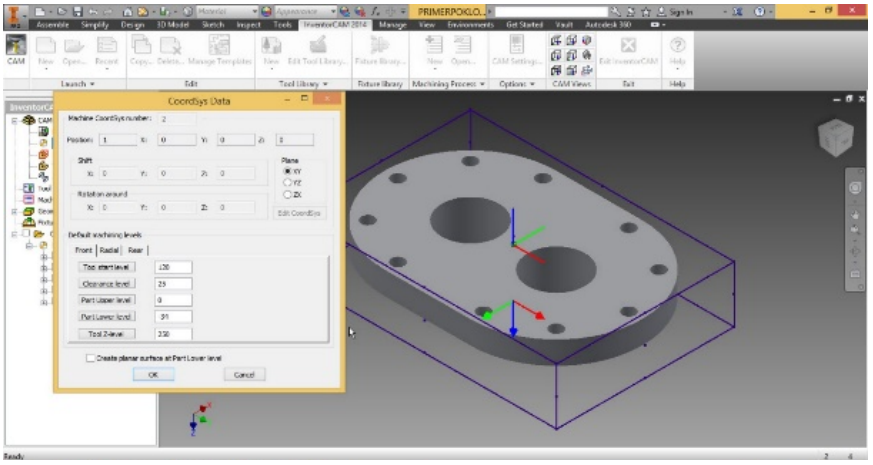


Figure 8. *Changing of view and defining new coordinate system for machining*

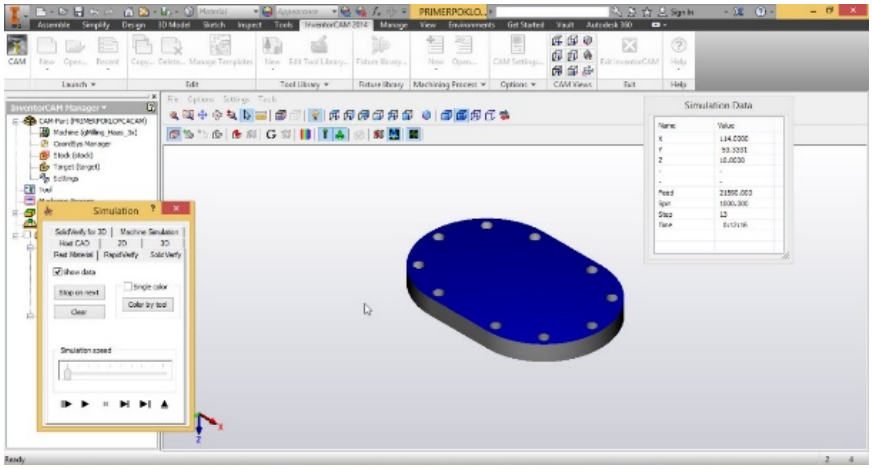


Figure 9. *Face milling of bottom surface*

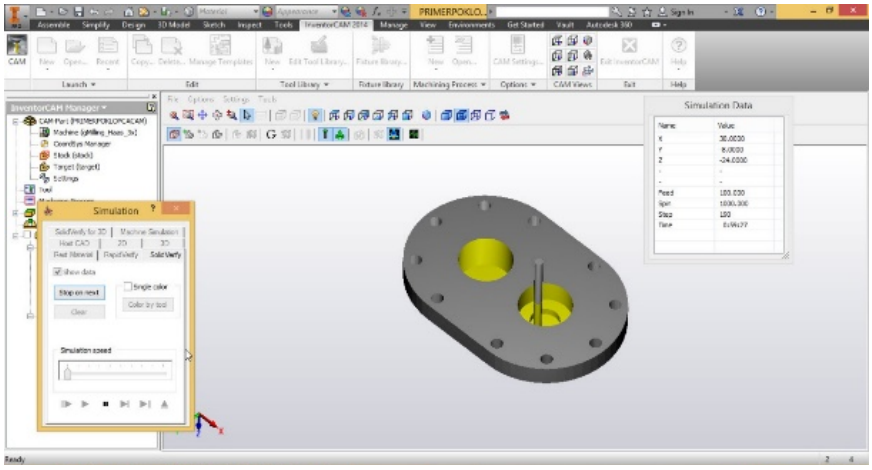


Figure 10. *Pocket milling*

Figure 9. and 10. presents the final two operations, the face milling of inner surface of gasket and the pocket miling of inner openings.

The information and benefits of this types of tutorial are:

- Visual – complete 3D view of part, views from beginning to the end of machining, view of tool movement in process, information of type of tool and its characteristics, information on CNC machine that is used. It can even be seen possible errors in initial setings or tool settings
- Data – G – code can be presented for complete part machining.

All above informations presents valuable information in production, and can be used for education of engineers, for learning different production technologies in machining, for speeding up production process and better usage of raw material.

4 CONCLUSION

Improvement of production must be reflected in the improvement of production technology solutions, improvement of tools and improvement of the expertise of employees.

In this paper it was presented possible use of CAD/CAM software in knowledge exchange between engineers. The education can be through seminars, small courses, or online materials.

The benefits of these tutorials are:

- Constant learning and implementation of practical knowledge,
- Better usage of companies resources,
- Quicker adjustments of new engineers in their working places, and better understanding of specifics production technologies,
- Upgrade of production technologies by knowledge exchange.

This way of learning can be implemented through lifelong learning, not so much in areas of communication with others, but in two segments:

- *Learning to know* - mastering learning tools rather than acquisition of structured knowledge.
- *Learning to do* – equipping people for the types of work needed now and in the future including innovation and adaptation of learning to future work environments.

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INVESTIGATION OF VIBRATION RESPONSE OF ORTHOTROPIC DOUBLE-NANOPLATE SYSTEM SUBJECTED TO INITIAL IN-PLANE PRELOAD

Nebojša Radić[1], Dejan Jeremić[2]

Abstract: Analytical methods are employed and explicit solutions for vibrational frequency are obtained for orthotropic double-nanoplate system subjected to an in-plane magnetic field for various boundary conditions. The nonlocal governing equations of motion are derived via Hamilton's principle with the consideration the Eringen's differential nonlocal elastic law. Effects of initial preload (compression and tension), magnetic field strength, size of nanoplate, and boundary conditions on vibrational frequency are presented.

Key words: Graphene, Initial preload, Magnetic field, Nanoplate, Nonlocal elasticity, Vibration

1 INTRODUCTION

Carbon nanotube (CNT) and graphene sheet (GS) have a great perspective to be applied in medicine, astronautics and energy storage systems. For a successful application of GS as a nanostructural component and a nanomaterial it is very important to know its vibrational behaviour. Experimental and molecular dynamic simulation (MD simulation) show that in nanostructural elements with very small dimensions their mechanical properties and behaviour change when these dimensions become very small. Due to very small dimensions of nanoplates, it is necessary to take into account the influence of atomic forces to their mechanical behaviour. The application of MD simulation is too complex and expensive, especially in the case of more complex nanostructures with a greater number of atoms. Because of that, a few classical continuum theories have been developed in which the small-scale size effect has been incorporated into constitutive equations and governing equations of motion/equilibrium. There belong the nonlocal elasticity theory [1-4], strain gradient theory [5,6] and couple stress theory [7,8]. The effect of in-plane preload on vibrations of nanoplate via nonlocal elasticity was investigated by Murmu and Pradhan [9]. Kiani [10] applied the nonlocal shear deformation theory to investigate the vibration of double-walled carbon nanotubes

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on elastic foundation subjected to axial preload. Mohammadi et al. [11] investigated the free vibration behaviour of circular graphene sheet under in-plane preload using nonlocal continuum theory. In recent time, double-layered nanoplate structures have been in the focus of research more. Radić and Jeremić [12] researched the nonlocal vibration and buckling of orthotropic double-layered graphene sheets with different boundary conditions subjected to hygrothermal loading using nonlocal elasticity theory and Galerkin's method.

When a nanostructure is exposed to the activity of magnetic field, then, as the consequence of the activity, Lorentz's forces occur, which are the body forces and act to every elementary particle of that structure. In the absence of experimental research on the influence of Lorentz's forces to the vibration and buckling behaviour of nanoplates, a great significance is given to the theoretical research based on Maxwell's equations. Güven [13] studied the effects of longitudinal magnetic field and initial stress on the transverse vibration of single-walled carbon nanotubes. Murmu et al. [14] examined vibration behaviour of double-walled carbon nanotubes subjected to a longitudinal magnetic field using a nonlocal Euler-Bernoulli beam theory. Kiani [15] investigated the vibration and instability of a single-walled carbon nanotube in a three-dimensional magnetic field using nonlocal Rayleigh beam theory. Transverse vibration behaviour of embedded single-layer graphene sheets exposed to in-plane magnetic field with simply supported boundary conditions is analysed by Murmu et al. [16]. Kiani [17] presented free vibration behaviour of single-layer nanoplates subjected to in-plane magnetic field with simply supported boundary conditions using nonlocal shear deformable plate theories. Vibration behaviour of double bonded orthotropic graphene sheets subjected to 2D magnetic field and biaxial in-plane preload using differential quadrature method was investigated by Ghorbanpour Arani et al [18]. Karličić et al. [19] investigated the nonlocal vibration of multi-nanoplate system embedded in viscoelastic medium under in-plane magnetic field. Transverse vibration analysis of the orthotropic DLGSs subjected to in-plane magnetic and initial in-plane preload with various boundary conditions has not been covered using nonlocal continuum mechanics until now.

In the present paper, using differential nonlocal elastic law we study the influence of a unidirectional in-plane magnetic field and initial in-plane preload on the vibration behaviour of DLGS. The governing equations of motion are derived based on new first-order shear deformation theory (NFSDT), Eringen's differential nonlocal elastic law and the Hamilton's principle. Analytical solution for frequency is based on functions which satisfy different boundary conditions.

2 PROBLEM FORMULATION

DLGS which consists of two layers of graphene sheets (GS_1 and GS_2), with length a, width b and thickness h embedded in Pasternak foundation subjected to in-plane magnetic field H_x has been illustrated in Fig.1.

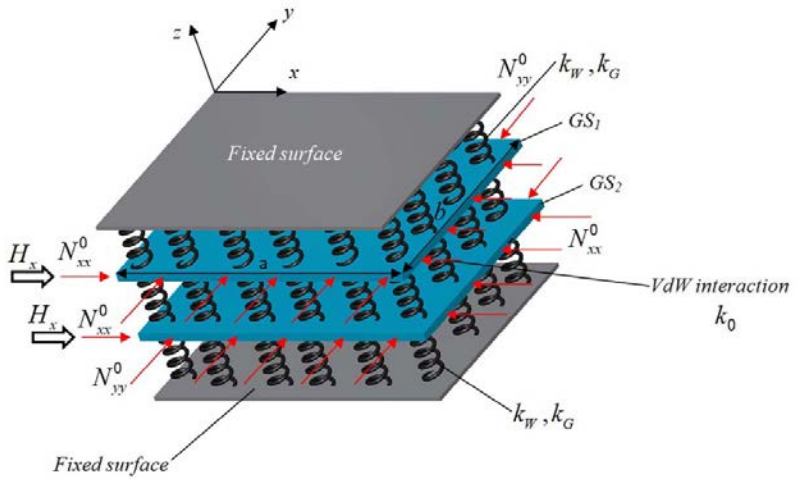


Figure 1. *Geometry, coordinate system and loading for orthotropic double-layered graphene sheet*

GS_1 and GS_2 are in the interaction by van der Waals (vdW) interaction forces shown by a set of springs with modulus k_0. Two sheets are surrounded by an external Pasternak elastic medium, where k_w and k_G are Winkler modulus parameter and shear modulus parameter respectively. As depicted N^0_{xx} and N^0_{yy} denote two uniform preload forces in the *x* and *y* directions. The material characteristics used for both graphene sheets are identical.

2.1 The new first-order shear deformation theory (NFSDT)

According to the new first-order shear deformation theory, the displacement field of the graphene sheet is expressed by

$$\begin{aligned} u_x(x,y,z) &= u(x,y) - z\frac{\partial \phi}{\partial x} \\ u_y(x,y,z) &= v(x,y) - z\frac{\partial \phi}{\partial y} \\ u_z(x,y,z) &= w(x,y) \end{aligned} \tag{1}$$

where u and v are the displacement of mid-plane along *x*- and *y*-axis respectively, w is transverse displacement of a point on the mid-plane of the graphene sheet, and ϕ is rotation parameter.

Nonzero strains of the NFSDT model are expressed as

$$\begin{Bmatrix}\varepsilon_{xx}\\ \varepsilon_{yy}\\ \varepsilon_{xy}\end{Bmatrix}=\begin{Bmatrix}\dfrac{\partial u}{\partial x}\\ \dfrac{\partial v}{\partial y}\\ \dfrac{\partial u}{\partial y}+\dfrac{\partial v}{\partial x}\end{Bmatrix}-z\begin{Bmatrix}\dfrac{\partial^2\theta}{\partial x^2}\\ \dfrac{\partial^2\theta}{\partial y^2}\\ 2\dfrac{\partial^2\theta}{\partial x\partial y}\end{Bmatrix},\begin{Bmatrix}\varepsilon_{yz}\\ \varepsilon_{xz}\end{Bmatrix}=\begin{Bmatrix}\dfrac{\partial w}{\partial y}-\dfrac{\partial\theta}{\partial y}\\ \dfrac{\partial w}{\partial x}-\dfrac{\partial\theta}{\partial x}\end{Bmatrix} \tag{2}$$

2.2 Nonlocal governing equations of motion

In the present paper, we consider a uniaxial magnetic field. Therefore, the effective Lorenz forces in the direction of z axis can be written as [20].

$$F_z=\int_{-h/2}^{h/2}f_z dz=\eta h H_x^2\left(\frac{\partial^2 w}{\partial x^2}-\frac{\partial^2\theta}{\partial y^2}\right) \tag{3}$$

In this study only the transverse vibrations of the DLGS are significant.

For this case, the equations that correspond to the in-plane displacements $(\delta u_1,\delta v_1)$ are not coupled with the equations that correspond to the displacements due to bending. If we apply the operator $\Re=1-(e_0\ell)^2\nabla^2$ equations of motion can be expressed via the displacement (w_1,ϕ_1)

$$\begin{aligned}&H_{55}\left(\frac{\partial^2 w_1}{\partial x^2}-\frac{\partial^2\phi_1}{\partial x^2}\right)+H_{44}\left(\frac{\partial^2 w_1}{\partial y^2}-\frac{\partial^2\phi_1}{\partial y^2}\right)-k_w w_1+k_G\left(\frac{\partial^2 w_1}{\partial x^2}+\frac{\partial^2 w_1}{\partial y^2}\right)-k_0\left(w_1-w_2\right)-\\&-N_{xx}^0\frac{\partial^2 w_1}{\partial x^2}-N_{yy}^0\frac{\partial^2 w_1}{\partial y^2}+\eta h H_x^2\left(\frac{\partial^2 w_1}{\partial x^2}-\frac{\partial^2\phi_1}{\partial y^2}\right)-\\&-\left(e_0\ell\right)^2\left[-k_w\left(\frac{\partial^2 w_1}{\partial x^2}+\frac{\partial^2 w_1}{\partial y^2}\right)+k_G\left(\frac{\partial^4 w_1}{\partial x^4}+2\frac{\partial^4 w_1}{\partial x^2\partial y^2}+\frac{\partial^4 w_1}{\partial y^4}\right)\right]\\&+\left(e_0\ell\right)^2 k_0\left(\frac{\partial^2 w_1}{\partial x^2}+\frac{\partial^2 w_1}{\partial y^2}-\frac{\partial^2 w_2}{\partial x^2}-\frac{\partial^2 w_2}{\partial y^2}\right)+\left(e_0\ell\right)^2 N_{xx}^0\left(\frac{\partial^4 w_1}{\partial x^4}+\frac{\partial^4 w_1}{\partial x^2\partial y^2}\right)\\&+\left(e_0\ell\right)^2 N_{yy}^0\left(\frac{\partial^4 w_1}{\partial y^4}+\frac{\partial^4 w_1}{\partial x^2\partial y^2}\right)-\left(e_0\ell\right)^2\eta h H_x^2\left[\left(\frac{\partial^4 w_1}{\partial x^4}+\frac{\partial^4 w_1}{\partial x^2\partial y^2}\right)-\left(\frac{\partial^4\phi_1}{\partial y^4}+\frac{\partial^4\phi_1}{\partial x^2\partial y^2}\right)\right]=\\&=\rho h\ddot{w}_1-\left(e_0\ell\right)^2\rho h\left(\frac{\partial^2\ddot{w}_1}{\partial x^2}+\frac{\partial^2\ddot{w}_1}{\partial y^2}\right)\end{aligned} \tag{4}$$

$$\begin{aligned}&D_{11}\frac{\partial^4\phi_1}{\partial x^4}+2\left(D_{12}+2D_{66}\right)\frac{\partial^4\phi_1}{\partial x^2\partial y^2}+D_{22}\frac{\partial^4\phi_1}{\partial y^4}+H_{55}\left(\frac{\partial^2 w_1}{\partial x^2}-\frac{\partial^2\phi_1}{\partial x^2}\right)+\\&+H_{44}\left(\frac{\partial^2 w_1}{\partial y^2}-\frac{\partial^2\phi_1}{\partial y^2}\right)=\frac{\rho h^3}{12}\left(\frac{\partial^2\ddot{\phi}_1}{\partial x^2}+\frac{\partial^2\ddot{\phi}_1}{\partial y^2}\right)-\left(e_0\ell\right)^2\frac{\rho h^3}{12}\left(\frac{\partial^4\ddot{\phi}_1}{\partial x^4}+2\frac{\partial^4\ddot{\phi}_1}{\partial x^2\partial y^2}+\frac{\partial^4\ddot{\phi}_1}{\partial y^4}\right)\end{aligned} \tag{5}$$

Eqs. (4) and (5) are related to GS_1. In the same way the equations of motion for GS_2 are obtained.

$$
\begin{aligned}
&H_{55}\left(\frac{\partial^2 w_2}{\partial x^2}-\frac{\partial^2 \phi_2}{\partial x^2}\right)+H_{44}\left(\frac{\partial^2 w_2}{\partial y^2}-\frac{\partial^2 \phi_2}{\partial y^2}\right)-k_W w_2+k_G\left(\frac{\partial^2 w_2}{\partial x^2}+\frac{\partial^2 w_2}{\partial y^2}\right)+k_0\left(w_1-w_2\right)+\\
&-N_{xx}^0\frac{\partial^2 w_2}{\partial x^2}-N_{yy}^0\frac{\partial^2 w_2}{\partial y^2}+\eta h H_x^2\left(\frac{\partial^2 w_2}{\partial x^2}-\frac{\partial^2 \phi_2}{\partial y^2}\right)-\\
&-\left(e_0\ell\right)^2\left[-k_W\left(\frac{\partial^2 w_2}{\partial x^2}+\frac{\partial^2 w_2}{\partial y^2}\right)+k_G\left(\frac{\partial^4 w_2}{\partial x^4}+2\frac{\partial^4 w_2}{\partial x^2\partial y^2}+\frac{\partial^4 w_2}{\partial y^4}\right)\right] \qquad (6)\\
&-\left(e_0\ell\right)^2 k_0\left(\frac{\partial^2 w_1}{\partial x^2}+\frac{\partial^2 w_1}{\partial y^2}-\frac{\partial^2 w_2}{\partial x^2}-\frac{\partial^2 w_2}{\partial y^2}\right)+\left(e_0\ell\right)^2 N_{xx}^0\left(\frac{\partial^4 w_2}{\partial x^4}+\frac{\partial^4 w_2}{\partial x^2\partial y^2}\right)\\
&+\left(e_0\ell\right)^2 N_{yy}^0\left(\frac{\partial^4 w_2}{\partial y^4}+\frac{\partial^4 w_2}{\partial x^2\partial y^2}\right)-\left(e_0\ell\right)\eta h H_x^2\left[\left(\frac{\partial^4 w_2}{\partial x^4}+\frac{\partial^4 w_2}{\partial x^2\partial y^2}\right)-\left(\frac{\partial^4 \phi_2}{\partial y^4}+\frac{\partial^4 \phi_2}{\partial x^2\partial y^2}\right)\right]=\\
&=\rho h\ddot{w}_2-\left(e_0\ell\right)^2\rho h\left(\frac{\partial^2 \ddot{w}_2}{\partial x^2}+\frac{\partial^2 \ddot{w}_2}{\partial y^2}\right)
\end{aligned}
$$

$$
\begin{aligned}
&D_{11}\frac{\partial^4 \phi_2}{\partial x^4}+2\left(D_{12}+2D_{66}\right)\frac{\partial^4 \phi_2}{\partial x^2\partial y^2}+D_{22}\frac{\partial^4 \phi_2}{\partial y^4}+H_{55}\left(\frac{\partial^2 w_2}{\partial x^2}-\frac{\partial^2 \phi_2}{\partial x^2}\right)+\\
&+H_{44}\left(\frac{\partial^2 w_2}{\partial y^2}-\frac{\partial^2 \phi_2}{\partial y^2}\right)=\frac{\rho h^3}{12}\left(\frac{\partial^2 \ddot{\phi}_2}{\partial x^2}+\frac{\partial^2 \ddot{\phi}_2}{\partial y^2}\right)- \qquad (7)\\
&-\left(e_0\ell\right)^2\frac{\rho h^3}{12}\left(\frac{\partial^4 \ddot{\phi}_2}{\partial x^4}+2\frac{\partial^4 \ddot{\phi}_2}{\partial x^2\partial y^2}+\frac{\partial^4 \ddot{\phi}_2}{\partial y^4}\right)
\end{aligned}
$$

The equations (4-7) present the equations of motion for orthotropic DLGSs.

3 SOLUTION BY GALERKIN'S METHOD

In this section, the equations of motion (4-7) are solved analytically using Galerkin's method to obtain the vibrational frequencies of the DLGSs subjected to in-plane preload. Before solving the equations of motion, the boundary conditions should be defined. In this study the graphene sheet is assumed to have simply supported (S), clamped (C) edges or have combinations of them. These boundary conditions are given as follows [12].

Simply supported (S):

$$
\begin{aligned}
&u_i=\frac{\partial \phi_i}{\partial y}=w_i=M_{xxi}=0, && \text{at } x=0,\mathrm{a}\\
&v_i=\frac{\partial \phi_i}{\partial x}=w_i=M_{yyi}=0, && \text{at } y=0,b;\ \ i=1,2 \qquad (8)
\end{aligned}
$$

Clamped (C):

$$
\begin{aligned}
&u_i=\frac{\partial \phi_i}{\partial x}=\frac{\partial \phi_i}{\partial y}=w_i=0, && \text{at } x=0,\mathrm{a}\\
&v_i=\frac{\partial \phi_i}{\partial x}=\frac{\partial \phi_i}{\partial y}=w_i=0, && \text{at } y=0,b;\ \ i=1,2 \qquad (9)
\end{aligned}
$$

The analytical solutions for the vibrational frequency are obtained for two characteristics of the vibration cases.

3.1 Out-of-phase vibration

In this case, two graphene sheets vibration asynchronously and it means that there is a relative displacement between them $(w_1 \neq w_2)$. The equation (10) represent the value for the vibrational frequency for out-of-phase vibration

$$\omega_{out} = \sqrt{\frac{-A_4 + \sqrt{A_4^2 - 4A_1A_5}}{2A_1}} \tag{10}$$

where

$$\begin{aligned}
A_1 &= \frac{\rho^2 h^4}{12}\left(\gamma_4 - \mu^2\delta_1\right)\left(\delta_1 - \mu^2\delta_2\right)\\
A_4 &= \rho h\left(\gamma_4 - \mu^2\delta_1\right)\left(B_3 - B_2\right) + \frac{\rho h^3}{12}\left(\delta_1 - \mu^2\delta_2\right)\left[P_3 + 2k_0\left(\mu^2\delta_1 - \gamma_4\right)\right]\\
A_5 &= P_3\left(B_3 - B_2\right) - B_2\left(B_4 - B_2\right) + 2k_0\left(\mu^2\delta_1 - \gamma_4\right)\left(B_3 - B_2\right)\\
P_1 &= k_w(\mu^2\delta_1 - \gamma_4) + k_G(\delta_1 - \mu^2\delta_2) + \eta h H_x^2\left[\gamma_1 - \mu^2(\gamma_3 + \gamma_6)\right]\\
\delta_1 &= \gamma_1 + \gamma_2\\
\delta_2 &= \gamma_3 + 2\gamma_6 + \gamma_5\\
B_2 &= H_{55}\gamma_1 + H_{44}\gamma_2\\
B_3 &= D_{11}\gamma_3 + 2(D_{12} + 2D_{66})\gamma_6 + D_{22}\gamma_5\\
B_4 &= \eta h H_x^2\left[\mu^2\left(\gamma_5 + \gamma_6\right) - \gamma_2\right]\\
P_3 &= P_1 + B_2 - N\left(\gamma_1 + k\gamma_2\right)\\
N_{xx}^0 &= N, \quad N_{yy}^0 = kN
\end{aligned} \tag{11}$$

3.2 In-phase vibration

In the case of in-phase vibration, two graphene sheets vibrate synchronously and it means that there is no relative displacement between them $(w_1 = w_2)$. The equation (12) represent the vibrational frequency for in-phase vibration

$$\omega_{in} = \sqrt{\frac{-A_2 + \sqrt{A_2^2 - 4A_1A_3}}{2A_1}} \tag{12}$$

where

$$\begin{aligned}
A_4 &= \rho h\left(\gamma_4 - \mu^2\delta_1\right)\left(B_3 - B_2\right) + \frac{\rho h^3}{12}\left(\delta_1 - \mu^2\delta_2\right)P_3\\
A_5 &= P_3\left(B_3 - B_2\right) - B_2\left(B_4 - B_2\right)
\end{aligned} \tag{13}$$

4 NUMERICAL RESULTS AND DISCUSSIONS

The material and geometrical properties of the orthotropic graphene sheet are adopted from papers [12,21] as follows : Young's modulus $E_1 = 1130\,GPa$ and

$E_2 = 1050\,GPa$ of the orthotropic graphene sheet, mass density $\rho = 2250 kg/m^3$, Poisson's ratio $\nu_{12} = 0.112$ and $\nu_{21} = 0.0803$, shear modulus $G_{12} = E_1/2(1+\nu_{12}) = 508.09\,GPa$ and $G_{13} = G_{23} = \frac{5}{6}G_{12} = 423.41 GPa$, thickness of graphene sheet $h = 0.34\,nm$. In the present study we have used the value for the magnetic field strength in the range $H_x = 0 \div 0.1251 A/nm$ and in the case of a square nanoplate with the dimensions $10\,nm$ it corresponds to the value of dimensionless magnetic parameter ($MP = \eta h H_x^2 \mathrm{a}^2 / D_{11}$) within the limits $0 \div 180$. Also, we have used the values $k_0 = 0.15\ GPa/nm$, $k_w = 0.075\ GPa/nm$, $k_G = 0.75\ N/m$, as in Ref. [12].

In the comparison study the following dimensionless parameters are used:

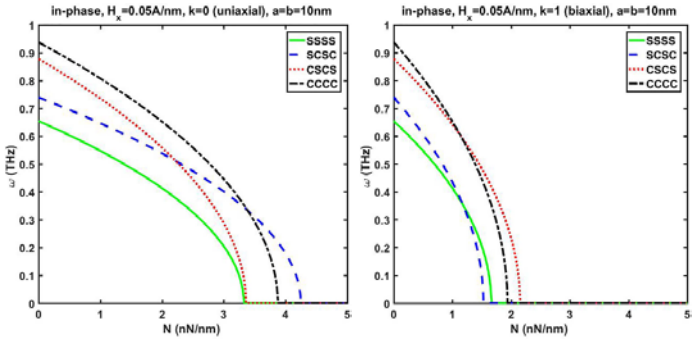
$$\omega_{N1} = \omega^2 \mathrm{a}^2 \sqrt{\frac{\rho h}{D_{11}}},\ \omega_{N2} = \frac{\omega^2 \mathrm{a}^2}{\pi^2}\sqrt{\frac{\rho h}{D_{11}}},\ k_{wN} = \frac{k_w \mathrm{a}^4}{D_{11}},$$

$$k_{GN} = \frac{k_G \mathrm{a}^2}{D_{11}},\ k_{0N} = \frac{k_0 \mathrm{a}^4}{D_{11}}, MP = \frac{\eta h H_x^2 \mathrm{a}^2}{D_{11}}$$

4.1 Parametric study

In this section, the effects of magnetic field strength, in-plane preload (compression and tension), various boundary conditions and size of nanoplate on the vibrational behaviour of DLGSs are discussed in detail.

Fig. 2(a) and (b) shows the variations of in-phase frequency with respect in-plane (uniaxial and biaxial) compression preload and various boundary conditions. The value of magnetic field strength is H_x=0.05 A/nm. In the case of uniaxial compression, the value of the frequency has the fastest decrease in the case of CSCS boundary conditions, and the slowest one in the case of SCSC boundary conditions.

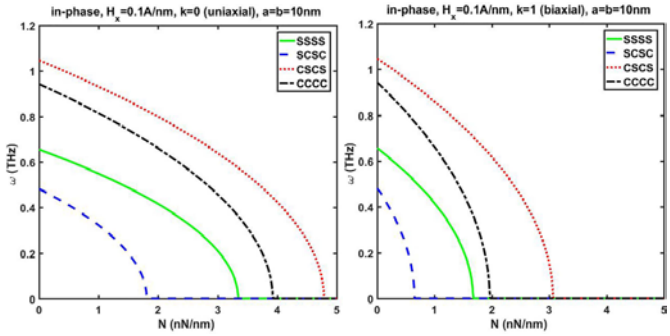


(a) *(b)*

Figure 2. *Change in in-phase frequency with respect to compression preload (uniaxial, biaxial) and various boundary conditions for magnetic field strength H_x=0.05 A/nm ($\mu = 1.345\,nm$)*

In the case of biaxial compression shown in Fig. 2b the value of the frequency has the fastest decrease in the case of CCCC boundary conditions, and the slowest one in the case of SSSS boundary conditions.

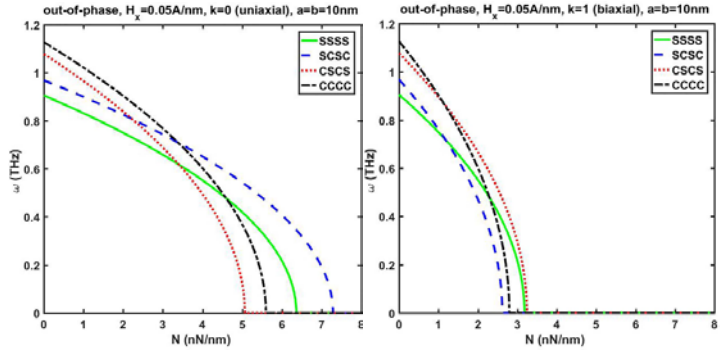
In relation to Fig 2 (a) and (b), in Fig 3 (a) and (b) only the value of magnetic field strength has been increased to H_x=0.1 A/nm. All the other parameters have the same value. A significant influence of magnetic field on the vibrational behaviour of DLGS can be seen. In both cases of (uniaxial and biaxial) compression the value of the frequency has a faster decrease in the case of CCCC and SCSC boundary conditions.



(a) *(b)*

Figure 3. *Change in in-phase frequency with respect to compression preload (uniaxial, biaxial) and various boundary conditions for magnetic field strength H_x=0.1 A/nm ($\mu = 1.345\,nm$)*

From Figure 4 (a) and (b) it can be clearly seen that in the case of out-of-phase vibration the value of the frequency for the case of CCCC and CSCS boundary conditions decreases significantly faster with the increase of value of in-plane preload (for uniaxial compression) in relation to the case of in-phase vibration. For biaxial compression, it can be noticed from Fig. 4b that the value of the frequency has the slowest decrease for the case of SSSS boundary conditions, and the fastest one for the case of CCCC boundary conditions.

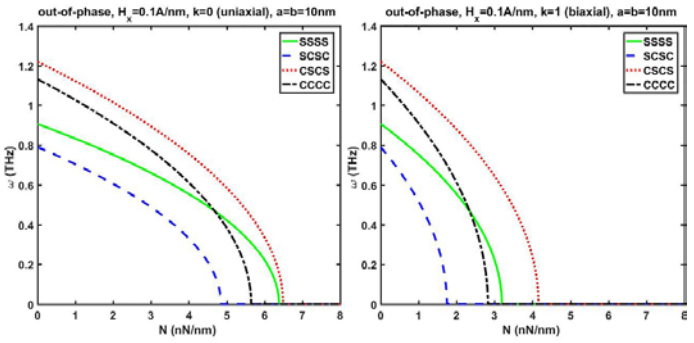


(a) *(b)*

Figure 4. *Change in out-of-phase frequency with respect to compression preload (uniaxial, biaxial) and various boundary conditions for magnetic field strength H_x=0.05 A/nm ($\mu = 1.345\,nm$)*

At the value of magnetic field strength Hx=0.1 A/nm in the case of out-of-phase vibration from Fig. 5(a) and (b) it can be noticed that the value of the frequency for the

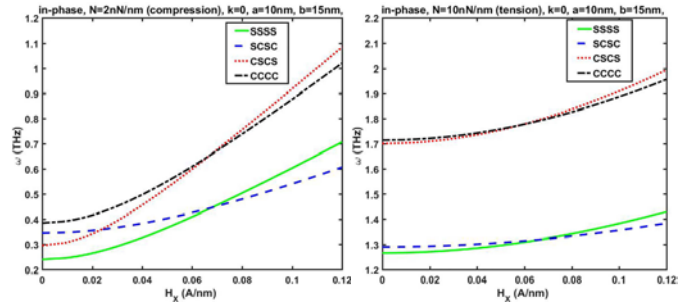
case of CCCC boundary conditions decreases significantly faster in relation to other three cases of boundary conditions.



(a) *(b)*

Figure 5. *Change in out-of-phase frequency with respect to compression preload (uniaxial, biaxial) and various boundary conditions for magnetic field strength H_x=0.1 A/nm ($\mu = 1.345\,nm$)*

The effects of increasing the magnetic field strength on the in-phase frequency of rectangular DLGS (a=10nm, b=15nm) with different boundary conditions are investigated in Fig. 6 (a) and (b). In Fig. 6a DLGS is loaded with uniaxial compression force N=2 nN/nm, and in Fig. 6b with uniaxial tension force N=10 nN/nm. With the increase of value of the magnetic field strength the value of the frequency increases for all four cases of boundary conditions. The value of the in-phase frequency in the case of uniaxial compression has the fastest increase in the case of CSCS boundary conditions and the slowest one in the case of SCSC boundary conditions. In the case of uniaxial tension (N=10 nN/nm) shown in Fig. 6b the value of in-phase frequency for CCCC and CSCSC boundary conditions is very close. It is the same with SSSS and SCSCS boundary conditions. In the case of activity of uniaxial tension force, the value of the in-phase frequency increases proportionally for all four observed cases of boundary conditions.

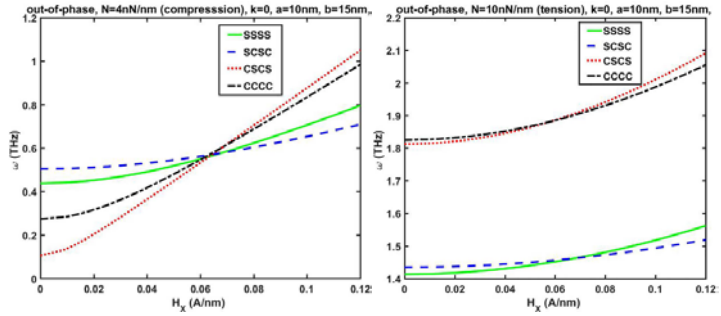


(a) *(b)*

Figure 6. *Change in in-phase frequency with respect to magnetic field strength, various boundary conditions and uniaxial in-plane (compression and tension) preload ($\mu = 1.345\,nm$)*

Fig. 7 (a) and (b) represents the effects of the magnetic field strength and various boundary conditions on out-of-phase frequency for rectangular DLGS (a=10 nm, b=15 nm). In Fig. 7a DLGS is exposed to the activity of uniaxial compression force (N=4

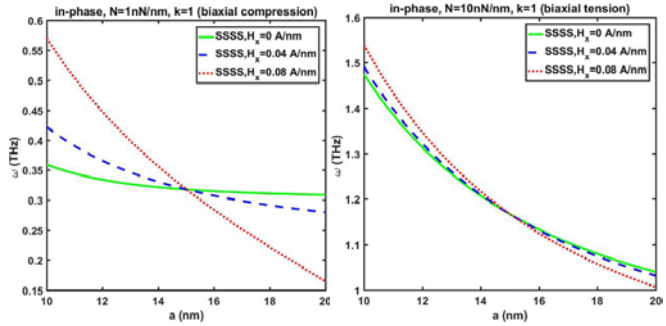
nN/nm), and in Fig. 7b to the activity of uniaxial tension force (N=4 nN/nm). It is obvious from Fig. 7a that in the case of activity of uniaxial compression force with the increase of value of the magnetic field strength the value of the out-of-phase frequency has the fastest increase in the case of CSCS boundary conditions. From Fig. 7b it can be noticed that the activity of uniaxial tension force in the case of out-of-phase vibrations causes the same effect as in the case of in-phase vibrations shown in Fig.6b.



(a) *(b)*

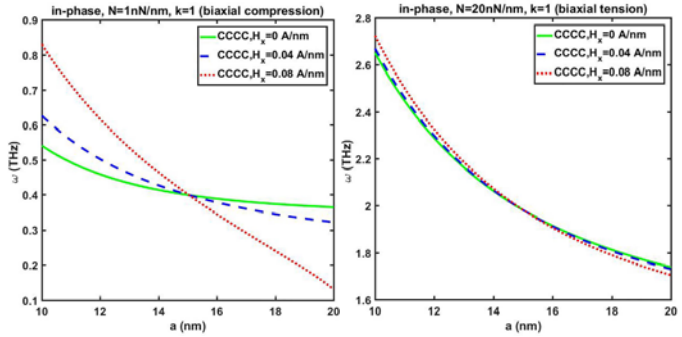
Figure 7. *Change in out-of-phase frequency with respect to magnetic field strength, various boundary conditions and uniaxial in-plane (compression and tension) preload* ($\mu = 1.345\,nm$)

Figs. 8, 9, 10 and 11 illustrate the effect of the size of the graphene sheet and increasing of the magnetic field strength on the in-phase frequency for SSSS, CCCC, SCSC and CSCS boundary conditions respectively. In Fig 8a, 9a, 10a, 11a DLGS is exposed to the activity of biaxial compression force, and in Fig 8b, 9b, 10b, 11b to the activity of biaxial tension force.



(a) *(b)*

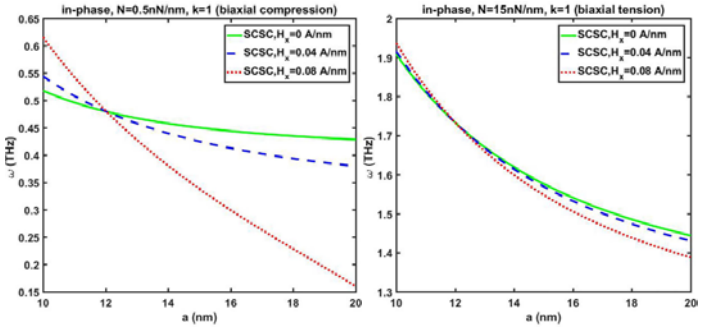
Figure 8. *Change in in-phase frequency with respect to length of DLGS, magnetic field strength and biaxial in-plane (compression and tension) preload for SSSS boundary conditions* ($\mu = 1.345\,nm$)



(a) *(b)*

Figure 9. *Change in in-phase frequency with respect to length of DLGS, magnetic field strength and biaxial in-plane (compression and tension) preload for CCCC boundary conditions ($\mu = 1.345\,nm$)*

It can be concluded from Fig. 8 and Fig. 9 that in the case of square nanoplates $(\mathrm{a} = b = 15\,nm)$, the change of magnetic field strength value under SSSS and CCCC boundary conditions does not affect the in-phase frequency value.

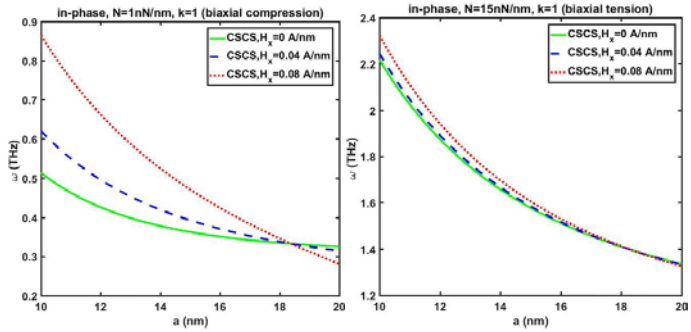


(a) *(b)*

Figure 10. *Change in in-phase frequency with respect to length of DLGS, magnetic field strength and biaxial in-plane (compression and tension) preload for SCSC boundary conditions ($\mu = 1.345\,nm$)*

It can be seen from Fig.10 that, in the case of rectangular nanoplates $(\mathrm{a} \approx 12\,nm,\ b = 15\,nm)$, the change of magnetic field strength value under SCSC boundary condition does not affect the in-phase frequency value.

Finally, from Fig.11 it can be noticed that in case of rectangular nanoplates $(\mathrm{a} \approx 18\,nm,\ b = 15\,nm)$, the change of magnetic field strength value under CSCS boundary condition does not affect the in-phase frequency value.



(a) *(b)*

Figure 11. *Change in in-phase frequency with respect to length of DLGS, magnetic field strength and biaxial in-plane (compression and tension) preload for CSCS boundary conditions ($\mu = 1.345\,nm$)*

These three cases, when the value of the in-phase frequency is independent from the change of value of the magnetic field strength at certain dimensions of DLGS occur in the case of biaxial compression and biaxial tension.

5 CONCLUSION

In this paper, by using Hamilton's principle, the equations of motion and boundary conditions were obtained base on the new first order shear deformation theory in the framework of the Eringen's differential nonlocal elastic law. The Galerkin's method has been used to solve the equations of motion of the DLGS for SSSS, CCCC, CSCS and SCSC boundary conditions. Numerical results are presented to investigate the effects magnetic field strength, initial preload (compression and tension), size of nanoplate and boundary conditions on vibrational frequency. It is observed that increasing the in-plane compression preload degrades the graphene sheet stiffness and frequency reduce until a critical point in which frequency becomes zero. Also, the frequency increase with the increase of the magnetic field strength for rectangular DLGS $(a = 10\,nm,\ b = 15\,nm)$.

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DIAGNOSTICS AND FAILURE OF PLAIN BEARINGS

Ranko Antunović[1], Goran Šiniković[2] ,Nikola Vučetić[3] , Amir Halep[4]

Abstract: Plain bearings have wide application in heavy mechanical engineering like mills, turbines, crushers, rolling mills and forging machines, presses and similar. Early detection of plain bearing failures is necessary in terms of systems maintenance and reliability as well as from the aspect of economy and protection of these production facilities. Failure and damage of plain bearings are most commonly manifested as wear, tear and plastic deformation of the material. Fracture and plastic deformation are damages related to strength, while wear, with all their manifestations, is associated with tribological processes. The research in this paper has shown that, in a reliable way, these problems can be detected at the very stage of their formation by vibration analysis and thermal analysis of bearing condition. This paper presents a part of the research done in the Laboratory for Applied Mechanics and Constructions at the Faculty of Mechanical Engineering in East Sarajevo. In this paper, the selection of plain bearing failures was performed, diagnostic models whose reliability was investigated in above mentioned Laboratory as well as on real industrial machines during their expulsion were developed.

Key words: diagnostic models, failure, plain bearing, technical diagnostics.

1. INTRODUCTION

Under the concept of technical diagnostics it means scientific and technical discipline which includes the theory, methods and tools for recognizing the condition of technical systems. The main aim of technical diagnostics is to detect and prevent potential failure of technical systems. This is achieved by measuring characteristic or diagnostic parameters and on the basis of certain criteria it concludes if they are within acceptable limits or not. The usage of sliding bearings is very present in practice, because of very long lifetime. Small problem in process oriented complex production system, as sliding bearing failure, can often cause long deadlocks during plant working, which results to huge financial costs in company business [1]. Monitoring and diagnostics sliding bearings failure are given in the literature [2]. Plain or sliding

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bearings are lubricated by the formation of a hydrodynamic film of lubricant, where the wedge formed lifts the shaft or journal off the bearing [3].

Research has shown that two most important indicators for the prediction of plain bearing failures are vibration analysis and bearing temperature analysis [4, 15].

Although the sliding bearing price is relatively low, any damage to the bearing that reduces the functional correctness of the system or failure occurence can cause significant indirect costs. On tehe basis of previous, the sliding bearings are considered as high-risk elements [2].

Basic causes that cause damage and failure of sliding bearings include many aspects of construction, material selection, materials mistakes, production and processing, assembly, control, testing, storage, transportation, maintenance, unforeseen exposure to overload, direct mechanical or chemical damage during operation [4]. Often, multiple causers contribute to the sliding bearing failure. The frequency of the individual causers given in Table 1 was obtained by monitoring 530 cases of sliding bearing leakage [5].

Table 1. *Causers and frequency of sliding bearing failures*

Failure causer	**Failure frequency, %**
Errors during production: • inadequate budgeting, • material mistakes, • irregularities during production and installation.	23,4 9,1 3,6 10,7
Errors during exploitation	39,1
Wear during long-term operation	30,5
Other	7,0

Failures and damages caused by said groups of causers are manifested, most often, as wear, breakage and plastic deformation of the material. These are, at the same time, the basic types of failures that can be divided into two categories, relative to material properties. One that is connected and dependent, above all, on the strength of the material and the other which is the function of tribological processes on the bearing-sleeve ground surfaces. Fracture and plastic deformation are damages in the function of strength, while wear and tear with all their manifestations are related to tribological processes.

2. SELECTION OF PLAIN BEARINGS FAILURE

There is general agreement that wear is the most frequent manifestation of failure in sliding bearings, as confirmed by the authors [6, 7]. The results show that abrasive and adhesive wear is the most present, then wear due to surface fatigue, while other types of wear are considerably less represented. These are, also, indicators that need to be taken into account when defining the bearing condition monitoring program during exploitation. Table 2 shows few plain bearings failure mechanisms.

Table 2. *Plain bearings failure mechanisms*

Failure type	Appearance	Cause	Manifest	Solution
Abrasion		Presence of solid impurities	Visible rolling of the bearing surface	The bearing damaged by abrasive wear should be dismantled and a new one installed
Wear and tear		Inadequate gap Inadequate supply of lubricants or inadequate supplies characteristics of lubricants	Frequent color surface change due to heating	The bearing can be used again if the causes are removed
Surface fatigue		Dynamic loading of plain bearings	Cracks occurrence	Eliminate the cause of surface fatigue
Cavitation erosion		Fluctuation of pressure in the bearing, vibration of the sleeve, inadequate flow lubricants through holes and channels	The occurrence of material destruction is always at the same or similar bearing location	Improving the bearing construction by increasing the oil pressure in the lubrication system
Corrosion		Corrosive action of the material	Visible corroded surfaces of materials	Changes in lubricant characteristics
Plastic deformation		Irregularities in the lubrication system, inadequate lubricant layer	Roofing of the bearing material on the surface and plastic streaming	Changes in lubrication system or lubricant characteristics
Fracture		Overload, impact load	Loss of bearing material from larger surfaces	Removing possible overloads or expressive impact loads

3. DIAGNOSTIC MODELS OF PLAIN BEARING

In order to correctly understand the diagnostic indicators of vibration and temperature measurements for damage of the plain bearing, a mathematical model of vibration and heating or cooling of the sliding bearing has been developed, which was confirmed by experimental tests [16, 17, 18].

3.1. Dynamic model of plain bearing

The dynamic model of the sleeve in the plain bearing is shown in Fig.1.

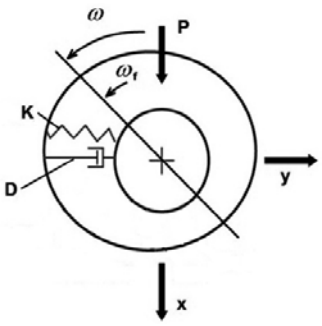


Figure 1. *The dynamic model of the sleeve in the plain bearing*

By introducing relations $z_r(t) = x_r(t) + jy_r(t)$, ie $z_r = z \cdot e^{-j\lambda_0 \omega}$ the differential equation of movement of the sleeve in the bearing is obtained (Eq. 1):

$$M \cdot \ddot{z} + D \cdot \dot{z} + (K - j \cdot \lambda_0 \cdot \omega \cdot D) \cdot z = F \cdot e^{j(\omega t + \delta)} \quad (1)$$

The parameters of the model are: M - modal mass, K - modular rigidity and D - damping of the environment.

The proportionality coefficient λo is one of the key factors affecting the stability of the rotor system, since the lubricant in the bearing acts as a spring. The proportionality coefficient depends on the dimensions of the bearing.

Damping in the lubricant is determined by the damping coefficient D corresponding to the dynamic viscosity of the lubricant. The bearing force of the fluid film (wedge) is equal in intensity and the opposite is in the direction of the radial force and is determined, according to the model, by the form (Eq. 2):

$$F_f = D \cdot \lambda_0 \cdot \omega \cdot z \quad (2)$$

Problems that occur in sliding bearings lead to high levels of vibration and noise. These problems mainly arise as a result of an inadequate gap in the bearing (oil gap) or the appearance of oil instability. An excessive gap in the bearing results in looseness and irregular lubrication, which in the vibration response of the system produces a characteristic vibration shown in Fig. 2.

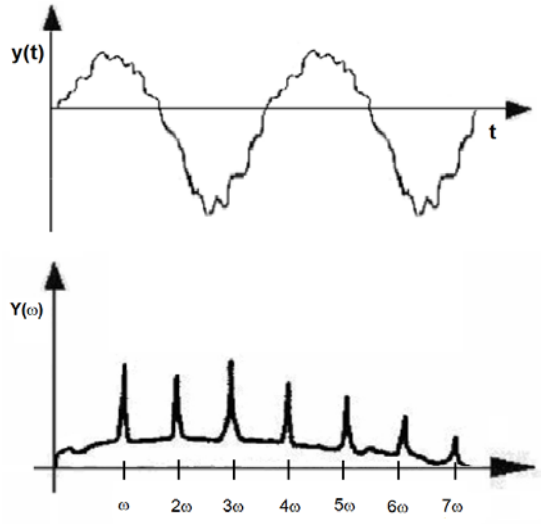


Figure 2. *Time recording and vibration spectral display due to excessive plain bearing gap*

Oil instability is manifested in the appearance of oil vortex and oil whip. The oil vortex occurs as a result of the orbital motion of the rotor and occurs at a frequency that is proportional to the rotation frequency and amounts usually 0.4 to 0.5 Ω with the growing amplitude as the number of rotations rises.

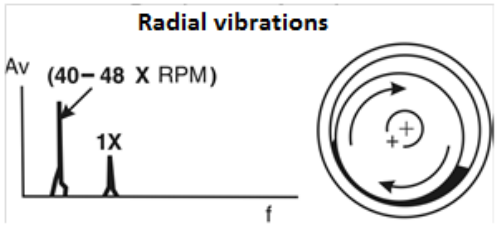


Figure 3*. Spectral display of oil instability*

In machines that operate above the first critical speed, the oil vortex usually passes into an oil whip which frequency is equal to the frequency in the formation of the same.

3.2. Temperature model of plain bearing

It is clear that the bearing heating or cooling process may be described by the differential equation of the first order. By solving this equation, with the condition for dynamic model of the first order (Eq. 4).

$$\frac{d\theta}{dt} + \frac{1}{T} \cdot \theta = 0 \tag{3}$$

The formula is obtained which models the cooling of the bearing, which may happen, for example, during the decline in rpm, according to the Newton's law of cooling [18]:

$$\theta(t) = \theta p \cdot \exp(-t/T) \tag{4}$$

The expression (4) may be corrected by introducing Θ_k, the final temperature measured when the steady-state is reached:

$$\theta(t) = (\theta p - \theta k) \cdot \exp(-t/T) + \theta k \quad (5)$$

On the contrary, when the heating process occurs, for example as a result of increased rpm, this process is described by the equation:

$$\theta(t) = (\theta k - \theta p) \cdot (1 - \exp(-t/T)) + \theta p \quad (6)$$

Figure 3. presents time diagrams of the cooling and heating of the journal bearing according to the equations (5) and (6).

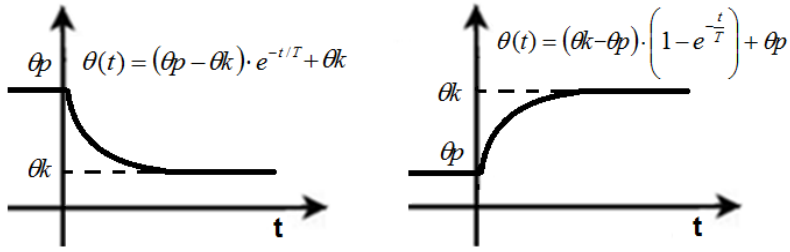


Figure 4. *Time diagram of cooling (left) and heating (right) of the journal bearing*

3.3. Vibration-thermal indicator of the plain bearing malfunction

In order to reliably determine the condition and prediction of plain bearing failure, it is necessary to observe and analyze simultaneously several parameters of the condition. One such method is based on the fuzzy logic and enables the diagnostics of the state of the element and determining the urgency of the need for intervention on the machine element. Thus, by applying the disjunctive probabilistic fuzzy operator, a vibration-thermal indicator of malfunction of the plain bearings (defect factor DFJB) can be defined which contains information about both the temperature and the vibration of the bearing defined as [17]:

$$DFJB = (x(\mathrm{q}) + w(v)) - x(\mathrm{q}) \times w(v) \quad (7)$$

If the temperature and vibrations are within the allowed limits, i.e. below the warning limit, then the value of the DFJB indicator = 0, and if at least one of the parameters (temperature or vibration) is above the limit, then the value of the DFJB indicator = 1 in accordance with the rules for disjunction. If any of the parameters are in the fuzzy warning area, then the indicator of the malfunction in the fuzzy area. It should be noted that in this factor of malfunction, besides the level of absolute and rotor vibrations in the analysis, other parameters such as the vibration spectrum or the thickness of the oil film can be included, which depends on the need for diagnosis.

4. CASE STUDY

4.1. Analysis of the turboaggregate plain bearing failure in thermal power plant Gacko

Turbine No. 1 and 3 bearing vibrations intensity were directly dependent on the load on the block. With a decrease in the block power, vibrations were dropped from a

speed of about 7-8 mm/s to a value of 6-7 mm/s, with the component vibration on the semicircons 1/2X, 3/2X, 5/2X visible in Fig. 5 appears.



Figure 5. *Spectral Vibration view from bearing No.1*

On the first bearing traces of damage to the part of the white metal surface on the lower half are visible (Fig. 6). According to the character of the damage it is clear that it is an electro-corrosion corrosion that occurs due to the breakdown of the vortex currents from the rotor to the stator part. The restoration of the bearing consists of showering the bearing surface, adjustment to the caliber and re-assembly.

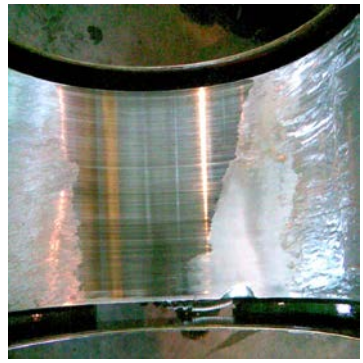


Figure 6*. Damage to the lower half of the bearing cup due to electro-erosion corrosion*

The removal of white metal on the lower half of the surface of the sliding bearing due to the failure of the rotor of 0.16 mm is visible.

4.2. Analysis of the turbo pump plain bearing failure in thermal power plant Gacko

The main vibration stimulus originates from the oil vortex and is dominant on bearing No. 1 in the horizontal radial direction. The presence of semi-harmonics in the spectral display of vibrations indicates problems with the lubrication of the bearing and the rotor-stator contact, Fig.7.

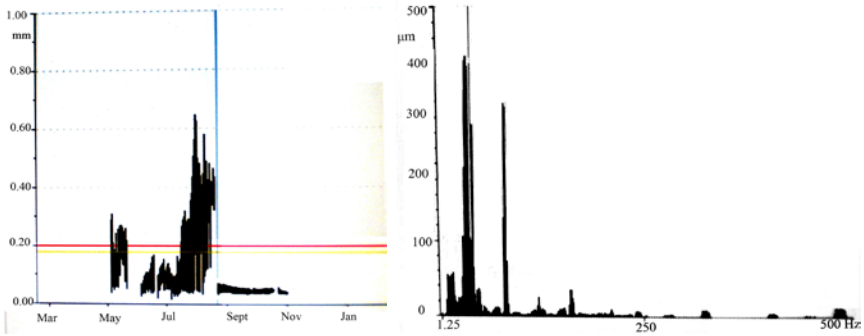


Figure7*. Vibration level and spectral display from the pump bearing no.1*

After the bearing was revised, damage was clearly detected and a new "lemon" bearing was developed which proved to be a good solution.



Figure 8*. Damage to the plain bearing (left) and the appearance of the new "lemon" bearing (right)*

4.3. Analysis of the electric motor plain bearing failure in Kakanj cement factory

By measuring the temperature and absolute vibration velocity on the housing of plain bearings, on one bearing housing absolute vibrations v = 9.3 mm / s and temperature Θ = 66 ºC were measured.

For the concrete application of the bearing, the vibration limits were va = 4 mm / s and vd = 12 mm / s, and the temperature limits Θa = 60 ºC and Θd = 90 ºC. After the fuzzification of the measured values of the vibration and temperature velocity is carried out, we obtain: x(Θ)=(66-60)/(90-60)=0.20 and w(v)=(9.3-4)/(12-4)=0.66. By calculating the vibration-thermal indicator of malfunction, the DFJB=(0.20+0.66)-0.20·0.66=0.73 is obtained. It can be noted that the value of the vibration-thermal indicator is greater than the two-fuzzy variables x and w. After the bearing was dismantled, significant damage was observed on the bottom half of the bearing bed, which is visible in Fig. 9. Thus, this example demonstrates the applicability and reliability of the vibration-thermal indicator of the plain bearing defect.

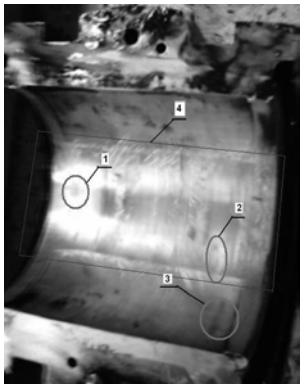


Figure 9. *Damage of the bottom half of the plain bearing bed*

The frequency spectrum of absolute vibrations on the housing of the bearing is shown in Fig. 10, from which one the shape of the frequency spectrum characteristic of wear of the bearing can be noticed.

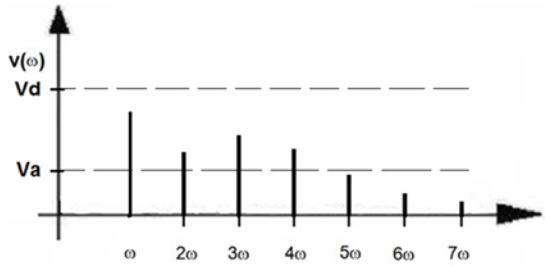


Figure 10. *Frequency spectrum of absolute vibrations measured on the housing*

5. DISCUSION AND CONCLUSION

Failures and damages caused by said groups of causers are manifested, most often, as wear, breakage and plastic deformation of the material. These are, at the same time, the basic types of failures that can be divided into two categories, relative to material properties. One that is connected and dependent, above all, on the strength of the material and the other which is the function of tribological processes on the bearing-sleeve ground surfaces.

Problems that occur with plain bearings lead to high levels of vibration and noise. These problems are mainly due to an inadequate gap in the oil spill or the occurrence of oil instability. Excessive gap in the bearing leads to looseness and irregular lubrication. Oil instability is manifested in the appearance of oil vortex and oil whip. Vibration-thermal malfunction indicator of the plain bearing (failure factor DFJB) contains processed temperature information and bearing vibration, but in some applications, other than temperature and vibration, other parameters can be included, such as, for example, the thickness of the oil bearing film or the strength of the ultrasonic bearing emission, and can be integrated in this plain bearing DFJB failure factor.

Further research can be carried out in this regard. Further research can be carried out for the function of belonging choice, because in this research the linear function of belonging was used, and other functions of belonging can also be used. Further research can be done in general with regard to the application of the fuzzy logic in technical diagnostics.

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REŠAVANJE KONTAKTNIH PROBLEMA METODOM KONAČNIH ELEMENATA

Snežana Vulović[1], Miroslav Živković[2], Rodoljub Vujanac[3], Jelena Živković[4]

Rezime: U ovom radu razmatran je kontakt između dva deformabilna tela u najopštijem slučaju. Kako konfiguracija tela koja ulaze u kontakt prethodno nije poznata, kontakt predstavlja nelinearni problem čak i kada su tela elastična. Analogija između trenja i plastičnosti je korišćena u numeričkoj implementaciji kontakta i prikazana je u ovom radu. Razvijeni model je implementiran u programski paket za analizu konstrukcija - PAK.

Ključne riječi: Metod konačnih elemenata, kontakt, penalti metod

SOLUTION OF CONTACT PROBLEMS USING THE FINITE ELEMENT METHOD

Abstract: The contact between two deformable bodies in general case is presented in this paper. Even when the bodies are elastic the contact represents a non-linear problem as the configuration of two bodies coming into the contact is not known beforehand. An analogy between friction and classical elasto-plasticity was used in the numerical implementation of the contact and it is presented in this paper. Developed numerical model is implemented in the inhouse software package PAK.

Key words: Finite Elemente Method, Contact, Penalty method

1 INTRODUCTION

Contact mechanics has its application in many engineering problems, for example: the interaction between soil and foundations in civil engineering, general bearing problems as well as bolt and screw joints in mechanical engineering. Effective application of solvers for contact problems based on the finite element method demands a high degree of experience since the general robustness and stability cannot be guaranteed. For this reason the development of more efficient, fast and stable finite element contact discretization is still a very important topic, especially due to the fact that engineering applications are becoming more and more complex.

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The aim of this paper is to provide the framework for contact problems with friction, based on the penalty [2-4,6] and the Lagrange multiplier method [4,6]. The Lagrange multiplier method provides exact solution but involves additional degrees of freedom. The penalty formulation is purely geometrically based and therefore no additional degrees of freedom must be added but the solution is dependent on the introduced penalty factor. Standard shape routines are used for the detection of contact between previously separated meshes and for the aplication of displacement constraints where the contact is identified. Both models are implemented into the inhouse software package for structural analysis, PAK [1], based on the finite element method. Numerical examples are shown to demonstrate a possibility of applying the developed method in the analysis of finite deformation problems.

2 FORMULATION OF THE MULTI-BODY FRICTIONAL CONTACT PROBLEM

A contact between two deformable bodies ($B^{(1)}$ and $B^{(2)}$) is considered, Figure 1. The contact surface is defined in the way that all material points where contact may occur at any time t are included. Using a standard notation in contact mechanics, each pair of contact surfaces involved in the problem will consist of slave ($\Gamma_C^{(1)}$) and master ($\Gamma_C^{(2)}$) surfaces. The condition that must be satisfied is that any part of slave surface cannot penetrate the master surface.

The projection point ($\bar{\mathbf{x}}$) of the current position of the slave node $\mathbf{x}^k$ onto the master surface, is defined as

$$\frac{\mathbf{x}^k - \bar{\mathbf{x}}(\bar{\xi}^1, \bar{\xi}^2)}{\left\| \mathbf{x}^k - \bar{\mathbf{x}}(\bar{\xi}^1, \bar{\xi}^2) \right\|} \cdot \bar{\mathbf{a}}_\alpha(\bar{\xi}^1, \bar{\xi}^2) = 0 \tag{1}$$

where $\alpha = 1,2$ and $\bar{\mathbf{a}}_\alpha(\bar{\xi}^1, \bar{\xi}^2)$ are the tangent covariant base vectors at the point. The definition of the projection point allows us to define the distance between any slave node and the master surface. The normal gap or the penetration g_N for slave node k is defined as the distance between the current position of this node and the master surface

$$g_N = (\mathbf{x}^k - \bar{\mathbf{x}}) \cdot \bar{\mathbf{n}} \tag{2}$$

Normal $\bar{\mathbf{n}}$ to the master surface $\Gamma_C^{(2)}$ at point $\bar{\mathbf{x}}$, can be defined using tangent vectors at the point $\bar{\mathbf{x}}$

$$\bar{\mathbf{n}} = \frac{\bar{\mathbf{a}}_1 \times \bar{\mathbf{a}}_2}{\left\| \bar{\mathbf{a}}_1 \times \bar{\mathbf{a}}_2 \right\|} \tag{3}$$

The gap (2) gives the non-penetration conditions as follows

$$g_N = 0 \text{ perfect contact; } g_N > 0 \text{ no contact; } g_N < 0 \text{ penetration} \tag{4}$$

The function (4) completely defines the contact kinematics for frictionless contact problem. If friction is modeled, tangential relative displacement must be introduced. In that case, the sliding path of the node $\mathbf{x}^k$ over the contact surface is described by total tangential relative displacement, in time interval from t_0 to t, as

$$g_T = \int_{t_0}^{t} \left\| \dot{\mathbf{g}}_T \right\| dt = \int_{t_0}^{t} \left\| \dot{\overline{\xi}}^{\alpha} \overline{\mathbf{a}}_{\alpha} \right\| dt = \int_{t_0}^{t} \sqrt{\dot{\overline{\xi}}^{\alpha} \dot{\overline{\xi}}^{\beta} a_{\alpha\beta}}\, dt \tag{5}$$

The time derivatives of parameter $\overline{\xi}^{\alpha}$ in equation (5) can be computed from the relation (1), [8]. In the geometrically linear case we obtain the following result

$$\overline{a}_{\alpha\beta} \dot{\overline{\xi}}^{\beta} = \left[\dot{\mathbf{x}}^k - \dot{\overline{\mathbf{x}}} \right] \cdot \overline{\mathbf{a}}_{\alpha} = \dot{g}_{T\alpha} \tag{6}$$

where $\overline{a}_{\alpha\beta} = \overline{\mathbf{a}}_{\alpha} \cdot \overline{\mathbf{a}}_{\beta}$ is the metric tensor in point $\overline{\mathbf{x}}$ of the master surface. From the equations (5) and (6) we can deduce the relative tangential velocity at the contact point

$$\dot{\mathbf{g}}_T = \dot{\overline{\xi}}^{\alpha} \overline{\mathbf{a}}_{\alpha} = \dot{g}_{T\alpha} \overline{\mathbf{a}}^{\alpha} \tag{7}$$

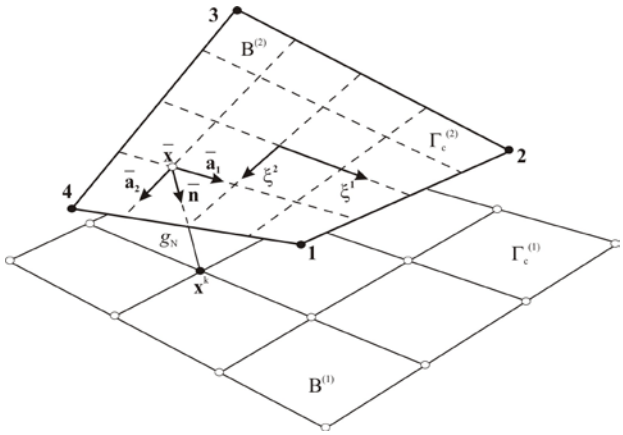


Figure 1. *Geometry of the 3D node-to-surface contact element*

For mathematical and computational modeling the surface characteristics have to be put into a constitutive interface constraint. A contact stress vector $\overline{\mathbf{t}}$ with respect to the current contact interface $\Gamma_C^{(2)}$ can be decomposed into a normal and tangential part

$$\overline{\mathbf{t}} = \overline{\mathbf{t}}_N + \overline{\mathbf{t}}_T = \overline{t}_N \overline{\mathbf{n}} + \overline{t}_{T\alpha} \overline{\mathbf{a}}^{\alpha} \tag{8}$$

where $\overline{\mathbf{a}}^{\alpha}$ is contravariant base vector. The stress acts on both surfaces obeying the action-reaction principle: $\overline{\mathbf{t}}(\overline{\xi}^1, \overline{\xi}^2) = -\mathbf{t}$ at the contact point $\overline{\mathbf{x}}$. The tangential stress $\overline{t}_{T\alpha}$ is zero in the case of frictionless contact. Condition $\overline{t}_N < 0$ indicates the existence of the contact. If there is no penetration between the bodies, then relations $g_N > 0$ and $\overline{t}_N = 0$ apply. This leads to

$$g_N \geq 0, \quad \overline{t}_N \leq 0, \quad \overline{t}_N g_N = 0 \tag{9}$$

which are known as Kuhn-Tucker conditions.

In tangential direction a distinction is made between stick and slip case. As long as no sliding between two bodies occurs, the relative tangential velocity is zero. If

the velocity is zero, also the tangential relative displacement (5) is zero. This state is called stick case with the following restriction:

$$\dot{\mathbf{g}}_T = \mathbf{0} \;\Leftrightarrow\; \mathbf{g}_T = \mathbf{0} \tag{10}$$

A relative movement between two bodies occurs if the static friction resistance is overcome and the loading is large enough so that the sliding process can be kept. Therefore the relative sliding velocity, respectively the sliding displacement, shows in opposite direction to the friction force. With this the tangential stress vector is restricted as follows:

$$t_{T\alpha}^{sl} = -\mu \left|\mathbf{t}_N\right| \frac{\dot{g}_{T\alpha}^{sl}}{\left\|\dot{\mathbf{g}}_T^{sl}\right\|} \tag{11}$$

where μ is friction coefficient. In the simplest form of Coulomb's law (11), μ is constant and there is no distinction between static and sliding friction.

After the introduction of the stick and slip constraints, one needs an indicator to decide whether stick or slip actually take place. Therefore an indicator function

$$f = \left\|\mathbf{t}_T\right\| - \mu \left|t_N\right| \tag{12}$$

is evaluated, which respects the Coulomb's model for frictional interface law. In the equation (12) the first term is $\left\|\mathbf{t}_T\right\| = \sqrt{t_{T\alpha} \overline{a}^{\alpha\beta} t_{T\beta}}$. The following contact states can be distinguished:

$$f = \begin{cases} \left\|\mathbf{t}_T\right\| - \mu \left|t_N\right| \le 0 & \rightarrow \text{ stick} \\ \left\|\mathbf{t}_T\right\| - \mu \left|t_N\right| > 0 & \rightarrow \text{ slip} \end{cases} \tag{13}$$

Using the penalty method for normal stress, constitutive equation can be formulated as

$$t_N = \varepsilon_N g_N \tag{14}$$

where ε_N is the normal penalty parameter. The tangential part is different for the stick and for the slip case. For the stick case a simple linear constitutive model can be used to describe the tangential stress

$$t_{T\alpha}^{stick} = \varepsilon_T g_{T\alpha} \tag{15}$$

where ε_T is the tangential penalty parameter. For the slip case the tangential stress is given by the constitutive law for frictional sliding (11). A backward Euler integration scheme and return mapping strategy are employed to integrate the friction equations (12). If the stick case is assumed, the trial values of the tangential contact pressure vector $t_{T\alpha}$, and the indicator function f at load step n+1 can be expressed in terms of their values at load step n as follows

$$t_{T\alpha\ n+1}^{trial} = t_{T\alpha\ n} + \varepsilon_T \Delta g_{T\alpha\ n+1} = t_{T\alpha\ n} + \varepsilon_T \overline{a}_{\alpha\beta} \Delta \xi_{n+1}^{\beta} \tag{16}$$

$$f_{Tn+1}^{trial} = \left\|\mathbf{t}_{Tn+1}^{trial}\right\| - \mu \left|t_{Nn+1}\right| \tag{17}$$

The return mapping is completed by

$$t_{T\alpha\ n+1} = \begin{cases} t^{trial}_{T\alpha\ n+1} & \text{if } f \le 0 \\ \mu \left| t_{Nn+1} \right| n^{trial}_{T\alpha\ n+1} & \text{if } f > 0 \end{cases} \tag{18}$$

with

$$n^{trial}_{T\alpha\ n+1} = \frac{t^{trial}_{T\alpha\ n+1}}{\left\| \mathbf{t}^{trial}_{Tn+1} \right\|} \tag{19}$$

The penalty method can be illustrated as a group of linear elastic springs that force the body back to the contact surface when overlapping or sliding occurs.

The principle of virtual works when two bodies at the time t are in contact can be written as (for a detailed legend of the symbols see [8])

$$\sum_{\alpha=1}^{2} \left(\int_{V^{(\alpha)}} \boldsymbol{\sigma}^{(\alpha)} : grad\, \delta \mathbf{u}^{(\alpha)} dV - \int_{V^{(\alpha)}} \rho^{(\alpha)} \left(\mathbf{b}^{(\alpha)} - \ddot{\mathbf{u}}^{(\alpha)} \right) \delta \mathbf{u}^{(\alpha)} dV - \int_{S_\sigma^{(\alpha)}} \boldsymbol{\sigma}^{(\alpha)} \cdot \mathbf{n} \cdot \delta \mathbf{u}^{(\alpha)} dA \right) - C_c = 0 \tag{20}$$

where C_c is "contact contribution". Contact contribution is formulated for the Lagrange multiplier method in case of contact with friction for the stick case as

$$C_c = \int_{S_C} \left(\lambda_N \delta g_N + \boldsymbol{\lambda}_T \cdot \delta \mathbf{g}_T \right) dA \tag{21}$$

and for the case of sliding

$$C_c = \int_{S_C} \left(\lambda_N \delta g_N + \mathbf{t}_T \cdot \delta \mathbf{g}_T \right) dA \tag{22}$$

where δg_N and $\delta \mathbf{g}_T$ are variation of gap and tangential displacement; λ_N and $\boldsymbol{\lambda}_T$ are normal and tangential Lagrange multipliers and $\mathbf{t}_T$ is tangential stress vector which is determined from constitutive law for frictional slip. Note that the Lagrange multiplier λ_N can be identified as the contact stress t_N.

Contact contribution for the penalty method is formulated as

$$C_c = \int_{S_C} \left(\varepsilon_N g_N \delta g_N + \mathbf{t}_T \cdot \delta \mathbf{g}_T \right) dA \tag{23}$$

Detailed description of the finite element formulation for penalty method and Lagrange multiplier method can be found in [8].

3 NUMERICAL EXAMPLES

3.1 Sticking of elastic block

Numerical example given in [9] is used to verify whether the developed algorithm is able to represent stick/slip behavior correctly. The example consists of elastic block pressed against a rough rigid foundation. Simultaneously to the vertical loading the block is pulled at right side by an uniformly normal stress, as shown in Figure 2.

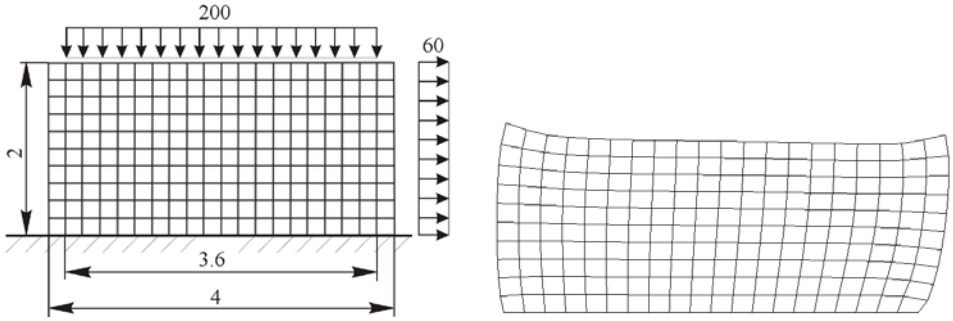


Figure 2. *Initial and deformed configuration*

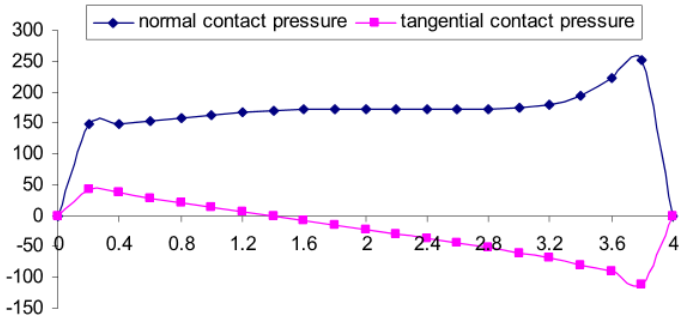


Figure 3. *Force-displacement repationship*

Material constants are: E = 1000MPa, ν = 0.3. Properties of the contact surface have been chosen as $\varepsilon_N = 10^8$, $\varepsilon_T = 10^4$, friction coefficient $\mu = 0.5$. The block is discretized using 200 four-node isoparametric elements. It should be noted that in case of using the developed algorithm the total load can be applied in only one step. Calculated normal contact pressure and tangential contact stress are shown in Figure 3, and it can be seen that there is a good agreement between these solutions and the solutions given in [9].

3.2 Sliding of elastic-plastic block

Sliding of elastic-plastic block through rigid tool is considered, as shown in Figure 4. Material properties of the block are: $E = 1000\text{MPa}$, $\nu = 0.3$, $\sigma_y = 100\text{MPa}$, $C_y = 10\text{MPa}$, $n = 0$. Due to the symmetry, only one half of the problem is modeled. The block is discretized with 2D elements (the steady state of deformation). Displacement of the block of 79.2cm is applied in 44 steps. Properties of the contact surface have been chosen as $\varepsilon_N = 1000$ и $\varepsilon_T = 500$, friction coefficient $\mu = 0.1$.

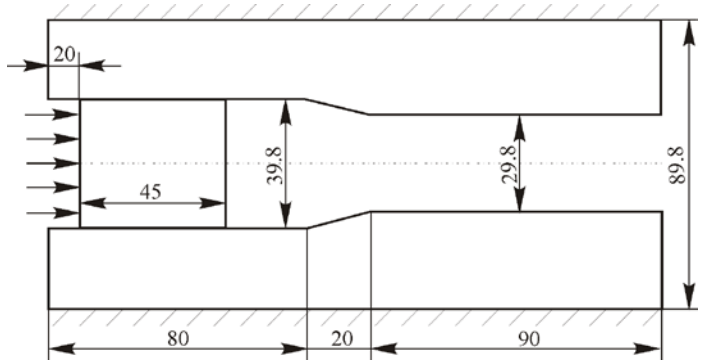


Figure 4. *Initial configuration*

Von Mises stress field on the considered block in 24th and 44th step is shown in Figure 5. Figure 6 shows relationship between contact force in x-direction and displacement.

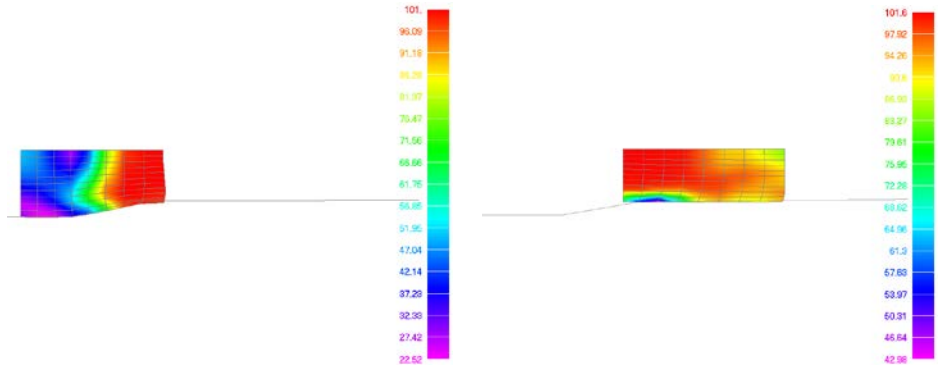


Figure 5. *Von Mises stress field in 24th step and 44th step*

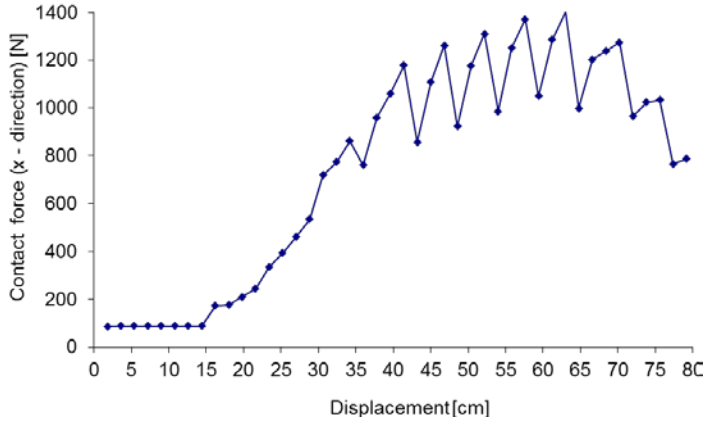


Figure 6. *Force-displacement relationship*

4 CONCLUSION

In this paper a model for three-dimensional contact problem with friction based on the penalty and Lagrange multiplier method was described. Using the penalty method calculation time is shorter but the results are strongly dependent on a chosen value of the penalty factor. The Lagrange multiplier method leads to the exact solution but with more iterations and significant extension of a number of degrees of freedom, as shown in [8]. Numerical examples shown in this paper and in [8] indicate a possibility of easy simultaneous use of both developed procedures in the analysis of finite deformation problems within one computer code.

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KINEMATIČKI MODEL PLATFORME ROBOTA BAZIRANOG NA JANSENOVOM MEHANIZMU

Radoslav Tomović[1], Vuk Vujošević[2], Marko Mumović[3] Aleksandar Tomović[4]

Rezime: Hodajući roboti imaju potencijal da budu široko upotrebljeni jednog dana, zbog njihovih lokomotornih sposobnosti. U ovom radu je predstavljen razvoj i kinematika hodajuće platforme bazirane na Jansenovom mehanizmu, jednom od najpopularnijih hodajućih mehanizama.

Ključne riječi: hodajući mehanizam, Jansen, kinmatika, robot, lokus.

KINEMATIC MODEL OF ROBOT BASED ON JANSEN MECHANISM

Abstract: Walking robots have potential of being widey used one day, because of their locomotion capabilities. In this paper are presented development and kinematics of walking platform based on Jansen mechanism, one of most popular wakling mechanisms.

Key words: walking mechanism, Jansen, kinematics, robot, locus.

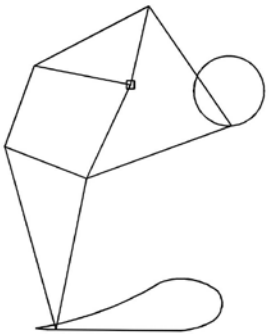
1 UVOD

Poznato je da životinje mogu da se kreću preko neravnih terena mnogo stabilnije nego klasična vozila. Odatle se javlja ideja za imitacijom životinjske lokomocije. Kada je riječ o tome najbolji način da se imitira lokomocija jeste pomoću hodajućih mehanizama. To su obično ravanski mehanizmi sa jednim stepenom slobode kretanja.

2 JANSENOV MEHANIZAM

Jansenov mehanizam je jedan od najpopularnijih hodajućih mehanizama. To je ravanski mehanizam koji ima 8 članova i jedan stepen slobode kretanja.

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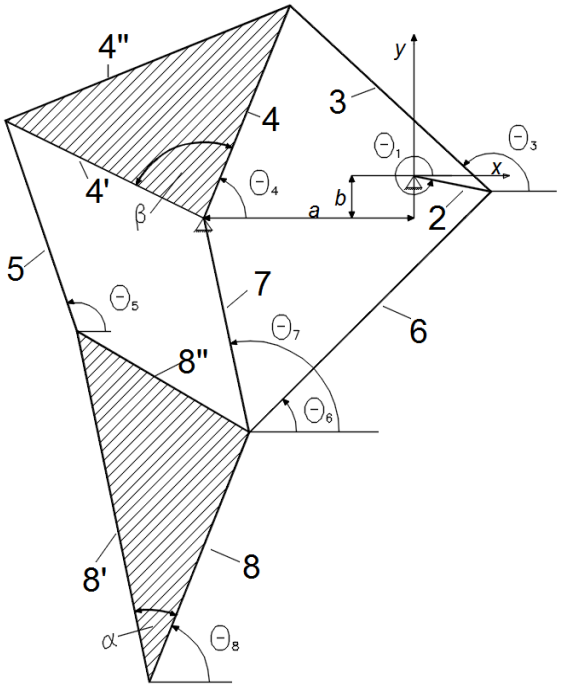
Slika 1. *Jansenov mehanizam* [1]

3 KINEMATIKA MEHANIZMA

Za kinematiku mehanizma korišćena je numerička metoda kompleksnog broja, i simulirana je u MATLAB softverskom okruženju. Metoda se sadrži od pronalaženja jednačina u zavisnosti od nepoznatih članova mehanizma. U ovom slučaju mehanizam ima 6 nepoznatih članova pa su potrebno 3 vektorske konture, odnosno sa projekcijama to je 6 jednačina.

3.1 Šema mehanizma

Na sledećoj slici dat je šematski prikaz mehanizma.



Slika 2. *Šematski prikaz mehanizma*

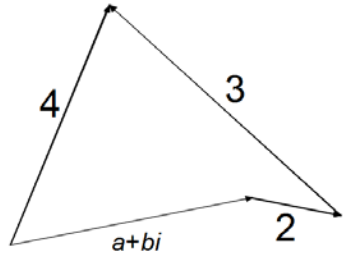
Sada je data tabela sa dužinama članova i pretpostavljenim ugovima između članova i realnog dijela ose, odnosno x-ose.

Tabela 1. Dužine članova i vrijednosti uglova mehanizma.

θ_i, α, β	Value in (^{o})	l_i	*Value (mm)*
θ_2	*330*	l_2	*15*
θ_3	*138*	l_3	*50*
θ_4	*78*	l_4	*41.5*
θ_5	*109*	l_4'	*40.1*
θ_6	*44*	l_4''	*55.8*
θ_7	*102*	l_5	*39.4*
θ_8	*68*	l_6	*61.9*
α	*87*	l_7	*39.3*
β	*34*	l_8	*49*
		l_8'	*65.7*
		l_8''	*36.7*
		a	*30*
		b	*7.8*

3.2 Geometrijska analiza

Kao što je ranije navedeno, ptrebne su 3 vektorske konture da bi se dobile jednačine. Prva kontura je između članova 2, 3, 4 i a.



Slika 3. *Prva vektorska kontura*

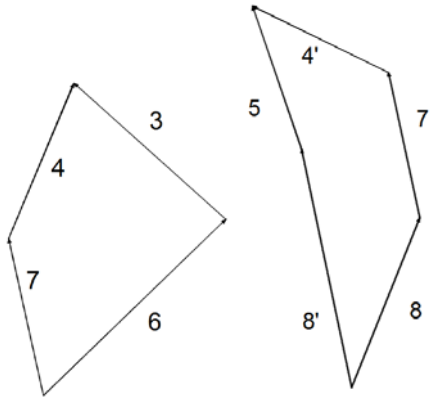
Prva kontura k_1:

$$l_2 e^{i\theta_2} + l_3 e^{i\theta_3} + (a + bi) = l_4 e^{i\theta_4} \tag{1}$$

Projekcije na Re i Im osu:

$$l_2 \cos(\theta_2) + l_3 \cos(\theta_3) + a = l_4 \cos(\theta_4) \tag{2}$$

$$l_2 \sin(\theta_2) + l_3 \sin(\theta_3) + b = l_4 \sin(\theta_4) \tag{3}$$



Slika 4. *Druga i treća vektorska kontura*

Druga kontura k2:

$$l_6 e^{i\theta_6} + l_3 e^{i\theta_3} = l_4 e^{i\theta_4} + l_7 e^{i\theta_7} \tag{4}$$

Sa projekcijama:

$$l_6 \cos(\theta_6) + l_3 \cos(\theta_3) = l_4 \cos(\theta_4) + l_7 \cos(\theta_7) \tag{5}$$

$$l_6 \cos(\theta_6) + l_3 \cos(\theta_3) = l_4 \cos(\theta_4) + l_7 \cos(\theta_7) \tag{6}$$

Treća kontura k_3:

$$l_8 e^{i\theta_8} + l_7 e^{i\theta_7} + l_4' e^{i(\theta_4+\alpha)} = l_8' e^{i(\theta_8+\beta)} + l_5 e^{i\theta_5} \tag{7}$$

Sa projekcijama:

$$l_8 \cos(\theta_8) + l_7 \cos(\theta_7) + l_4' \cos(\theta_4'+\alpha) = l_8' \cos(\theta_8'+\beta) + l_5 \cos(\theta_5) \tag{8}$$

$$l_8 \sin(\theta_8) + l_7 \sin(\theta_7) + l_4' \sin(\theta_4'+\alpha) = l_8' \sin(\theta_8'+\beta) + l_5 \sin(\theta_5) \tag{9}$$

Diferenciranjem ovih jednačina i zapisom u matrični oblik dobija se Jakobijanova matrica.

$$J = \begin{bmatrix} -l_3\sin(\theta_3) & l_4\sin(\theta_4) & 0 & 0 & 0 & 0 \\ l_3\cos(\theta_3) & -l_4\cos(\theta_4) & 0 & 0 & 0 & 0 \\ -l_3\sin(\theta_3) & l_4\sin(\theta_4) & 0 & -l_6\sin(\theta_6) & l_7\sin(\theta_7) & 0 \\ l_3\cos(\theta_3) & -l_4\cos(\theta_4) & 0 & l_6\cos(\theta_6) & -l_7\cos(\theta_7) & 0 \\ 0 & -l_4'\sin(\theta_4'+\alpha) & -l_5\sin(\theta_5) & 0 & -l_7\sin(\theta_7) & -l_8\sin(\theta_8) - l_8'\sin(\theta_8'+\beta) \\ 0 & l_4'\cos(\theta_4'+\alpha) & l_5\cos(\theta_5) & 0 & l_7\cos(\theta_7) & -l_8\cos(\theta_8) - l_8'\cos(\theta_8'+\beta) \end{bmatrix}$$

Sada izračunavanjem ovih jednačina sa prepostavljem uglovima dobija se neko odstupanje Δ

$$J \cdot [\delta\theta] = [\Delta] \tag{10}$$

Gdje su:

$$[\delta\theta] = [\delta\theta_3 \quad \delta\theta_4 \quad \delta\theta_5 \quad \delta\theta_6 \quad \delta\theta_7 \quad \delta\theta_8],$$

$$[\Delta] = \begin{bmatrix} \Delta_{1x} & \Delta_{1y} & \Delta_{2x} & \Delta_{2y} & \Delta_{3x} & \Delta_{3y} \end{bmatrix}$$

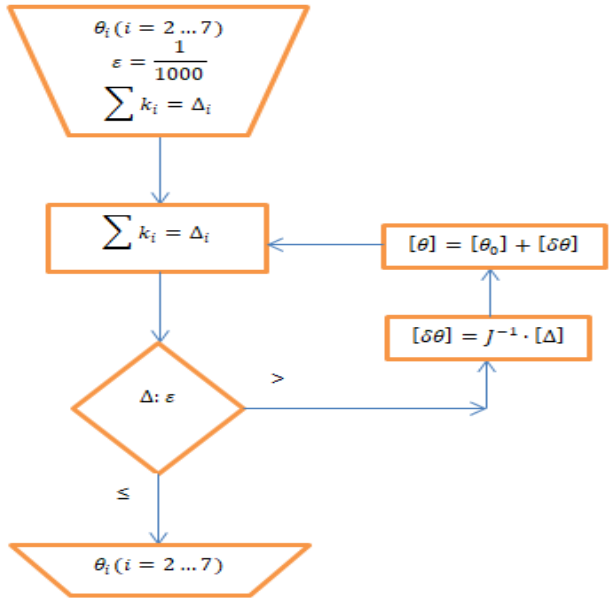
Sada $[\delta\theta]$ se računa

$$[\delta\theta] = J^{-1} \cdot [\Delta] \tag{11}$$

Novi uglovi se računaju:

$$[\theta] = [\theta_0] + [\delta\theta] \tag{12}$$

Na sledećoj slici prikazan je algoritam.



Slika 6. *Algoritam*

3.3 Brzina i ubrzanje

Kako ove konture zavise od pogonskih i gonjenih članova, mogu se zapisati kao $k = f(q_p, q_g)$.

Gdje su:
q_p – pogonski član,
q_g – gonjeni članovi.
Sada diferenciranjem dobija se brzina.

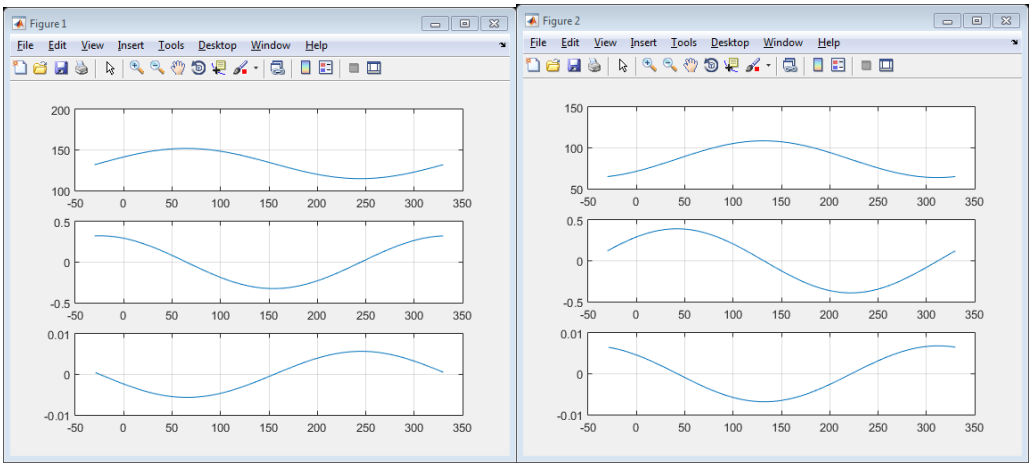
$$J \cdot \begin{bmatrix} \dot{q}_g \end{bmatrix} = -\begin{bmatrix} \frac{\partial k}{\partial q_p} \end{bmatrix} \cdot \dot{q}_p \Rightarrow \begin{bmatrix} \dot{q}_g \end{bmatrix} = -J^{-1} \cdot \begin{bmatrix} \frac{\partial k}{\partial q_p} \end{bmatrix} \cdot \dot{q}_p \tag{13}$$

Diferenciranjem jednačine (13) dobija se ubrzanje. Ako se uzme u obzir da je brzina obrtanja pogonskog člana konstanta, njen izvod će biti 0, pa se dobija sledeća jednačina:

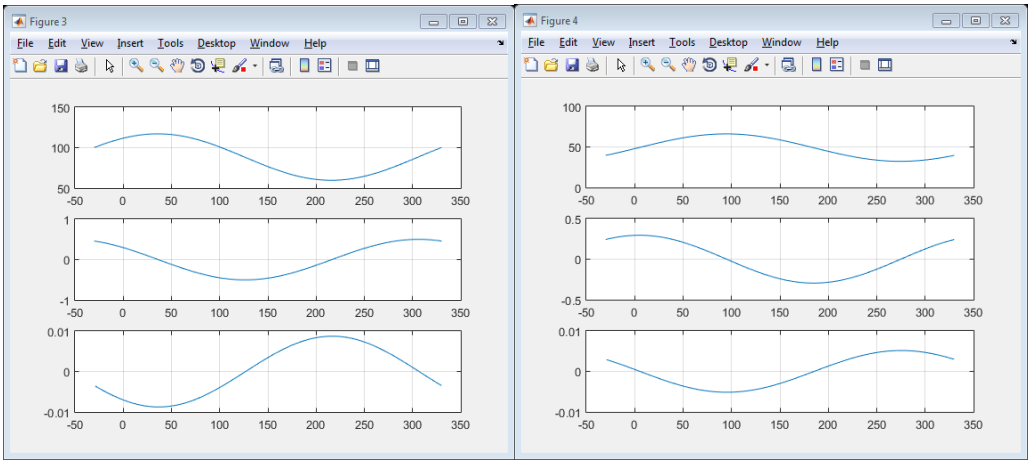
$$\left[\frac{\partial^2 k}{\partial q_p^{\,2}}\ \frac{\partial^2 k}{\partial q_g^{\,2}}\right]\cdot\begin{bmatrix}\dot{q}_p^{\,2}\\ \dot{q}_g^{\,2}\end{bmatrix}+2\cdot\left[\frac{\partial^2 k}{\partial q_p \partial q_g}\right]\begin{bmatrix}\dot{q}_p\\ \dot{q}_g\end{bmatrix}+\left[\frac{\partial^2 k}{\partial q_g^{\,2}}\right]\cdot\begin{bmatrix}\ddot{q}_g\end{bmatrix}=0 \tag{14}$$

4 SIMULACIJA

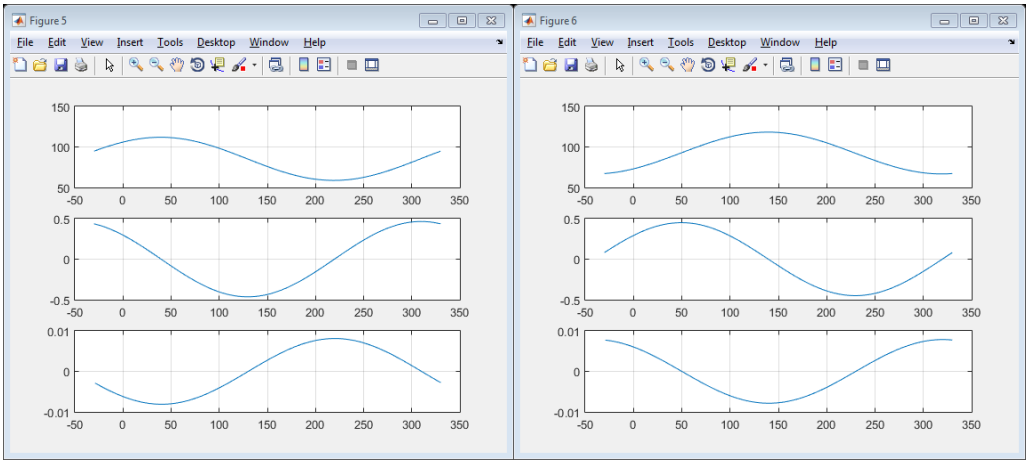
Na sledećim graficima prikazani su položaj, brzina i ubrzanje gonjenih članova.



Slika 7. *Polozaj brzina i ubrzanje člana 3 i 4*



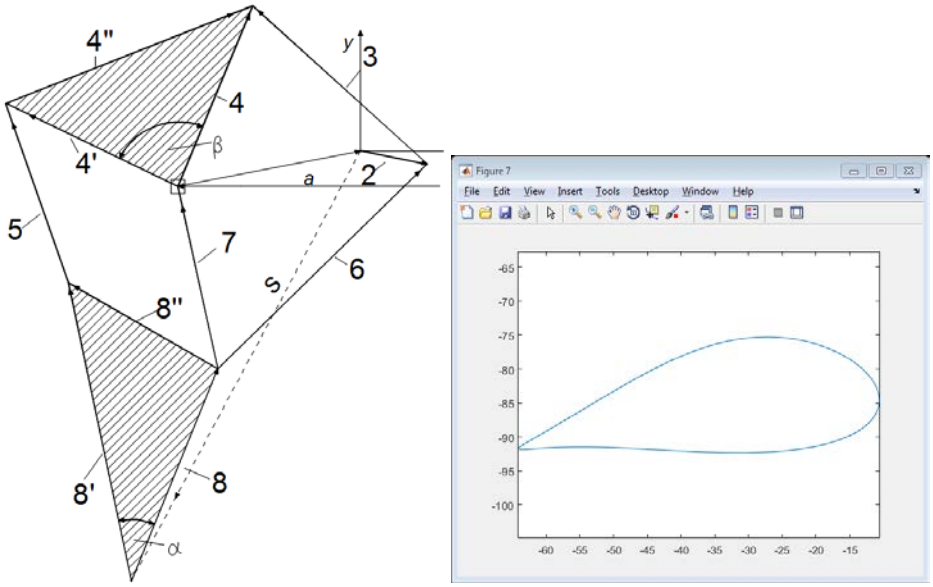
Slika 8. *Polozaj brzina i ubrzanje članova 5 i 6*



Slika 9. *Polozaj brzina i ubrzanje članova 7 i 8*

5 LOKUS

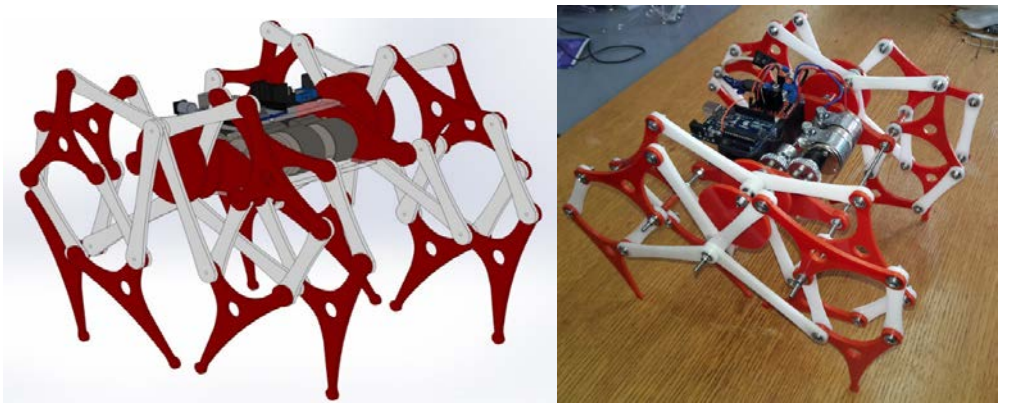
Pri rotaciji pogonskog člana konstanom brzinom, noga mehanizma pravi neku zakrivljenu liniju. Ta linija se zove lokus mehanizma. Sada ako se predstavi lokus mehanizma nekim vektorom S, projektovanjem toga vektora na *x* i *y* ose dobiće se oblik lokusa.



Slika 10. *Šema mehanizma sa S vektorom i oblik lokusa*

6 RAZVOJ HODAJUĆE PLATFORME

Na sledećim slikama se vidi 3d model platforme i njen prototip.



Slika 11. *3d model i prototip platforme*

7 ZAKLJUČAK

Ovaj mehanizam ima prednosti i mana, jedna od glavnih mana jeste to što je ovaj mehanizam ima jedan stepen slobode i njgov lokus je konstanta zakrivljena linija i ne može se promijeniti. Uprkos tome ima potencijal da bude široko korišćen jednog dana. Sa kinematskom analizom moguće je znati brzinu kretanja čitave platforme, što je jedan od neophodnih koraka za budući rad.

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PRORAČUN TROSEGMENTNOG STUBA ZA JAVNU RASVJETU

Spasoje Trifković[1], Miroslav Milutinović[2], Saša Golijanin[3]

Rezime: U radu je izvršen statički proračun stuba sa za javnu rasvjetu sa proračunom čvrstoće stuba u kritičnim presjecima za najnepovoljniji slučaj opterećenja stuba. Visina stuba je 8m sa tri segmenta iste dužine prečnika 133mm, 108mm i 76mm sa dvije noseće lire visine dužine 1,5m.

Ključne riječi: čelične konstrukcije, djelovanje vjetra, statička analiza

CALCULATION OF THREE SECTION PUBLIC LIGHTING POLES

Abstract: In this paper there are static calculation of public lighting pole for public lighting with the calculation of the strenght in critical sections for the most unsuitable case of load. The height of the pole is 8m with three segments of the same length, the first section lenght is 133mm, the second 108mm and third 76mm. The pole has two supporting brackets with lenghts and height of 1.5m.

Key words: steel structures, wind action, static analysis

1 UVOD

Analiza opterećenja stuba javne rasvjete radi se za najnepovoljniji slučaj opterećenja stuba, a to je stub visine 8 metara sa dvije noseće lire dužine i visine po 1,5m pod uglom od 180^0.

Opterećenja stuba su sljedeća:

- Opterećenje od sopstvene težine G_{ST},
- Opterećenje usled dejstva vjetra F_w,
- Opterećenje usled dejstva atmosferilija (snijeg),
- Opterećenje izazvano seizmičkim promjenama,
- Opterećenje usljed oscilovanja izazvano udarima vjetra.

Opterećenje usljed sopstvene težine obuhvata težinu svih dijelova stuba koji se nalaze iznad oslone ploče i iznosi:

$$G_{ST} = 978 \ N$$

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[3] Saša Golijanin, dipl.ing.maš., "SG engineering"s.p., Pale, BiH, sasag@teol.net

Opterećenje usljed dejstva vjetra zavisi od geografske širine i nadmorske visine lokacije montaže stuba kao i ruže vjetrova regiona u kojem se stub montira. Za proračun će se uzeti najnepovoljniji slučaj opterećenja usljed dejstva vjetra koji iznosi:

$$G_W = 1500 \frac{\mathrm{N}}{\mathrm{m}^2}$$

S obzirom da uticaj vjetra ima dimenziju pritiska, opterećenje od vjetra se manifestuje kao kontinualno opterećenje tj:

$$q_{Wi} = G_W \cdot D_i$$

gdje je "D_i" prečnik cijevi stuba koja je izložena dejstvu vjetra, iz čega se izračunava ukupna sila izazvana dejstvom vjetra na stub koja djeluje na pojedini elemenat konstrukcije stuba.

$$F_{Wi} = q_{W_i} \cdot L_i$$

Opterećenje usljed dejstva snijega na konstrukciju je takođe veličina koja zavisi od geografske širine i nadmorske visine lokacije montaže stuba a za uslove klimatske zone I, ta vrijednost iznosi:

$$G_S = 2000 \frac{\mathrm{N}}{\mathrm{m}^2}$$

Analogno opterećenju od vjetra usljed dejstva snijega specifično kontinualno opterećenje iznosi:

$$q_S = G_S \cdot D_i$$

a odgovarajuća sila izračunava se prema:

$$F_s = q_s \cdot L_i$$

Opterećenja usljed seizmičkih promjena kao i opterećenje usljed oscilovanja konstrukcije usljed udarnog dejstva vjetra za ovakve vrste konstrukcije ne uzimaju se u obzir zbog relativno male težine i visine konstrukcije, kao i zbog izrazito elastičnih svojstava konstrukcije.

2 OPTEREĆENJA U POJEDINIM PRESJECIMA STUBA

Vrijednosti opterećenja u pojedinim presjecima stuba (momenti savijanja, aksijalne i transferzalne sile) izražene su u brojčanim vrijednostima opterećenja i date u tabeli broj 1. a pojedinačne geometrijske veličine stuba date su na slici broj 1.

Tabela 1.

Pozicija	G_{ST} *(N)*	L_i *(mm)*	F_w *(N)*	D *(mm)*
teleskop 1.	252	2666	532	133
teleskop 2.	204	2667	432	108
teleskop 3.	142	2667	305	76,1
noseća lira	180	4334	390	60
svjetiljka	100	-	-	-

2.1 Momenti savijanja

Presjek "A-A":

$$M_A = F_{W1} \cdot 1333 + F_{W2} \cdot 4000 + F_{W3} \cdot 6666 + F_{W4} \cdot (1142 + 8000)$$

$$M_A = 8{,}04 \ kNm$$

Presjek "B-B":

$$M_B = F_{W2} \cdot 1333 + F_{W3} \cdot 4000 + F_{W4} \cdot (6666 + 1142)$$

$$M_B = 4{,}32 \ kNm$$

Presjek "C-C":

$$M_C = F_{W3} \cdot 1333 + F_{W4} \cdot (2667 + 1142)$$

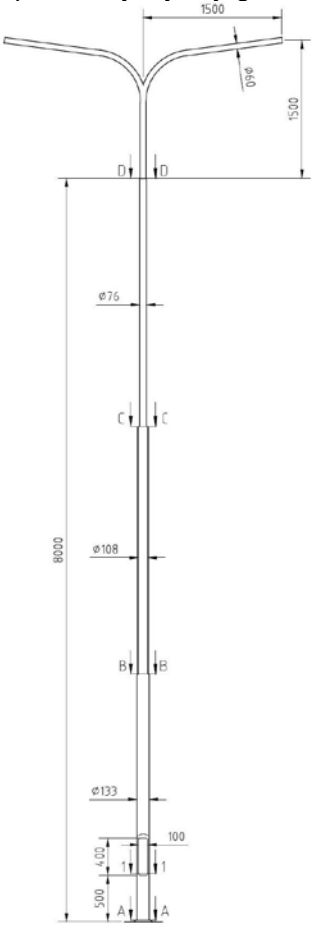
$$M_C = 1{,}892 \ kNm$$

Presjek "D-D":

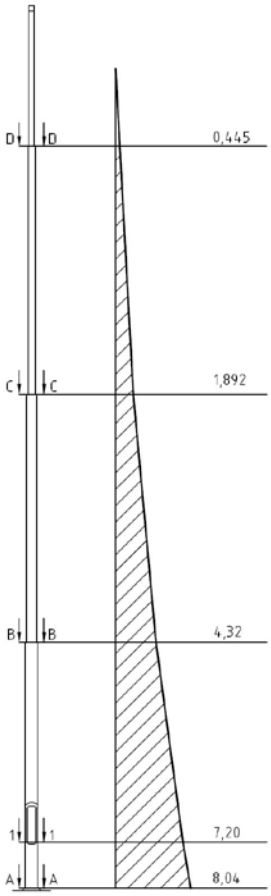
$$M_D = F_{W4} \cdot 1142$$

$$M_D = 0{,}445 \ kNm$$

Na slici broj 2. predstavljen je dijagram momenata savijanja stuba.



Slika 1.



Slika 2.

2.2 Transferzalne sile po presjecima

Presjek "A-A":

$$F_{TA} = F_{W1} + F_{W2} + F_{W3} + F_{W4}$$

$$F_{TA} = 1659 \ N$$

Presjek "B-B":

$$F_{TB} = F_{TA} - F_{W1}$$

$$F_{TB} = 1127 \ N$$

Presjek "C-C":

$$F_{TC} = F_{TB} - F_{W2}$$

$$F_{TC} = 695 \ N$$

Presjek "D-D":

$$F_{TD} = F_{TC} - F_{W3}$$

$$F_{TD} = 390 \ N$$

2.3 Aksijalne sile po presjecima

Presjek "A-A":

$$F_{AA} = G_{ST1} + G_{ST2} + G_{ST3} + G_{ST4} + 2 \cdot G_{SS}$$

$$F_{TA} = 978 \ N$$

Presjek "B-B":

$$F_{AB} = F_{AA} - G_{ST1}$$

$$F_{AB} = 726 \ N$$

Presjek "C-C":

$$F_{AC} = F_{AB} - G_{ST2}$$

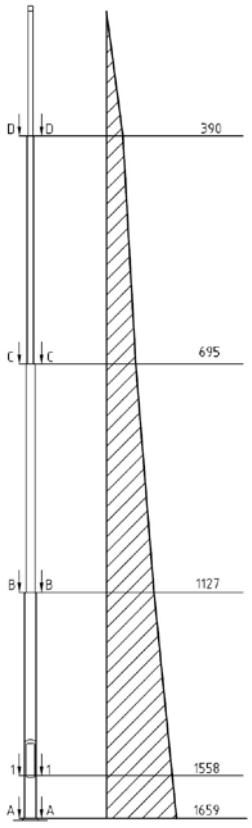
$$F_{AC} = 522 \ N$$

Presjek "D-D":

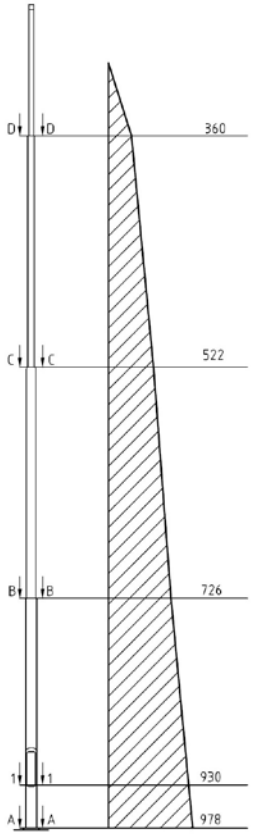
$$F_{AD} = F_{AC} - G_{ST3}$$

$$F_{AD} = 360 \ N$$

Na slici 3 prikazan je dijagram transferzalnih sila a na slici 4. dijagram aksijalnih sila.



Slika 3.



Slika 4.

3 KRITIČNI PRESJEK STUBA ZA RASVJETU

Kritični presjek stuba za rasvjetu nalazi se na najnižoj teleskopskoj cijevi na mjestu gdje je na cijevi izrezan pravougaoni otvor dimenzija 100x400 mm, koji predstavlja revizioni otvor za spajanje elektro kablova. Početak izrezanog dijela cijevi (revizionog otvora) nalazi se na visini od 500mm od gornje površine noseće stope stuba za rasvjetu, pa se kritični presjek stuba za rasvjetu nalazi na rastojanju od 505mm od gornje površine noseće stope stuba. Na slici broj 1. kritični presjek označen je kao presjek ”1-1”.

Vrijednosti statičkih opterećenja u tom presjeku iznose:

3.1 Moment savijanja kritičnog presjeka

$$M_{1-1} = M_A - F_{TA} \cdot 0,505$$
$$M_{1-1} = 7,2 \ kNm$$

3.2 Transferzalna sila u kritičnom presjeku

$$F_{T1-1} = F_{TA} - \Delta F_T$$

Gdje je :

$$\Delta F_T = 0,133 \cdot 0,505 \cdot 1500$$
$$\Delta F_T = 101 \ N$$

pa je vrijednost transferzalne sile u kritičnom presjeku:

$$F_{T1-1} = 1558 \ N$$

3.3 Aksijalna sila u kritičnom presjeku

$$F_{A1-1} = F_{AA} - \Delta F_A$$

Gdje je :

$$\Delta F_A = \left(0,133^2 - 0,127^2\right) \cdot \frac{\pi}{4} \cdot 0,505 \cdot 7850 \cdot g$$
$$\Delta F_A = 48 \ N$$

pa je vrijednost aksijalne sile u kritičnom presjeku:

$$F_{A1-1} = 930 \ N$$

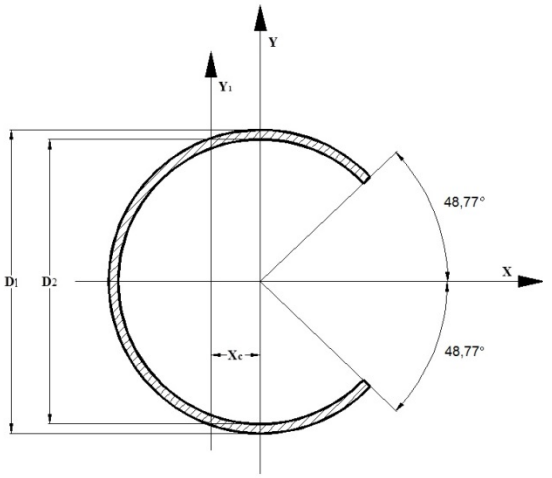
4 GEOMETRIJSKE VRIJEDNOSTI PRESJEKA

Relevantne geometrijske vrijednosti pojedinih presjeka konstrukcije stuba za rasvjetu date su u tabeli broj 2. To su površine i otporni momenti presjeka.

Tabela 2.

Presjek	*Prečnik cijevi (mm)*	*Površina (mm^2)*	*Otporni moment (mm^3)*
"A-A"	133/3	1225	38942
"B-B"	108/3	989	25276
"C-C"	76,1/3	689	12114
"D-D"	60/3	537	7292

Za određivanje naponskih stanja u kritičnom presjeku potrebno je odrediti geometrijske karakteristike kritičnog presjeka prema sledećim obrascima (prema slici broj 5.).



Slika 5.

Relevantne vrijednosti računaju se prema sledećim obrascima [1] :

Površina kritičnog presjeka:

$$A = \frac{D_1^2 - D_2^2}{4} \cdot \pi \left(1 - \frac{\alpha}{180°}\right)$$

Otporni moment kritičnog presjeka za osu Ox:

$$W_x = \frac{D_1^2 - D_2^2}{32 \cdot D_1} \cdot \left(\pi - \alpha + 0{,}5 \cdot \sin 2\alpha\right)$$

Otporni moment kritičnog presjeka za osu Oy1:

$$W_{Y1} = \frac{I_{Y1}}{X_{\max}}$$

gdje je:

I_{Y1} - moment inercije za osu Y_1,

D_1 - vanjski prečnik cijevi = 133 mm,

D_2 - unutrašnji prečnik cijevi = 127 mm,

α - ugao isječenog dijela = 48,77°.

Momenat inercije za osu Y_1 izračunava se prema:

$$I_{Y1} = \frac{D_1^2 - D_2^2}{64} \cdot \left(\pi - \alpha - 0{,}5 \cdot \sin 2\alpha\right) - X_C^2 \cdot A$$

a vrijednosti X_C i X_{max} se izračunavaju prema:

$$X_C = \frac{\int x_C \cdot dA}{\int dA} = 21{,}3458 \ mm$$

$$X_{\max} = X_C + 0{,}5 \cdot D_1 \cdot \cos\alpha = 65{,}17 \ mm$$

Slijedi:

$A = 893 \ mm^2 \qquad W_x = 34536 \ mm^2 \qquad W_y = 16456 \ mm^2$

Za proračun je mjerodavan otporni momenat W_Y jer je manji.

5 ANALIZA NAPONA PO PRESJECIMA

5.1 Naponi usljed aksijalnih i transferzalnih sila

Naponi u presjecima usljed dejstva aksijalnih i transferzalnih sila provjeriti će se u kritičnom presjeku stuba za rasvjetu kao i u presjeku “A-A” u polju presjeka osnovnog materijala i polju presjeka zavarenog spoja.

Dozvoljeni naponi za projektovani materijal Č.1533 iznose:

$$\sigma_E = 590 \frac{N}{mm^2} \qquad \tau_E = 380 \frac{N}{mm^2}$$

5.2 Naponi u presjeku “A-A”

Vrijednost tangencijalnog napona u materijalu u presjeku “A-A” iznosi:

$$\tau_{A-A} = \frac{F_{TA}}{A_A}$$

gdje je :

F_{TA} - transferzalna sila u presjeku "A-A" = 1659 N,

A_A - površina presjeka teleskopske cijevi = 1225 mm^2.

Slijedi:

$$\tau_{A-A} = 1{,}35 \frac{N}{mm^2} < \tau_E$$

Vrijednost tangencijalnog napona je daleko manja od dozvoljene vrijednosti, pa nije potrebno računati koeficijent sigurnosti.

Vrijednost normalnog napona u materijalu u presjeku “A-A" iznosi:

$$\sigma_{A-A} = \frac{M_A}{W_A}$$

gdje je :

M_A – moment savijanja presjeka "A-A" = 8,04 kNm,

W_A – otporni moment presjeka "A-A" = 16456 mm^3.

Slijedi:

$$\sigma_{A-A} = 206{,}5 \frac{N}{mm^2} < \sigma_E$$

Koeficijent sigurnosti iznosi:

$$S = \frac{\sigma_E}{\sigma_{A-A}} = \frac{590}{206{,}5} = 2{,}87$$

5.3 Naponi u kritičnom presjeku

Vrijednost tangencijalnog napona u kritičnom presjeku iznosi:

$$\tau_{1-1} = \frac{F_{T1-1}}{A_{1-1}}$$

gdje je:
F_{T1-1} - transferzalna sila u kritičnom presjeku = 1558 N,
A_{1-1} - površina kritičnog presjeka = 893 mm^2

$$\tau_{1-1} = 1,74 \frac{N}{mm^2} < \tau_E$$

Vrijednost tangencijalnog napona je mala pa nije potrebno računati koeficijent sigurnosti.
Vrijednost normalnog napona u kritičnom presjeku iznosi:

$$\sigma_{1-1} = \frac{M_{1-1}}{W_Y}$$

M_{1-1} – moment savijanja presjeka "1-1" = 7,2 kNm,
W_Y – otporni moment presjeka "1-1" = 38942 mm^3.
Slijedi:

$$\sigma_{1-1} = 488.56 \frac{N}{mm^2} < \sigma_E$$

Koeficijent sigurnosti iznosi:

$$S = \frac{\sigma_E}{\sigma_{1-1}} = \frac{590}{488,56} = 1,21$$

6 ZAKLJUČAK

Na osnovu rezultata računske provjere može se konstatovati da je konstrukcija trosegmentnog suba za javnu rasvjetu dužine 8 m sa dvije lire izvedena kompaktno, sa koeficijentima sigurnosti dovoljnim za bezbjednu upotrebu. Proračun je pokazao da da je vrijednost tangencijalnog napona u kritičnim presjecima daleko manja od dozvoljene vrijednosti dok je vrijednost normalnog napona u presjeku "1-1" visoka. Vrijednost normalnog napona mogla bi se smanjiti pomjeranjem revizionog otvora sa sadašnjih 500mm na veću visinu a time bi se i olakšalo održavanje.

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POČETNA ISTRAŽIVANJA S CILJEM RAZVOJA METODOLOGIJE ZA PROCJENU INTEGRITETA CILINDARSKOG SKLOPA AVIONSKOG KLIPNOG MOTORA

Nikola Vučetić[1], Gordana Jovičić[2], Vladimir Milovanović[3], Branimir Krstić[4], Dragan Rakić[5], Radoslav Tomović[6], Ranko Antunović[7]

Rezime: U radu je dat pregled istraživanja mehaničkih otkaza različitih strukturnih elemenata vazduhoplova, kao u učestalost pojedinih mehanizama otkaza. Naveden je konkretan problem pucanja glave cilindra avionskog vazdušno hlađenog klipnog motora, te je predstavljen plan i cilj istraživanja u cilju razvoja metodologije za procjenu integriteta cilindarskog sklopa. U okviru planiranih istraživanja neophodno bi bilo izvršiti eksperimentalnu analizu mehaničkih karakteristika legure aluminijuma 242.0 na sobnoj i povišenoj temperaturi, kao i numeričku analizu cilindarskog sklopa. Prikazani su očekivani rezultati istraživanja, kao i zaključna razmatranja vezana za značaj samog istraživanja.

Ključne riječi: glava cilindra, mehanički otkaz, procjena integriteta, povišena temperatura, prslina, vazduhoplov.

RESEARCH WITH THE AIM OF METHODOLOGY FOR THE INTEGRITY ASSESSMENT OF AIRCRAFT PISTON ENGINE CYLINDER ASSEMBLY DEVELOPMENT

Abstract: This paper shows an overview of the investigation of various structural elements of the aircraft mechanical failures, as well as frequency of certain failure mechanisms. The specific problem of aircraft air-cooled piston engine cylinder head fracture is presented and the plan and the aim of the research were presented in order to develop a methodology for the integrity assessment of cylinder assembly. Within the planned research it is necessary to perform an experimental analysis of the mechanical properties of aluminum alloy 242.0 at room temperature and elevated temperature, as well as the numerical analysis of the cylinder assembly. The expected results of the

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research, as well as the final considerations related to the significance of the research are presented.

Key words: cylinder head, mechanical failure, integrity assessment, elevated temperature, crack, aircraft.

1 UVOD

Mehanički otkazi različitih strukturnih elemenata vazduhoplova su čest slučaj u praksi [1,2,3,4,5,6,7,8,9,10,11,12,13,14,15]. Brojni su uzročnici otkaza poput korozije, grešaka u materijalu, odnosno poroznosti, visokocikličnog zamora i slično. Ovakvi elementi u savremenoj vazduhoplovnoj industriji moraju zadovoljiti povećan nivo pouzdanosti u toku rada. Zamor materijala, praćen korozijom, je bio dominantan uzrok pucanja vratila na kormilu borbenog mlaznog aviona [1]. Branimir Krstić i sar. [2] su analizirali problem pucanja cijevi stajnog trapa helikoptera Gazelle SA 341H. Na osnovu sprovedenog istraživanja, korozija se pokazala kao glavni uzročnik otkaza. Pucanje montažnog vijka na glavnom nosaču mjenjača helikoptera [3] se dogodilo tokom leta, pri čemu se pristupilo analizi i utvrđivanju uzroka otkaza na osnovu spektroskopske, fraktografske, metalografske analize, te analize konačnim elementima na osnovu kojih je potvrđeno da je lom vijka na dva dijela nastao u prisustvu korozije. S ciljem analize uzroka pucanja poluge stajnog trapa civilnog aviona [4], Bagnoli i sar. su izvršili vizuelni pregled, spektrografsku analizu, metalografsku analizu i analizu metodom konačnih elemenata. Na osnovu navedenog utvrdili su da je postojanje inicijalne prsline na spoljašnjoj površini izazvalo prethodni problem. Inspekcijom nakon leta primijećeno je postojanje prslina na APU jedinici vazduhoplova C27-J. Bagnoli i sar. [5] su analizom navedenog problema došli do zaključka da je visikociklični zamor bio presudan za navedeni otkaz. Uzrok pada aviona u Holandiji je bio predmet istraživanja u radu [10]. Fraktografskom analizom je utvrđeno da je naponska korozija dovela do otkaza pogonskog motora. Na šestocilindričnom avionskom motoru nakon, približno, 600 časova rada primijećene su prsline između rashladnih rebara na aluminijumskoj glavi cilindra na strani izduvnog otvora i oko izduvnog ventila [11]. Prsline su otkrivene korišćenjem penetrantske tečnosti. Na osnovu makroskopskog ispitivanja, hemijske analize i miskorstrukturne analize utvrđeno je da je poroznost materijala bila dominantan uzrok problema. Analizom pucanja preklopne poluge aviona MB339 CD bavili su se Allegrucci i sar. [12]. Elektronskom miskroskopijom je utvrđeno da se prslina pojavila na unutrašnjim ivicama na mjestima sa najvišim naponima, što je potvrđeno i analizom konačnim elementima. Dalja ispitivanja su dovela visokociklični zamor u vezu sa otkazom. U publikaciji [13] je analiziran uzroka pojave zamorne prsline na kućištu cilindra koji predstavlja dio hidrauličnog sistema aviona. Na osnovu analize problema izveden je zaključak da bi promjena geometrije udubljenja cilindra, s ciljem smanjivanja napona, mogla da bude rješenje navedenog istraživanja. Pojava pucanja uljnog katera avionskog klipnog motora [14] navela je da se Zhongjian i sar. posvete analizi navedenog problema. Utvrdili su postojanje visokocikličnog zamora na kliznom ležaju u kućištu uljnog kartera. U radu [15] je prikazan mehanizam loma propelera aviona Cesna-185. Istraživanje je uključivalo metalografiju, test tvrdoće i fraktografsku analizu.

2 UČESTALOST MEHANIZAMA OTKAZA

Na osnovu sprovedenih istraživanja, Findlay i Harrison su dali procjenu učestalosti mehanizama otkaza vazduhoplovnih komponenti [16], tabela 1.

Tabela 1. *Učestalost mehanizama otkaza vazduhoplovnih komponenti [16]*

Mehanizam otkaza	**Zastupljenost otkaza kod vazduhoplovnih komponenti [%]**
Zamor	55
Korozija	16
Prerećenje	14
Naponska korozija, zamorna korozija	7
Habanje, abrazija, erozija	6
Korozija usljed povišene temperature	2

Rezultati iz tabele 1 pokazuju da se kod otkaza vazduhoplovnih komponenti kao dominantan uzrok tretira zamor sastavnih komponenti [17,18,19,20].

Jedan od učestalih mehaničkih otkaza na vazdušno hlađenim klipnim avionskim motorima je pucanje glave cilindra. Na osnovu izvještaja nadležnih vazduhoplovnih vlasti zemalja širom svijeta [21,22,23,24] zabilježeno je čak 47 ovakvih otkaza na motorima sa klasičnom vazdušno hlađenom konstrukcijom koja podrazumijeva da je svaki cilindarski sklop (cilindar), koji sačinjavaju tijelo cilindra i glava cilindra, posebna cjelina sa prepoznatljivim i jasno izraženim dubokim rashladnim rebrima na spoljašnjoj strani [25].

3 PREDMET I CILJ ISTRAŽIVANJA

Ovaj rad predstavlja nastavak istraživanja uzroka problema pucanja glave cilindra školskog aviona Utva [25,26,27,28] u cilju razvoja metodologije za procjenu integriteta cilindarskog sklopa avionskog klipnog motora izloženog visokocikličnom mehaničkom i termičkom opterećenju.

Poseban značaj, doprinos i kompleksnost istraživanja ogleda se u činjenici da u literaturi nema zastupljenih radova koji se odnose na eksperimentalno utvrđivanje mehaničkih karakteristika navedenog materijala, za razliku od mnogobrojnih legura aluminijuma koje su bile čest predmet istraživanja brojnih autora [29,30,31,32,33,34].

Razmatranje navedenog problema bi zahtjevalo sprovođenje eksperimentalnih ispitivanja legure aluminijuma 242.0, kao sastavne legure glave cilindra, gdje bi se, pored karakteristika na sobnoj temperaturi, odredile i mehaničke karakteristike materijala na povišenoj temperaturi koja predstavlja temperaturu koja se javlja u toku eksploatacije.

3.1 Hemijska analiza materijala

Analiza hemijskog sastava aluminijuma 242.0, od koga je izrađena glava cilindra avionskog motora Lycoming IO-360-B1F, je urađena metodom fluorescentne spektografije H-zracima. Hemijska analiza legure aluminijuma 242.0 je izvršena u Laboratoriji za ispitivanje materijala/proizvoda u okviru preduzeća Orao a.d. iz Bijeljine.

Rezultati analize hemijskog sastava materijala u potpunosti odgovaraju standardnoj specifikaciji za aluminijsku leguru 242.0, tabela 2.

Tabela 2. *Rezultati hemijskog sastava aluminijske legure 242.0*

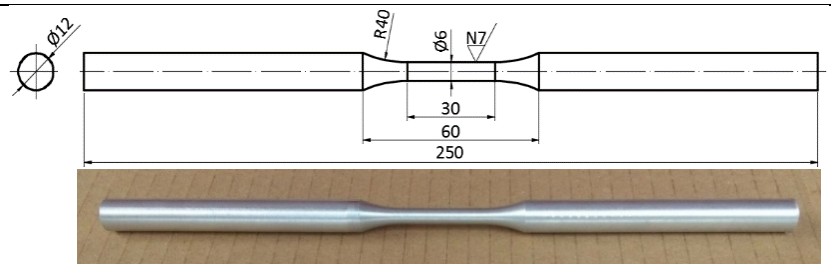
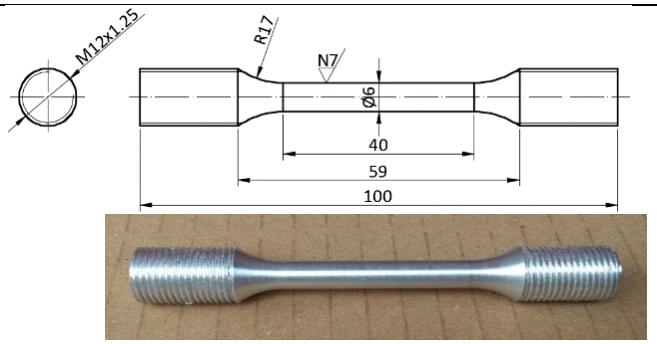
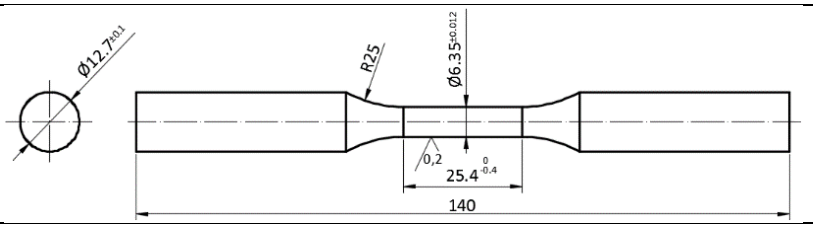
Element	Cu	Cr	Fe	Mg	Mn	Ni	Si	Ti	Zn
Удио [%]	4,02 (3,5-4,5)	0,20 (0-0,25)	0,45 (0-1,0)	1,52 (1,2-1,8)	0,06 (0-0,35)	2,29 (1,7-2,3)	0,46 (0-0,7)	0,15 (0-0,25)	0,03 (0-0,35)

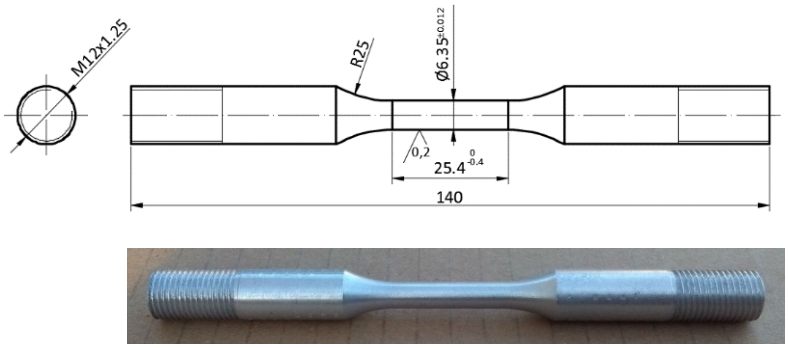
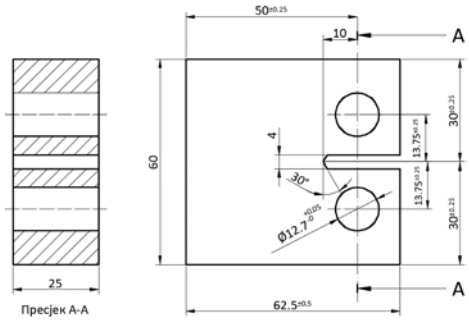
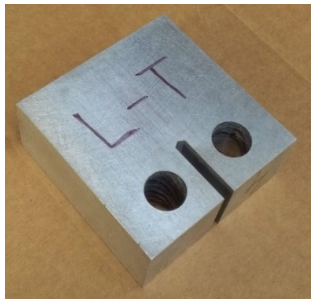
Inače, osnovna primjena navedene legure je izrada cilindarskih glava vazdušno hlađenih avionskih motora.

3.2 Eksperimentalna ispitivanja mehaničkih karakteristika

U tabeli 3 prikazane su planirane vrste ispitivanja nad navedenom legurom aluminijuma u cilju određivanja mehaničkih karakteristika materijala i osnovnih parametara mehanike loma neophodnih pri daljoj analizi problema.

Tabela 3. *Ispitivanje mehaničkih karakteristika legure aluminijuma 242.0*

Vrsta ispitivanja	**Crtež i izgled epruvete**
Ispitivanje statičkih karakteristika na sobnoj temperaturi	
Ispitivanje statičkih karakteristika na povišenoj temperaturi	
Ispitivanje zamornih karakteristika na sobnoj temperaturi	

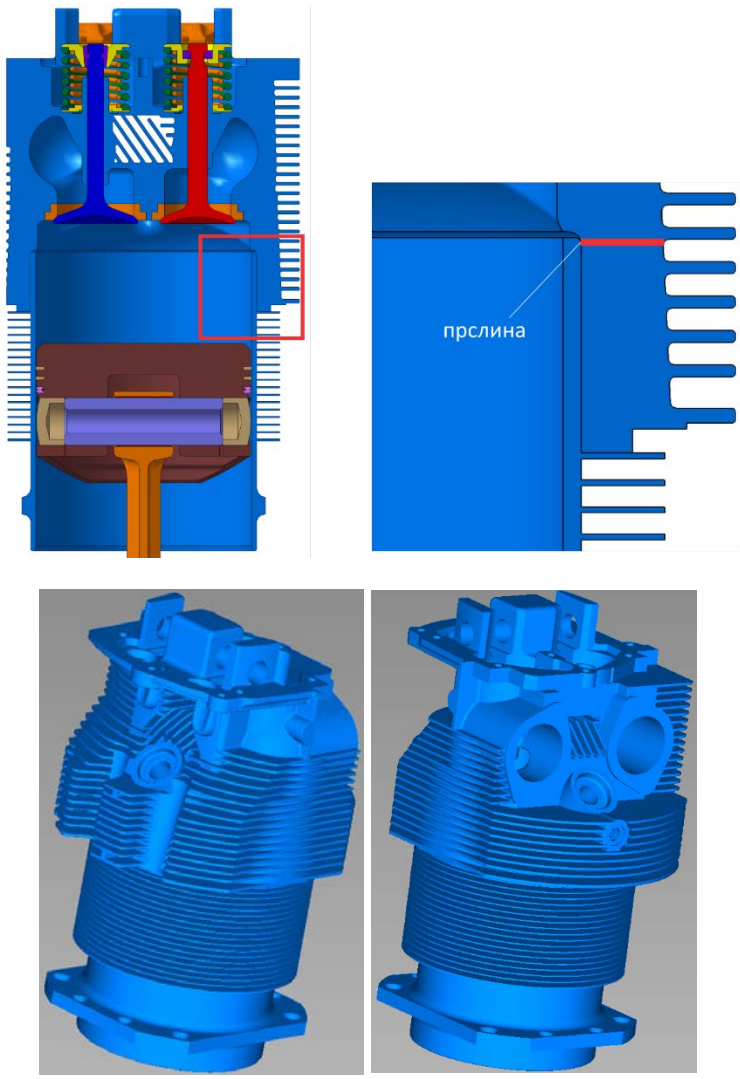
	
Ispitivanje zamornih karakteristika na povišenoj temperaturi	
Ispitivanje lomne žilavosti na sobnoj i povišenoj temperaturi	 

Eksperimentalno određene rezultate bi pratila numerička analiza u okviru koje bi se modeliralo složeno termomehaničko opterećenje.

3.3 Numerička analiza cilindarskog sklopa

Cilindarski sklop je vazdušno hlađen i čine ga tijelo (cilindar) i glava cilindra. Tijelo cilindra je izrađeno od otkivka CrNiMo čelika oznake AISI 4140 (prema American Iron and Steel Institute sistemu označavanja). Unutrašnji dio cilindra je brušen i honovan, a na spoljašnjem dijelu su duboka rashladna rebra. Veza cilindra sa kućištem motora je ostvarena preko osam vijaka.

Model cilindarskog sklopa *Lycoming IO-360-B1F* agregata prikazan je na slici 1.



Slika 1. *Model cilindarskog sklopa avionskog klipnog motora*

Zbog zahtjeva za dobrom toplotnom provodljivošću i dobrim mehaničkim karakteristikama na povišenim temperaturama, glava cilindra je izrađena postupkom livenja od legure aluminijuma oznake 242.0 (prema American National Standard Institute sistemu označavanja) sa mašinski obrađenom komorom za sagorijevanje. Na spoljašnjoj strani glave cilindra se, takođe, nalaze duboka rashladna rebra.

Stoga, granični uslovi bi trebali da se razmotre pažljivo i da se što realnije simuliraju realna ograničenja i opterećenja, kao i tip konačnog elementa, te gustina konačno-elementne mreže. Veza tijela i glave cilindra se ostvaruje na način da se glava cilindra zagrijava do temperature od približno 350^0C, pa se tako zagrijana pričvršćuje na tijelo cilindra navojnom vezom preko navoja na spoljašnjoj strani tijela cilindra i

unutrašnjoj strani glave cilindra. Hlađenjem glave cilindra ostvaruje se čvrsto nalijeganje u zoni navoja, kao i između glatkih cilindričnih površina iznad navojnog spoja. Dakle, veza cilindra i glave bi bila numerički simulirana kao kruta veza. Postolje cilindra bi bilo fiksirano, što odgovara i realnom slučaju, jer je u praksi tijelo cilindra vezano vijcima za kućište motora. Opterećenje bi bilo modelirano kao složeno mehaničko (pritisak na glavu cilindra) i termičko koje odgovara temperaturi kojoj je izložena glava cilindra u toku eksploatacije. Prethodni problem bi bio razmatran u nekom od numeričkih programskih paketa zasnovanih na analizi metodom konačnih elemenata.

4 OČEKIVANI REZULTATI

Primjenom prethodno navedenih istraživanja očekuju se sljedeći ključni rezultati:

- Određivanje mehaničkih karakteristika materijala legure aluminijuma 242.0 na sobnoj i povišenoj temperaturi;
- Određivanje parametara mehanike loma legure aluminijuma 242.0: prag faktora intenziteta napona, žilavost loma, brzina rasta prsline;
- Utvrđivanje potencijalnog uzroka pojave prsline na glavi cilindra avionskog vazdušno hlađenog klipnog motora i otkaza istog;
- Razvoj metodologije za procjenu integriteta cilindarskog sklopa avionskog vazdušno hlađenog klipnog motora pri visokocikličnom mehaničkom i termičkom opterećenju;
- Određivanje broja ciklusa do otkaza, odnosno radnog vijeka cilindarskog sklopa sa inicijalnom prslinom;
- Utvrđivanje mogućih daljih pravaca istraživanja;

5 ZAKLJUČAK

U naučnoj domaćoj i svjetskoj literaturi je, uprkos velikom broju slučajeva otkaza cilindarskih sklopova vazdušno hlađenih avionskih klipnih motora usljed postojanja prsline, zabilježen mali broj radova koji su razmatrali navedenu problematiku. Na osnovu navedene činjenice moguće je spoznati važnost istraživanja koje bi, na osnovu eksperimentalno određenog dovoljnog broja podataka o ispitivanom materijalu, te na osnovu numeričke analize modela cilindarskog sklopa, omogućilo da se u potpunosti i sa dovoljnom sigurnošću i tačnošću procijeni integritet cilindarskog sklopa avionskog klipnog motora.

Cilj ove disertacije bi bio razvoj metodologije za eksperimentalnu i numeričku procjenu integriteta cilindarskog sklopa avionskog klipnog motora sa uočenom prslinom na glavi cilindra izloženog promjenljivom mehaničkom i termičkom opterećenju, a koja bi mogla da bude primjenljiva i na ostale konstruktivne mašinske elemente. To bi omogućilo da se na jednostavan i brz način izvrši procjena integriteta cilindarskog sklopa klipnog motora sa uočenom prslinom, zahvaljujući čemu bi se postigle značajne uštede u troškovima projektovanja, proizvodnje, kao i ispitivanja drugih vitalnih elemenata motora sa unutrašnjim sagorijevanjem koji su bili ili se još uvijek nalaze u fazi eksploatacije, što bi navedenu metodologiju činilo efektivnom i efikasnom u primjeni.

Poseban doprinos ove disertacije bi se ogledao kroz kompleksnost prirode opterećenja razmatranog problema u kome se pojavljuju, pored dinamičkih, i termička opterećenja koja bi se morala uzeti u obzir pri eksperimentalnoj i numeričkoj analizi u okviru graničnih uslova i zadatih opterećenja.

Ovakvi rezultati bi bili od velikog značaja, kako pri izradi ove disertacije, tako i za dalja istraživanja u oblasti mehanike loma i zamora vezana za problematiku pucanja konstruktivnih elemenata izrađenih od pomenutog materijala za koji se, u trenutno dostupnoj literaturi, ne može pronaći dovoljan broj eksperimentalnih rezultata utvrđenih na sobnoj, a posebno na povišenoj temperaturi. Doprinos i značaj ove disertacije bi se ogledao u spoznaji učestalosti problema pucanja glave cilindra avionskog vazdušno hlađenog klipnog motora, kao i u mogućnosti razvoja iznad pomenute metodologije.

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ANALIZA VIBRACIJA JEDNOSLOJNIH GRAFENSKIH NANOPLOČA PRIMJENOM NELOKALNE TEORIJE GRADIJENTA DEFORMACIJE

Biljana Mijatović[1], Dejan Jeremić[2], Nebojša Radić[3]

Rezime: U ovom radu je analizirano vibraciono ponašanje jednoslojnih grafenskih nanoploča. Jednačine kretanja su izvedene na osnovu Hamiltonovog principa primjenom Eringenovog zakona, a zatim su riješene primjenom Galerkinove metode za različite granične uslove. Prezentovan je uticaj Vinklerovog parametra, nelokalnih parametara, dimenzija nanoploče, graničnih uslova i broja polutalasa na frekvenciju oscilovanja.

Ključne riječi: Galerkinov metod, jednačine kretanja, jednoslojna grafenska nanoploča, teorija nelokalnog gradijenta deformacije.

ANALYSIS OF VIBRATION BEHAVIOUR OF SINGLE-LAYERED GRAPHENE NANOPLATES USING NONLOCAL STRAIN GRADIENT THEORY

Abstract: The present study investigates the vibration behaviour of single-layered grapheme nanoplate. Equations of motion are derived by using Hamilton's principle with the consideration the Eringen's law and then analytically solved by using Galerkin's method with various boundary conditions. Effects of Winkler's parameter, nonlocal parameters, size of nanoplate, boundary conditions and number of half waves on vibrational frequency are presented.

Key words: Equations of motion, Galerkin's method, nonlocal strain gradient theory, single-layered graphene nanoplate.

1. UVOD

Teorija nelokalnog gradijenta deformacije je prvo formulisana od strane Mindline [1] i ona predstavlja drugu nelokalnu teoriju koja uzima u obzir veličinu

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posmatranog objekta na njegovo mehaničko ponašanje. Prva formulacija teorije nelokalnog gradijenta deformacije je vrlo složena i sadrži 18 nezavisnih materijalnih konstanti za izotropni homogeni elastični materijal. Zbog toga se pojavilo nekoliko radova sa ciljem redukcije broja nezavisnih materijalnih konstanti.

Kod teorije nelokalnog gradijenta deformacije je efekat veličine inkorporiran u model sa malim nelokalnim parametrom dužine (poznat kao parametar gradijenta deformacije). U nelokalnoj teoriji gradijenta deformacije napon zavisi od deformacije i njenog gradijenta. Konstitutivna jednačina teorije nelokalnog gradijenta deformacije predstavlja parcijalnu diferencijalnu jednačinu u kojoj su linearni diferencijalni operator i parametar gradijenta deformacije primjenjeni na deformaciju na desnoj strani jednačine, dok se na lijevoj strani nalazi napon. Za razliku od deformacijski upravljane nelokalne elastične teorije, naponski upravljana nelokalna elastična teorija predviđa samo efekat povećanja krutosti. Lim i dr. [2] su prezentovali jedan redukovani model teorije nelokalnog gradijenta deformacije višeg reda. Ovaj model u sebi sadrži dva parametra dužine (nelokalni parametar napona i parametar gradijenta deformacije). U ovom redukovanom modelu je istovremeno inkorporiran efekat veličine gradijenta napona i efekat veličine gradijenta deformacije. Koristeći isti model u radovima [3,4,5] je izvršena analiza post-izvijanja, vibracija i širenje talasa u nanogredama. U sva tri rada je za primjenjeni model korišten izraz teorija nelokalnog gradijenta deformacije (NSGT). Zhu i Li [6] su pokazali da je NSGT kombinacija konstitutivnih jednačina deformacijski upravljanih i naponski upravljanih nelokalnih teorija. Koristeći napon-deformacija upravljanu nelokalnu teoriju zavisno od koeficijenta nelokalnog parametra napona i parametra gradijenta deformacije mogu se modelirati nanostrukture sa efektom smanjenja krutosti i efektom povećanja krutosti. Zbog toga se u posljednje vrijeme ova teorija od strane mnogih istraživača koristi u analizi mehaničkog ponašanja struktura koji zavise od veličine [7,8].

U ovom radu su korištene teorija nelokalnog gradijenta deformacije za analizu vibracija jednoslojne grafenske nanoploče. Dva parametra veličine koji se zovu nelokalni parametar napona i parametar gradijenta deformacije su razmatrani i ubačeni u model. Jednačine kretanja su izvedene korištenjem Hamiltonovog principa, a zatim su analitički riješene primjenom Galerkinove metode. Vrijednosti frekvencije oscilovanja su izvedena za više graničnih uslova.

2. TEORIJA NELOKALNOG GRADIJENTA DEFORMACIJE

Lim [2] je predložio generalnu konstitutivnu jednačinu teorije nelokalnog gradijenta deformacije višeg reda u diferencijalnom obliku.

$$[1-(e_1 a)^2\nabla^2][1-(e_0 a)^2\nabla^2]t_{ij} = C_{ijkl}[1-(e_1 a)^2\nabla^2]\varepsilon_{kl} - C_{ijkl}l^2[1-(e_0 a)^2\nabla^2]\nabla^2\varepsilon_{kl} \quad (1)$$

2.1 Nova smičuća deformaciona teorija prvog reda (NFSDT)

U skladu sa smičućom deformacionom teorijom prvog reda (FSDT), polje pomjeranja bilo koje tačke posmatrane ploče može se definisati kao:

$$u_x(x,y,z) = u(x,y) - z\frac{\partial\theta}{\partial x}$$
$$u_y(x,y,z) = v(x,y) - z\frac{\partial\theta}{\partial y} \quad (2)$$
$$u_z(x,y,z) = w(x,y)$$

U jednačini (2) *u,v* su pomjeranja tačke *(x,y)* u srednjoj ravni, *w* je pomjeranje tačke *(x,y)* u poprečnom pravcu. Dalje, *θ* je parametar rotacije normalne na srednju ravan oko *y* i *x* osa.

Komponente tenzora deformacije koje su različite od nule date su sljedećim izrazom:

$$\begin{Bmatrix}\varepsilon_{xx}\\ \varepsilon_{yy}\\ \varepsilon_{xy}\end{Bmatrix} = \begin{Bmatrix}\dfrac{\partial u}{\partial x}\\ \dfrac{\partial v}{\partial y}\\ \dfrac{\partial u}{\partial y}+\dfrac{\partial v}{\partial x}\end{Bmatrix} - z\begin{Bmatrix}\dfrac{\partial^2\theta}{\partial x^2}\\ \dfrac{\partial^2\theta}{\partial y^2}\\ 2\dfrac{\partial^2\theta}{\partial x\partial y}\end{Bmatrix}, \begin{Bmatrix}\varepsilon_{yz}\\ \varepsilon_{xz}\end{Bmatrix} = \begin{Bmatrix}\dfrac{\partial w}{\partial y}-\dfrac{\partial\theta}{\partial y}\\ \dfrac{\partial w}{\partial x}+\dfrac{\partial\theta}{\partial x}\end{Bmatrix} \quad (3)$$

2.2 Nelokalne jednačine kretanja

Nelokalna konstitutivna jednačina pravougaone grafenske nanoploče je sljedeća:

$$\begin{Bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \sigma_{xy}\\ \sigma_{yz}\\ \sigma_{zx}\end{Bmatrix} - (e_0 a)^2\nabla^2\begin{Bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \sigma_{xy}\\ \sigma_{yz}\\ \sigma_{zx}\end{Bmatrix} = \begin{Bmatrix}Q_{11} & Q_{12} & 0 & 0 & 0\\ Q_{21} & Q_{22} & 0 & 0 & 0\\ 0 & 0 & Q_{66} & 0 & 0\\ 0 & 0 & 0 & C_{44} & 0\\ 0 & 0 & 0 & 0 & C_{55}\end{Bmatrix}\begin{Bmatrix}\varepsilon_{xx}\\ \varepsilon_{yy}\\ \varepsilon_{xy}\\ \varepsilon_{yz}\\ \varepsilon_{zx}\end{Bmatrix} \quad (4)$$

Gdje su Q_{ij} i C_{ij} krutosti ortotropne grafenske ploče definisane na osnovu:

$$Q_{11} = \frac{E_1}{1-\nu_{12}\nu_{21}},\ Q_{12} = \frac{\nu_{12}E_2}{1-\nu_{12}\nu_{21}} = Q_{21} = \frac{\nu_{21}E_1}{1-\nu_{12}\nu_{21}},\ Q_{22} = \frac{E_2}{1-\nu_{12}\nu_{21}}, \quad (5)$$
$$Q_{66} = G_{12}, C_{44} = G_{23},\ C_{55} = G_{31}$$

Gdje su E_1 i E_2 Jangovi moduli elastičnosti u pravcima osa x i y, a G_{12}, G_{13}, G_{23} moduli klizanja i ν_{12}, ν_{21} Poasonovi koeficijenti.

Rezultante nelokalnog napona M_i i Q_j su definisani:

$$M_i = \int_{-h/2}^{h/2} z\sigma_i dz$$
$$Q_j = K_S \int_{-h/2}^{h/2} \sigma_j dz \qquad (i = xx, yy, xy;\ j = yz, zx) \tag{6}$$

U kojoj je $K_s = 5/6$ koeficijent transverzalnog smicanja. Uvrštavanjem jednačine (3) i (4) u jednačinu (6), nelokalne konstitutivne jednačine kretanja glase:

$$M_{xx} - (e_0 a)^2 \nabla^2 M_{xx} = -\left[D_{11} \frac{\partial^2 \phi}{\partial x^2} + D_{12} \frac{\partial^2 \phi}{\partial y^2} \right]$$
$$M_{yy} - (e_0 a)^2 \nabla^2 M_{yy} = -\left[D_{22} \frac{\partial^2 \phi}{\partial y^2} + D_{12} \frac{\partial^2 \phi}{\partial x^2} \right] \tag{7}$$
$$M_{xy} - (e_0 a)^2 \nabla^2 M_{xy} = -2D_{66} \frac{\partial^2 \phi}{\partial x \partial y}$$
$$Q_{xz} - (e_0 a)^2 \nabla^2 Q_{xz} = H_{55} \left(\frac{\partial w}{\partial x} - \frac{\partial \phi}{\partial x} \right) \tag{8}$$
$$Q_{yz} - (e_0 a)^2 \nabla^2 Q_{yz} = H_{44} \left(\frac{\partial w}{\partial y} - \frac{\partial \phi}{\partial y} \right)$$

Gdje su $D_{ij}(i, j = 1, 2, 6)$ i H_{44}, H_{55} krutosti na savijanje i smičuće krutosti grafenske ploče.

Jednačina kretanja bazirana na NFSDT može biti dobijena uz pomoć Hamiltonovog principa. Varijacijski oblik jednačine kretanja može biti predstavljen kao:

$$\int_0^T \left(\delta U + \delta V - \delta K \right) dt = 0 \tag{9}$$

Gdje je δU varijacija energije deformacije, δV je varijacija rada spoljašnjih sila, a δK je varijacija kinetičke energije.

Varijacija energije deformacije za grafenske nanoploče može se računati kao:

$$\delta U = \int_{-h/2}^{h/2} \int_A (\sigma_{xx}\delta\varepsilon_{xx} + \sigma_{yy}\delta\varepsilon_{yy} + \sigma_{xy}\delta\varepsilon_{xy} + \sigma_{yz}\delta\varepsilon_{yz} + \sigma_{xz}\delta\varepsilon_{xz})dAdz$$
$$= \int_A \left[-M_{xx1}\frac{\partial^2\delta\theta}{\partial x^2} - M_{yy1}\frac{\partial^2\delta\theta}{\partial y^2} - 2M\sigma_{xy1}\frac{\partial^2\delta\theta}{\partial x\partial y} + Q_{yz1}\frac{\partial\delta(w-\theta)}{\partial y} + Q_{xz1}\frac{\partial\delta(w-\theta)}{\partial x} \right] dA \quad (10)$$

Varijacija rada spoljašnjih sila elastičnog medijuma, unutrašnjeg elastičnog medijuma i ravanske sile može biti oblika:

$$\delta V = -\int_A \left(-k_W w + k_G \nabla^2 w\right)\delta w \quad (11)$$

Gdje je k_W Vinklerov osnovni parameter, k_G je parameter smicanja elastičnog medijuma.

$$\delta K = \int_V \left(\dot{u}_x\delta\dot{u}_x + \dot{u}_y\delta\dot{u}_y + \dot{u}_z\delta\dot{u}_z\right)\rho dAdz = \int_A \left[\rho h\dot{w} + \frac{\rho h^3}{12}\left(\frac{\partial\dot{\theta}}{\partial x}\frac{\partial\delta\dot{\theta}}{\partial x} + \frac{\partial\dot{\theta}}{\partial y}\frac{\partial\delta\dot{\theta}}{\partial y}\right)\right] dA \quad (12)$$

Korištenjem izraza za δU , δV i δK iz jednačina (10), (11), (12), u jednačini (9) sprovođenjem parcijalne integracije i smatrajući da su koeficijenti uz δw i $\delta\theta$ jednaki nuli, jednačina kretanja za grafensku nanoploču glasi:

$$\delta w : \frac{\partial Q_{yz}}{\partial y} + \frac{\partial Q_{xz}}{\partial x} - k_w w + k_G\nabla^2 w = \rho h\ddot{w}\,, \quad (13)$$

$$\delta\theta : \frac{\partial M_{xx}}{\partial x^2} + 2\frac{\partial M_{xy}}{\partial x\partial y} + \frac{\partial M_{yy}}{\partial y^2} - \frac{\partial Q_{yz}}{\partial y} - \frac{\partial Q_{xz}}{\partial x} = -\frac{\rho h^3}{12}\nabla^2\ddot{\theta}$$

Ako se primjeni operator $\Re = 1 - \left(e_0 l\right)^2\nabla^2$ u jednačini (14) i dodaju jednačine (7) i (8) u konačnoj jednačini, tada jednačina kretanja može biti izražena pomoću pomjeranja $\left(w, \theta\right)$

$$H_{55}\left\{\left(\frac{\partial^2 w}{\partial x^2}-\frac{\partial^2 \theta}{\partial x^2}\right)-l^2\left[\left(\frac{\partial^4 w}{\partial x^4}+\frac{\partial^4 w}{\partial x^2\partial y^2}\right)-\left(\frac{\partial^4 w}{\partial x^4}+\frac{\partial^4 \theta}{\partial x^2\partial y^2}\right)\right]\right\}$$
$$+H_{44}\left\{\left(\frac{\partial^2 w}{\partial y^2}-\frac{\partial^2 \theta}{\partial y^2}\right)-l^2\left[\left(\frac{\partial^4 w}{\partial y^4}+\frac{\partial^4 w}{\partial x^2\partial y^2}\right)-\left(\frac{\partial^4 \theta}{\partial x^2\partial y^2}+\frac{\partial^4 \theta}{\partial y^4}\right)\right]\right\}$$
$$-k_W\left[w-\mu_0^2\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}\right)\right]+ \qquad (14)$$
$$k_G\left\{\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}\right)-\mu_0^2\left[\left(\frac{\partial^4 w}{\partial x^2}+\frac{\partial^4 w}{\partial x^2\partial y^2}\right)+\left(\frac{\partial^4 w}{\partial x^2\partial y^2}+\frac{\partial^4 w}{\partial y^4}\right)\right]\right\}+$$
$$N_{xx}\left[\frac{\partial^2 w}{\partial x^2}-\mu_0^2\left(\frac{\partial^4 w}{\partial x^4}+\frac{\partial^4 w}{\partial x^2\partial y^2}\right)\right]$$
$$+N_{yy}\left[\frac{\partial^2 w}{\partial y^2}-\mu_0^2\left(\frac{\partial^4 w}{\partial x^2\partial y^2}+\frac{\partial^4 w}{\partial y^4}\right)\right]=\rho h\left[\frac{\partial^2 w}{\partial t^2}-\mu_0^2\left(\frac{\partial^4 w}{\partial x^2\partial t^2}+\frac{\partial^4 w}{\partial t^2}\right)\right]$$

$$D_{11}\left[\frac{\partial^4 \theta}{\partial x^4}-l^2\left(\frac{\partial^6 \theta}{\partial x^6}+\frac{\partial^6 \theta}{\partial x^4\partial y^2}\right)\right]+2\left(D_{12}+2D_{66}\right)\left[\frac{\partial^4 \theta}{\partial x^2\partial y^2}-l^2\left(\frac{\partial^6 \theta}{\partial x^4\partial y^2}+\frac{\partial^6 \theta}{\partial x^2\partial y^4}\right)\right]$$
$$+D_{22}\left[\frac{\partial^4 \theta}{\partial y^4}-l^2\left(\frac{\partial^6 \theta}{\partial x^2\partial y^4}+\frac{\partial^6 \theta}{\partial y^6}\right)\right] \qquad (15)$$
$$+H_{55}\left\{\left(\frac{\partial^2 w}{\partial x^2}-\frac{\partial^2 \theta}{\partial x^2}\right)-l^2\left[\left(\frac{\partial^4 w}{\partial x^4}-\frac{\partial^4 w}{\partial x^2\partial y^2}\right)-\left(\frac{\partial^4 \theta}{\partial x^4}+\frac{\partial^4 \theta}{\partial x^2\partial y^2}\right)\right]\right\}$$
$$+H_{44}\left\{\left(\frac{\partial^2 w}{\partial y^2}-\frac{\partial^2 \theta}{\partial y^2}\right)-l^2\left[\left(\frac{\partial^4 w}{\partial x^2\partial y^2}+\frac{\partial^4 w}{\partial y^4}\right)-\left(\frac{\partial^4 \theta}{\partial x^2\partial y^2}+\frac{\partial^4 \theta}{\partial y^4}\right)\right]\right\}$$
$$=\frac{\rho h^3}{12}\left\{\left(\frac{\partial^4 \theta}{\partial x^2\partial t^2}+\frac{\partial^4 \theta}{\partial x^2\partial t^2}\right)-\mu_0{}^2\left[\left(\frac{\partial^6 \theta}{\partial x^4\partial t^2}+\frac{\partial^6 \theta}{\partial x^2\partial y^2\partial t^2}\right)+\left(\frac{\partial^6 \theta}{\partial x^2\partial y^2\partial t^2}+\frac{\partial^6 \theta}{\partial y^4\partial t^2}\right)\right]\right\}$$

3. RJEŠENJA POMOĆU GALERKINOVE METODE

U ovom dijelu jednačina kretanja je riješena analitički uz pomoć Galerkinove metode da bi se izračunale frekvencije oscilovanja grafenske nanoploče izložene dejstvu ravanskih sila usljed higrotermalnog efekta. Prije rješavanja jednačine kretanja potrebno definisati granične uslove. U ovom radu pretpostavljeno je da su krajevi grafenske ploče postavljeni na proste oslonce, uklješteni ili su kombinacija ove dvije vrste oslanjanja. Granični uslovi su:

Prosti oslonac (S) :

$$u_i=\frac{\partial \theta_i}{\partial y}=w_i=M_{xxi}=0, \qquad \text{za } x=0,\text{a}$$

$$v_i = \frac{\partial \theta_i}{\partial x} = w_i = M_{yyi} = 0, \qquad \text{za } y = 0, b \; i\text{=}1 \tag{16}$$

Uklještenje (C):

$$u_i = \frac{\partial \theta_i}{\partial x} = \frac{\partial \theta_i}{\partial y} = w_i = 0, \quad \text{za } x = 0, \text{a} \tag{17}$$

$$v_i = \frac{\partial \theta_i}{\partial x} = \frac{\partial \theta_i}{\partial y} = w_i = 0, \qquad \text{za } y = 0, b \;\; i\text{=}1$$

Zadovoljavajući navedene granične uslove veličina pomjeranja se može napisati kao:

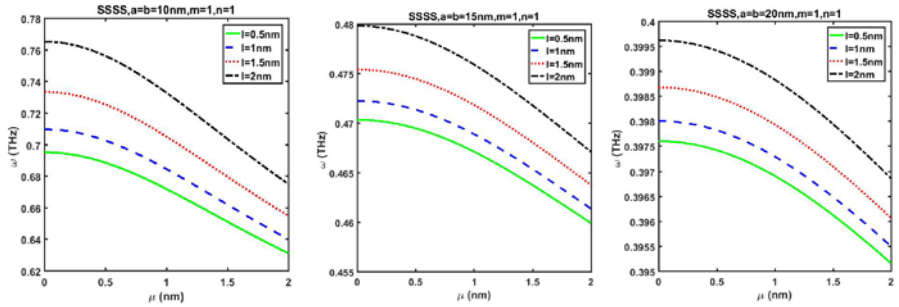
$$\begin{aligned} w(x,y) &= W_{mn} X(x) Y(y) e^{i\omega t} \\ \theta(x,y) &= \theta_{mn} X(x) Y(y) e^{i\omega t} \end{aligned} \tag{18}$$

Gdje je $i = \sqrt{-1}$ imaginarna jedinica, (W_{mn}, θ_{mn}) proizvoljni parametar, $\omega = \omega_{mn}$ označava frekvenciju oscilovanja za odgovarajući mod oscilovanja, m i n su brojevi polutalasa oscilovanja, a funkcije X(x) i Y(y) zadovoljavaju granične uslove.

Uvrštavanjem jednačine (18) u jednačinu (15) i primjenjujući Galerkinov metod, analitička rješenja jednačine kretanja koristeći parametre W_{mn} i θ_{mn} može biti napisana u obliku:

$$\left(\begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix} - \omega^2 \begin{bmatrix} m_{11} & 0 \\ 0 & m_{22} \end{bmatrix} \right) \begin{Bmatrix} W_{mn} \\ \theta_{mn} \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \end{Bmatrix} \tag{19}$$

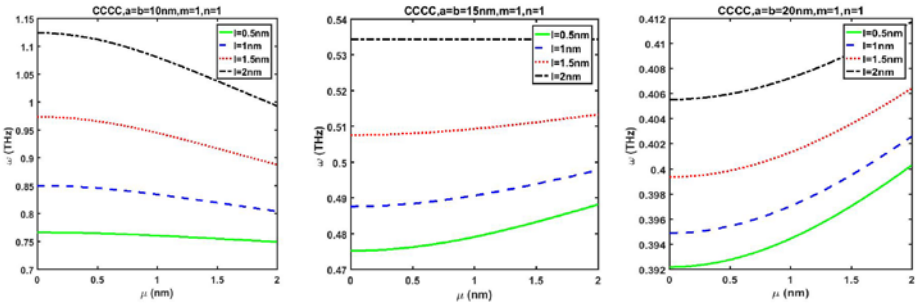
Materijalne i geometrijske karakteristike ortotropne grafenske nanoploče koja je analizirana u ovom radu imaju sljedeće vrijednosti: Jangov modul elastičnosti $E_1 = 1130\,GPa$ i $E_2 = 1050\,GPa$, gustina mase $\rho = 2250 kg/m^3$, Poasonov koeficijent $\nu_{12} = 0.112$ i $\nu_{21} = 0.0803$, modul smicanja $G_{12} = E_1 / 2(1+\nu_{12}) = 508.09\,GPa$ i $G_{13} = G_{23} = \frac{5}{6} G_{12} = 423.41 GPa$, debljina nanoploče $h = 0.34\,nm$.



(a) *(b)* *(c)*

Slika 1. *Promjena frekvencije oscilovanja u zavisnosti od vrijednosti nelokalnih parametara za slučaj SSSS graničnih uslova*

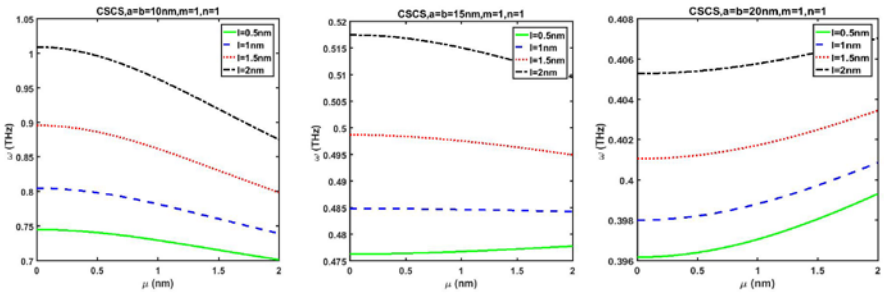
Na slici 1. je prikazana zavisnost između frekvencije oscilovanja i nelokalnog parametra napona za nanoploču koja je prosto oslonjena na sve četri ivice. Sa slike se jasno može vidjeti da se sa povećanjem vrijednosti nelokalnog parametra smanjuje vrijednost frekvencije oscilovanja (efekat smanjenja krutosti). Važno je uočiti sa slike da se sa povećanjem vrijednosti nelokalnog gradijenta deformacije povećava vrijednost frekvencije oscilovanja (efekat povećanja krutosti). Sa povećanjem dimenzija nanoploče smanjuje se vrijednost frekvencije oscilovanja.



(a) *(b)* *(c)*

Slika 2. *Promjena frekvencije oscilovanja u zavisnosti od vrijednosti nelokalnih parametara za slučaj CCCC graničnih uslova*

Na slici 2. je prikazana zavisnost između frekvencije oscilovanja i nelokalnog parametra napona za nanoploču koja ima uklještene sve četri ivice. Sa povećanjem vrijednosti nelokalnog parametra u slučaju kada je a=b=10 nm i m=n=1 smanjuje se vrijednost frekvencije oscilovanja, što se može uočiti sa slike. U ostalim slučajevima povećava se vrijednost oscilovanja. Takođe se sa slike može uočiti da se sa povećanjem vrijednosti nelokalnog gradijenta deformacije povećava vrijednost frekvencije oscilovanja (efekat povećanja krutosti). Sa povećanjem dimenzija nanoploče smanjuje se vrijednost frekvencije oscilovanja.



(a) *(b)* *(c)*

Slika 3. *Promjena frekvencije oscilovanja u zavisnosti od vrijednosti nelokalnih parametara za slučaj CSCS graničnih uslova*

Na slici 3. je prikazana zavisnost između frekvencije oscilovanja i nelokalnog parametra napona za nanoploču koja je na dvije ivice uklještena, a na dvije ivice prosto oslonjena (CSCS). Pri tome je izvršena varijacija nelokalnog gradijenta deformacije, dužine nanoploče pri čemu je broj polutalasa m=n=1. Sa slike se vidi da se sa povećanjem vrijednosti nelokalnog parametra smanjuje vrijednost frekvencije oscilovanja samo u slučaju kada je a=b=10, a u svim ostalim slučajevima se povećava. Ponovo se može uočiti sa slike da se sa povećanjem vrijednosti nelokalnog gradijenta deformacije povećava vrijednost frekvencije oscilovanja (efekat povećanja krutosti). Sa povećanjem dimenzija nanoploče smanjuje se vrijednost frekvencije oscilovanja.

4. ZAKLJUČAK

Primjenom nelokalne teorije gradijenta deformacije mehaničko ponašanje nanoploča može se opisati u znatno širem opsegu jer kao što smo pokazali na svim prethodnim slikama sa povećanjem vrijednosti nelokalnog parametra gradijenta deformacije povećava se vrijednost frekvencije oscilovanja. Ono što predstavlja problem u primjeni teorije nelokalnog gradijenta deformacije jeste značajno složeniji sistem parcijalnih diferencijalnih jednačina kojima je opisano kretanje. To u slučaju Galerkinovog metoda značajno usložnjava približno analitičko rješenje i zahtjeva znatno više vremena za rješavanje sistema parcijalnih diferencijalnih jednačina.

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RAZVOJ GRAFIČKOG KORISNIČKOG SUČELJA ZA UPRAVLJANJE MOBILNIM ROBOTOM

Boris Crnokić[1], Miroslav Grubišić[2]

Rezime: U ovome radu je prikazan razvoj GUI za upravljanje kretanjem mobilnog robota. GUI je realiziran u programskom okruženju MATLAB/Simulink. Za testiranje GUI korišten je mehatronički mobilni robotski sustav „Robotino“ i simulacijsko okruženje „RobotinoSIM“. Funkcija razvijenog GUI je mogućnost prikupljanja podataka od senzorskog sustava robota, reproduciranje dobivenih podataka, upravljanja kretanjem mobilnog robota u svim smjerovima, te pokretanje složenih algoritama navigacije mobilnog robota. Razvijeni GUI kasnije je implementiran u sustav upravljanja navigacijom mobilnog robota.

Ključne riječi: Grafičko korisničko sučelje, Upravljanje mobilnim robotom, MATLAB/Simulink, Robotino

DEVELOPMENT OF A GRAPHICAL USER INTERFACE FOR MOBILE ROBOT MOTION CONTROL

Abstract: This paper presents development of a graphical user interface (GUI) for mobile robot motion control. GUI is implemented in the MATLAB / Simulink programming environment. Mechatronic mobile robotic system "Robotino" and the simulation environment "RobotinoSIM" are used to test the functionality of the GUI. The functions of the developed GUI are: the ability to collect and to reproduce data from the sensor system of the robot, to control motions of the mobile robot in all directions, and to run complex algorithms for mobile robot navigation. GUI presented in this paper was later implemented in the control system of mobile robot navigation.

Key words: Graphical user interface, Mobile robot control, MATLAB/Simulink, Robotino

1 UVOD

U posljednje dvije decenije mobilni roboti privlače sve više pozornosti znanstvenika jer njihov spektar uporabe je sve veći u različitim poljima, kao što je: istraživanje svemira, podvodna istraživanja, autoindustrija, vojna industrija, medicina, servisni roboti, roboti za posluživanje i zabavu, itd. Mogućnosti razvoja mobilnih robota

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s visokim stupnjem autonomije su jako velike zbog sve većih zahtjeva za primjenom takvih sustava, ali i zbog sve većeg napretka u razvoju računalnih, elektroničkih i mehaničkih sustava. Veliki utjecaj na konstrukciju robota, senzore i aktuatore ima okolina, te svrha i način primjena robota. Postoje dva smjera kod razvoja mobilnih robota. Jedan smjer se bazira na projektiranju robota prema točno definiranoj zadaći koju treba obavljati, dok drugi smjer se više obazire na sposobnost robota da obavlja bilo kakve zadaće u različitim okolinama i situacijama. Općenito, primjenu robota moguće je klasificirati prema stupnju nestrukturiranosti okoline i stupnju autonomije koja je potrebna za izvršavanje određenih zadaća. [1]

Grafičko korisničko sučelje (GUI – engl. Graphical User Interface) je oblik sučelja koje omogućava korisnicima interakciju s različitim elektroničkim, mehatroničkim ili robotskim sustavima preko grafičkih ikona i vizualnih indikatora. GUI je jako važna komponenta interakcije čovjeka i robota, te omogućava jednostavnije upravljanje samim robotom. Grafička korisnička sučelja se razvijaju s obzirom na konstrukciju, ograničenja i namjenu robota. S obzirom na to, moguće je pronaći različite oblike korisničkih grafičkih sučelja. U radu [2] prikazano je grafičko korisničko sučelje tele-robotskog sustava koji omogućava korisnicima da provode vizualni nadzor i tele-manipulacijske operacije unutar kompleksa akceleratora u CERN-u. Interaktivno korisničko grafičko sučelje SinguLab prikazano je u radu [3]. Ovo GUI se koristi za analizu singularnosti kod paralelnih robota. Ovo sučelje upoznaje korisnika sa analizom singularnosti, pokazujući sve korake tijekom procedure te prikazujući algebarska i grafička rješenja. U ovome primjeru ali i mnogim drugim sličnima pokazano je da je potreban neki novi pristup u kreiranju GUI radi sve većeg broja različitih korisnika koji operiraju s robotima. U tome smjeru ide i razvoj grafičkog korisničkog sučelja baziranog na kognitivnoj infokomunikaciji (CogInfoCom), a što je prikazano u radu [4]. Područje robotike doživljava ogromnu ekspanziju i roboti su zastupljeni u svakom segmentu života, međutim još uvijek su roboti jako komplicirani za programiranje osobama koje nemaju iskustva. Cilj je napraviti korisnička sučelja tako jednostavna i laka za uporabu da ih mogu koristiti i osobe koje nemaju prethodna iskustva. [5] Kod kreiranja GUI vrlo je važno poznavati osnovna načela interakcije čovjeka i robota. Grafičko korisničko sučelje bazirano na interakciji čovjeka i robota, dizajnirano za upravljanje heterogenim multi-robotskim timovima za urbana pretraživanja i spašavanje, prikazano je u radu [6]. Dizajn grafičkog korisničkog sučelja je složena zadaća koja zahtijeva znanja o ljudskom kognitivnom ponašanju, načinima dizajniranja i načinima programiranja. U radu [7] prikazan je razvoj grafičkog korisničkog sučelja za upravljanje robotskom rukom koja je sposobna da prikuplja i vraća uzorke u radnom okruženju. Upravljanje mobilnim robotima zahtijeva razvoj specijaliziranih grafičkih korisničkih sučelja koja moraju imati mogućnosti povezivanja preko bežičnih protokola kako bi se osigurala autonomija i mobilnost robota.[8] U ovome radu je prikazan razvoj i implementiranje grafičkog korisničkog sučelja za upravljanje mobilnim robotom „Robotino“. GUI je razvijeno i implementirano u programskom okruženju Matlab/Simulnik.

2 MOBILNI ROBOT “ROBOTINO”

Njemačka tvrtka *Festo Didactic* proizvela je nekoliko serija mehatroničkog mobilnog robotskog sustava „Robotino“ koji se koristi za obrazovanje, obuku ali i za znanstveno-istraživačke svrhe (Slika 1.).



Slika 1. *Robotino® 2*

Robotino posjeduje raznolike vrste senzora, aktuatora i programskih sučelja koja su na najvišoj razini u svijetu mobilne robotske tehnike. Mobilni robotski sustav Robotino je primjenljiv i prilagodljiv za srednjoškolsko i fakultetsko obrazovanje, u jednostavnim ali i složenijim znanstveno-istraživačkim projektima, te kroz treninge i obuke u programima cjeloživotnog učenja i obrazovanja. Ovaj fascinantni i motivirajući sustav koristi se širom svijeta u obrazovnim i istraživačkim institucijama. Širok je spektar mogućnosti kreiranja programa učenja ili istraživačkih projekata uz pomoć Robotina, a neki od njih su: prikupljanje, skaliranje i analiza podataka s velikog broja različitih senzora i primjena tih podataka za različite aplikacije; upoznavanje s elektromotornom pogonskom i upravljačkom jedinicom; proučavanje zatvorenog kruga upravljanja mehatroničkog sustava; grafičko programiranje aplikacija mobilnog robota; programiranje aplikacija mobilnog robota u različitim programskim jezicima; digitalna obrada slike i praćenje objekata; unutarnja i vanjska navigacija robota uz izbjegavanje prepreka, simuliranje virtualnih aplikacija u proizvodnim linijama i laboratorijama i još mnoge aplikacije u oblasti mobilne i servisne robotike. [9] Napajanje Robotina je osigurano s dvije nadopunjive baterije po 12 V, kapaciteta od 4 h . Sustav može raditi samostalno ali i vezan za vanjsko računalo (Wi-Fi veza). Aplikacije na Robotinu moguće je programirati pomoću namjenskog programa Robotino View, ali i pomoću različitih programskih jezika kao što su: .Net, C++, C, C#, JAVA, s MATLAB ili Lab View sučeljem.

3 UPRAVLJANJE MOBILNIM ROBOTIMA

Roboti s kotačima imaju sve već primjenu u industriji, različitim servisnim uslugama, obrazovanju, odnosno, u svim područjima gdje je potrebno autonomno kretanje robota. Osnovne kretnje robota u okruženju bez prepreka su kretanje od točke do točke i kretanje po odrađenoj putanju, te se upravljački koncepti baziraju upravo na tim značajkama. Međutim, roboti se vrlo često nalaze u okruženju s preprekama, tako da upravljanje nije baš uvijek tako jednostavna zadaća. Najlakša podjela načina upravljanja mobilnih robota je na upravljačke sustave visoke razine i upravljačke sustave niske razine. Upravljački sustavi visoke razine koriste određene pristupe koji omogućavaju kreiranje sigurnih i pouzdanih upravljačkih algoritama. Najčešće korišteni pristupi u sustavima visoke razine su:

- Pristup Model-Planiranje-Djelovanje
- Pristup temeljen na ponašanju
- Pristup temeljen na automatima s konačnim brojem stanja

Upravljački sustavi niske razine najčešće se baziraju na upravljanju brzinom kotača ili na upravljanju pogonskim sustavom robota. Kod pristupa Model-Planiranje-Djelovanje informacije sa senzora se koriste za kreiranje modela okoline koji se koristi za planiranje (kreiranje) sekvenci ponašanja s kojim će robot doći do cilja. U ovakvom sustavu konačno kretanje robota je u biti izvršavanje toga plana. Prednost ovoga pristupa je posjedovanje globalnog znanja (okoline) u modelu, a što omogućuje optimizaciju, te je moguće dobiti povjerljive informacije o planu kretanja. Nedostaci ovoga pristupa su nastaju kada treba implementirati sve funkcionalne cjeline prije bilo kakvog testiranja, te sustav postaje računalno prezahtjevan. Ovakav sustav upravljanja zahtijeva vrlo točne podatke sa senzora radi dobivanja preciznih modela, i samim time radi vrlo loše u dinamičkim okruženjima. Pristup temeljen na ponašanju, kao i kod jednostavnih bioloških sustava, ponašanje izravno povezuje sa senzorima i aktuatorima. Prema hijerarhiji sustava, viša razina ponašanja se nalazi na najvišem sloju ponašanja niže razine, te slažući jednostavna ponašanja moguće je dobiti vrlo složeno ukupno ponašanje. U ovakvom pristupu inkrementalni razvoj je prirodan, a što je velika prednost, te modularnost ovakvog sustava olakšava primjenu uz jako dobro ponašanje u dinamičkim okruženjima. Međutim, u ovako posluženom sustavu, vrlo je teško odrediti što će robot točno uraditi. Ne postoje sigurnosti da će za određene performanse biti kompletirano izvršenje tražene zadaće, pa tako ispravljanje pogrešaka može biti jako teško. S druge strane, automati s konačnim brojem stanja pružaju mogućnost kreiranja sustava upravljanja temeljenog na kombiniranju različitih ponašanja. Prikazivanjem ponašanja robota kao stanja konačnog automata realizira se upravljanje kretanjem robota. Ovakvi sustavi upravljanja mogu kombinirati pristup Model-Planiranje-Djelovanje i pristup temeljen na ponašanju.

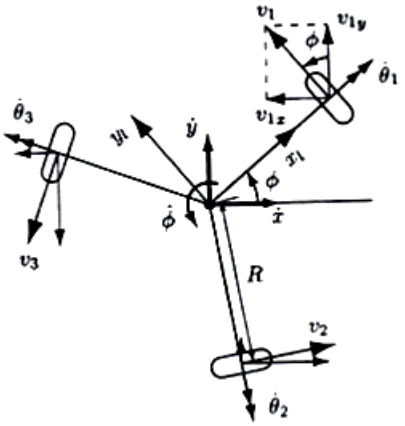
4 MATEMATIČKO MODELIRANJE MOBILNOG ROBOTA ROBOTINO

Dizajniranje mobilnog robota koji će precizno, sigurno i pouzdano obavljati tražene zadaće, i za kojega će biti moguće realizirati stabilan sustav upravljanja, zahtijeva poznavanje matematičkih modela robota. Različiti aspekti kod dizajniranja mobilnog robota mogu obuhvaćati: pozicioniranje modela robota u okolini, analizu pokretljivosti robota s obzirom na kinematskam ograničenja, generalizirano upravljanje razvijenih kinematičkih i dinamičkih modela, te u konačnici dizajniranje upravljačkih pravila.[10] Potrebno je napomentu da zbog ograničenja u broju stranica rada nije bilo moguće detaljno prikazati matematičke modele s detaljnim izvodima jednadžbi, već su prikazanane samo konačne (pojednostavljene) jednadžbe i osnovni podaci o kinematičkom i dinamičkom modelu, te o modelu upravljačkog sustava.

4.1 Kinematički model robota

Na osnovu informacija o poziciji robota, dobivenih s enkodera, te primjenom kinematičkog modela, tj. inverznog kinematičkog modela, moguće je naporaviti procjenu podataka o brzini i ubrzanju robota. Ovo je najjednostavnije i najbrže rješenje, s visokom točnošću na kratkim rastojanjima ako se uzmu u obzir sljedeće pretpostavke: trenje između kotača i podloge je beskonačno, središte mase je locirano u geometrijskom centru robota i rastojanje između središta robota i kotača koji dodiruje podlogu je konstanto. Kinematički model Robotina prikazan je na Slici 2. Zamjenom transformacijske matrice brzina kotača u vanjskoj kutnoj brzini s $T_{k\rightarrow v}$, dobije se ovakav pojednostavljeni oblik izraza. Ovaj model predstavlja osnovne odnose za određivanje pozicije robota u realnom okruženju. Ovakva metoda pruža jednostavnu matematičku proceduru za procjenu trenutačne pozicije robota bazirane na prethodno određenoj

poziciji kada su poznati brzina i vrijeme kretanja do trenutačne pozicije.



$$\begin{bmatrix} x_v(t_1) \\ y_v(t_1) \\ \theta(t_1) \end{bmatrix} = \begin{bmatrix} x_{v,0} \\ y_{v,0} \\ \theta_0 \end{bmatrix} + r \int_{t0}^{t1} \left((T_{k\to v})^{-1} \begin{bmatrix} \omega_1(t) \\ \omega_2(t) \\ \omega_3(t) \end{bmatrix} dt \right)$$

Gdje je:

$\boldsymbol{x_v(t_1)}$ *i* $\boldsymbol{y_v(t_1)} - vanjske\ kordinate\ u\ trenutku\ t_1$

$\boldsymbol{\theta(t_1)} - kut\ orijentacije\ u\ trenutku\ t_1$

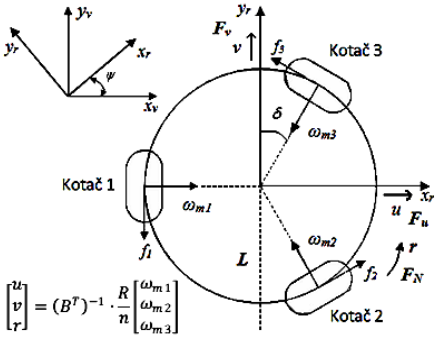
$\boldsymbol{x_{v,0}}$ *i* $\boldsymbol{y_{v,0}} - vanjske\ kordinate\ u\ trenutku\ t_0$

$\boldsymbol{\theta_0} - kut\ orijentacije\ u\ trenutku\ t_0$

Slika 2. *Kinematički model mobilnog robota Robotino* [11]

4.2 Dinamički model robota

Prvi korak kod dizajniranja upravljačkog sustava robota je izvođenje jednadžbi kretanja robota. Dinamički model je bitan za analizu strukture i konstrukcije robota i sintezu upravljanja. U ovome primjeru prikazan je pojednostavljeni model, odnosno urađeno je nekoliko pojednostavljenja radi lakšeg prikaza dinamičkog modela robota. Za tu svrhu uzete su sljedeće pretpostavke: nema proklizavanja kod sva tri kotača; sila trenja je pojednostavljena i prikazana je preko koeficijenta viskoznog trenja; električna vremenska konstanta motora je zanemarena. Očekuje se da će kontroler u povratnoj vezi na temelju ovog pojednostavljenog modela moći nadoknadit nemodeliranu dinamiku. Kao i u kinematičkom modelu, uzeta su dva koordinatna sustava, robotski koordinatni sustav i vanjski koordinatni sustav. Robotski koordinatni sustav je fiksiran na robota, dok je vanjski koordinatni sustav fiksiran u prostoru u kojem se robot kreće. Dinamički model analize sila prikazan je na Slici 3. [12]

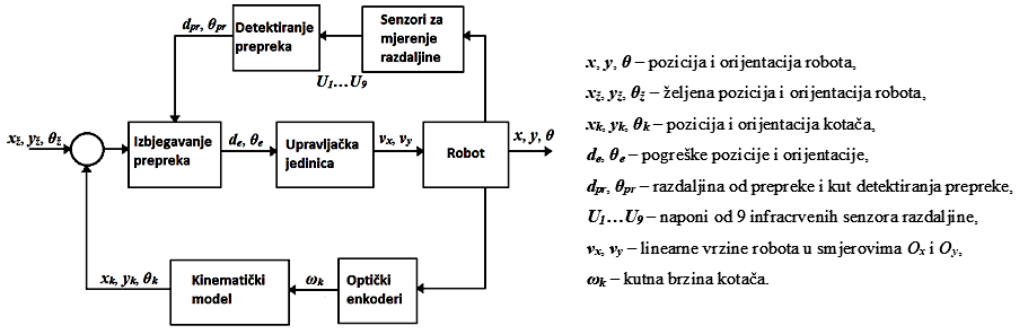


γ	kutna brzina vrtnje tijela *[rad/s]*
u, v	komponente brzine robotskog koordinatnog sustava *[m/s]*
F_u, F_v	komponente sila robotskog koordinatnog sustava *[N]*
f_1, f_2, f_3	sile trenja za svaki od kotača *[N]*
ω_{m1}, ω_{m2}, ω_{m3}	kutne brzine svakog od motora *[rad/s]*
R	polumjer kotača *[m]*
L	polumjer tijela robota *[m]*
n	prijenosni omjer reduktora
δ	kut orijentacije kotača *(30°)*
x_r, y_r	koordinatni sustav robota
x_v, y_v	vanjski koordinatni sustav
Ψ	kut orijentacije robota *[rad]*
B	geometrijska matrica

Slika 3. *Dinamički model analize sila kod mobilnog robota Robotino*

4.3 Model upravljačkog sustava

Upravljački sustav ima dva kruga s povratnom vezom. Glavna povratna pruža informacije o trenutnoj poziciji robota u odnosu na željenu poziciju. Druga povratna veza koristi infracrvene senzore za otkrivanje prepreka u okruženju. Blok dijagram sustava za reguliranje kretanja Robotina je prikazan na Slici 4.

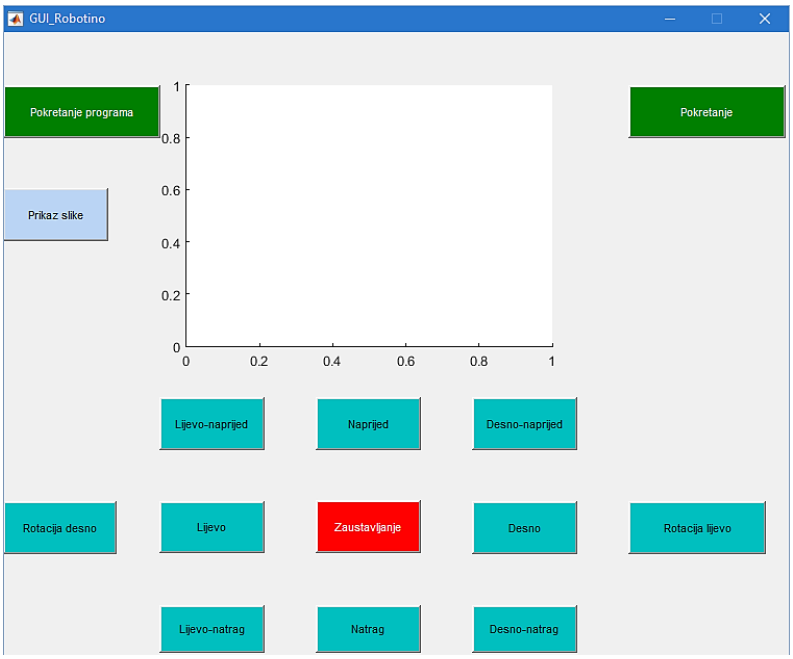


Slika 4. *Model upravljačkog sustava mobilnog robota Robotino*

Modul robota koji uključuje strukturu upravljanja kretanjem, između ostalog, sastoji se od sljedećih komponenti: svesmjerni kotači koji transformiraju linearne brzine robota u brzine kotača, unutarnji PID kontroler za brzine kotača, DC motori koji pogone robota, mehaničke i druge komponente, infracrveni senzori razdaljine, optički enkoderi. Modul kinematičkog modela procjenjuje trenutačnu poziciju. Ovaj modul kao ulaze koristi informacije dobivene s optičkih enkodera, a za izlaze daje vrijednosti koje određuju trenutačnu dvodimenzionalnu poziciju i orijentaciju robota. Jedinica za detektiranje prepreka koristi 9 infracrvenih senzora razdaljine za detektiranje objekata unutar razdaljine od 40 cm. Pošto se senzori nalaze pod kutom od 40° ne postoje tzv. nevidljive točke. U ovisnosti od izmjerenog napona modul za detektiranje prepreka pruža razdaljinu od prepreke d_{pr} i kut orijentacije θ_{pr} na kojoj se nalazi prepreka.

5 GRAFIČKO KORISNIČKO SUČELJE

Grafičko korisničko sučelje omogućava pokretanje algoritma upravljanja, ali i pojedinačno upravljanje kretanjem robota u različitim smjerovima. U GUI su inkorporirane funkcije prikupljanja informacija sa senzora, detektiranja prepreka i poduzimanja zadaća kretanja i izbjegavanja prepreka. GUI u ovome projektu je izrađen u programskom okruženju Matlab. Grafičko korisničko sučelje je prikazano na Slici 5. Upravljanje osnovnim kretnjama Robotina (naprijed, natrag, lijevo, desno, …) moguće je nakon poziva naredbe „Pokretanje“. Ova funkcija je napravljena zbog pružanja mogućnosti da robot bude doveden u željenu poziciju ispred prepreke prilikom testiranja algoritma upravljanja. Sam algoritam aktivira se pozivom naredbe „Pokretanje programa“, nakon čega robot počinje autonomno kretanje izbjegavajući sve prepreke za koje je istreniran kroz sustav umjetnih neuronskih mreža. Dodatna funkcija je „Prikaz slike“, gdje se nakon aktiviranja te funkcije prikazuje slika okoline robota u realnom vremenu. Kôdovi nekih od naredbi grafičkog korisničkog sučelja prikazani su na Slici 6.



Slika 5. *GUI za Robotina*

```
% --- Izvršava se pritiskom na pushbutton1 („Pokretanje programa").
function pushbutton1_Callback(hObject, eventdata, handles)
% hObject    rukovanje do figure pushbutton1
% eventdata  informacije o bloku za izvršavanje redoslijeda događaja
% handles    struktura s rukovanjem i korisničkim podacima
global OmniDriveId  DistanceSensor8Id
global img          DistanceSensor0Id  BumperId
global CameraId     DistanceSensor1Id  ComId
DistanceSensor_setComId(DistanceSensor0Id, ComId);
DistanceSensor_setComId(DistanceSensor1Id, ComId);
DistanceSensor_setComId(DistanceSensor8Id, ComId);
Bumper_setComId(BumperId, ComId);

global stp
global stoppressed
stoppressed=0;
stp=0;
while((Bumper_value(BumperId) ~= 1)) && stoppressed==0
    tic;
    OmniDrive_setVelocity(OmniDriveId, 50, 0 ,0)

    % Kada istekne 60 sekundi prekida se while petlja
        break;
    end;
         OmniDrive_setVelocity (OmniDriveId,50,0,0);
    if ~(Camera_setStreaming(CameraId, 1) == 1)
         disp('Camera_setStreaming failed.');
    end;
    if (Camera_grab(CameraId) == 1)
        img = Camera_getImage( CameraId );
        class=img_class(img)
    if (class==1)
        break;
    end
    end

end

tStart = tic;
while((Bumper_value(BumperId) ~= 1)) && stoppressed==0
    OmniDrive_setVelocity(OmniDriveId, 100, 0 ,0)
    tElapsed = toc(tStart);
     if(tElapsed >= 60 )
        break;
    end;
    value0 = DistanceSensor_voltage(DistanceSensor0Id)
    value1 = DistanceSensor_voltage(DistanceSensor1Id)
    value8 = DistanceSensor_voltage(DistanceSensor8Id)
     if((0.7 <= value0)|(0.7 <=value1)|(0.7 <= value8))&(class==1)
        % Prilazak prepreci
        break;
    else
        % Prepreka nije ispred robota
        OmniDrive_setVelocity(OmniDriveId, 100, 0 ,0);
    end;
end
 OmniDrive_setVelocity(OmniDriveId, 0, 0 ,0);
 delay(1)
 OmniDrive_setVelocity(OmniDriveId, 0, 100 ,0);
 delay(3)
 OmniDrive_setVelocity(OmniDriveId, 100, 0 ,0);
```

```
% --- Izvršava se pritiskom na pushbutton2 („Lijevo").
function pushbutton2_Callback(hObject, eventdata, handles)
% hObject    rukovanje do figure pushbutton2
% eventdata  informacije o bloku za izvršavanje redoslijeda događaja
% handles    struktura s rukovanjem i korisničkim podacima
global OmniDriveId
OmniDrive_setVelocity (OmniDriveId,0,50,0);


% --- Izvršava se pritiskom na pushbutton3 („Desno").
function pushbutton3_Callback(hObject, eventdata, handles)
% hObject    rukovanje do figure pushbutton3
% eventdata  informacije o bloku za izvršavanje redoslijeda događaja
% handles    struktura s rukovanjem i korisničkim podacima
global OmniDriveId
OmniDrive_setVelocity (OmniDriveId,0,-50,0);


% --- Izvršava se pritiskom na pushbutton4 („Naprijed").
function pushbutton4_Callback(hObject, eventdata, handles)
% hObject    rukovanje do figure pushbutton4
% eventdata  informacije o bloku za izvršavanje redoslijeda događaja
% handles    struktura s rukovanjem i korisničkim podacima
global OmniDriveId
OmniDrive_setVelocity (OmniDriveId,50,0,0);


% --- Izvršava se pritiskom na pushbutton5 („Natrag").
function pushbutton5_Callback(hObject, eventdata, handles)
% hObject    rukovanje do figure pushbutton5
% eventdata  informacije o bloku za izvršavanje redoslijeda događaja
% handles    struktura s rukovanjem i korisničkim podacima
global OmniDriveId
OmniDrive_setVelocity (OmniDriveId,-50,0,0);


% --- Izvršava se pritiskom na pushbutton6 („Zaustavljanje").
function pushbutton6_Callback(hObject, eventdata, handles)
% hObject    rukovanje do figure pushbutton6
% eventdata  informacije o bloku za izvršavanje redoslijeda događaja
% handles    struktura s rukovanjem i korisničkim podacima
global  OmniDriveId
global stoppressed
stoppressed=1;
OmniDrive_setVelocity (OmniDriveId,0,0,0);

% --- Izvršava se pritiskom na pushbutton8 („Prikaz slike").
function pushbutton8_Callback(hObject, eventdata, handles)
% hObject    rukovanje do figure pushbutton8
% eventdata  informacije o bloku za izvršavanje redoslijeda događaja
% handles    struktura s rukovanjem i korisničkim podacima
global CameraId
global img
if ~(Camera_setStreaming(CameraId, 1) == 1)
        disp('Camera_setStreaming failed.');
    end;
    if (Camera_grab(CameraId) == 1)
        img = Camera_getImage( CameraId );
    end
axes(handles.axes1);
  imshow(img);
```

Slika 6. *Kôdovi nekih od naredbi grafičkog korisničkog sučelja*

6 ZAKLJUČCI

U budućnosti, za primjenu mobilnih robota, operatorima će trebati sve veći broj kompleksnih i preciznih povratnih informacija. Kada se operira s mobilnim robotima jako je važno razaznavanje okoline, te detektiranje i izbjegavanje prepreka, a upravo te informacije je moguće prenijeti operatoru preko grafičkog korisničkog sučelja. Jedan od najvažnijih stvari kod primjene GUI u sustavima upravljanja mobilnim robotom je mogućnost praćenja okoline u slučajevima kada robot ima ugrađenu kameru. Ovo pruža bezgranične mogućnosti operatoru da istraži radni prostor robota iz više pogleda, a što ne bi bilo moguće u slučajevima kada je okolina opasna ili nedostupna. Grafičko korisničko sučelje prikazano u ovome radi pruža mogućnosti za jednostavno upravljanje kretanjem mobilnog robota, ali i za nadzor nad okolinom u kojoj se robot kreće. Prikazano sučelje omogućava korisnicima s vrlo malo iskustva o upravljanju s mobilnim robotima da koriste mobilnog robota Robotino za jednostavne i složene zadaće kretanja robota.

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OCENJIVANJE PARAMETARA PREMISA TS MODELA ZA NELINEARNE RACIONALNE SISTEME SA POREMEĆAJIMA

Vojislav Filipovic[1], Vladimir Djordjevic[2]

Rezime: U radu je razmatran problem ocenjivanja parametara premisa (funkcija pripadnosti) Takagi-Sugenovog (TS) modela za nelinearne racionalne sisteme. Fazi logika se ponaša kao univerzalni aproksimator koji nelinearnom sistemu stavlja u korespodenciju konačan skup linearnih modela. Parametri premise dobijaju se primenom klaster analize i Gustafson-Keselovog algoritma. U radu je uveden novi nelinearni racionalni model koji uključuje na delove polinomijalne poremećaje. Ovakav opis poremećaja je pogodan za modelovanje industrijskih procesa.

Ključne riječi: Klaster analiza, Na delove polinomijalni poremećaj, Nelinearni racionalni model, TS model

PREMISES PARAMETER ESTIMATION OF TS MODELS FOR RATIONAL NONLINEAR SYSTEMS WITH DISTURBANCE

Abstract: In paper is considered a problem of premises parameters estimation (set membership functions) of Takagi-Sugeno (TS) model for nonlinear rational systems with disturbances. Fuzzy logic behaves as universal approximator which nonlinear rational systems puts into a finite collection of linear models. Premises parameters are given by using cluster analysis and Gustafson-Kessel algorithm. In the paper is introduced new nonlinear rational model in the presence of piecewise polynomial disturbance. Such description of disturbances is suitable for modeling of industrial processes.

Key words: Cluster analysis, Nonlinear rational model, Piecewise polynomial disturbacnes, TS model

1 UVOD

Fizički fenomeni na globalnom nivou su nelinearni i njima je, u području automatskog upravljanja, posvećena velika pažnja. U ovom području jedan od pristupa

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je primena funkcije Ljapunova za analizu i sintezu nelinearnih sistema [1-3]. Drugi prilaz je zasnovan na primeni diferencijalne geometrije. U ovoj teoriji je vrlo važan princip linearizacije povratnom spregom. Tako se postupak projektovanja regulatora prenosi u linearni domen u kojem postoji niz vrlo efikasnih metoda projektovanja. U monografiji [4] predložen je novi tip povratne sprege (regulator sa hodom unazad). Ovaj tip regulatora superiorniji je u odnosu na regulatore zasnovane na linearizaciji povratnom spregom jer zadržava neke korisne nelinearnosti.

U ovom radu razmatraju se problem vezani za primenu fazi logike u projektovanju regulatora za nelinearne sisteme. Fazi logika omogućava proizvoljno tačnu aproksimaciju nelinearnog fenomena konačnom kolekcijom linearnih fenomena [5]. Za dobijanje fazi modela koriste se dvostepena procedura: (i) klaster analiza koja omogućava određivanje broja fazi pravila i funkcija pripadnosti i (ii) rekurzivna identifikacija zaključaka fazi pravila. U ovom radu se razmatra problem (i) u kojem se primenjuje Gustafson-Keselov algoritma [6] za klaster analizu.

Ključni doprinos rada je model nelinearnog racionalnog sistema. Uveden je na delove polinomijalni poremećaj koji dobro opisuje poremećaje industrijskih procesa [7]. Umesto polinoma mogu se koristiti splajnovi. U području linearnih sistema primenom Šenon-Kulebakinovih operatora omogućena je sinteza regulatora kao u slučaju da poremećaj ne postoji. Takođe se uvodi observer poremećaja i primenom unutrašnjeg principa modela [8] ocena poremećaja se uvodi u regulator što značajno poboljšava njegove performanse. Takva koncepcija može se primeniti na Takagi-Sugenove modele [8]. Primena strategije podešavanja polova sistema sa povratnom spregom primenjena je na Takagi-Sugenov model u [9].

Simulacije na računaru ilustruju dobijanje parametara premise.

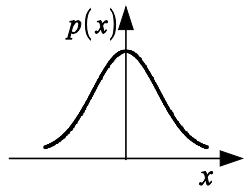
2 NELINEARNI RACIONALNI MODEL I MODELOVANJE POREMEĆAJA

Nelinearni racionalni modeli predstavljaju najopštiju formu nelinearnih sistema. U primenama je često prisutan NARMAX model [10]. To je linearan po parametrima i nelinearan po merenjima model. Racionalni modeli su nelinearni i po parametrima i po merenjima. Brojni su primeri primene na primer u industriji [11] i u biologiji [12]. Identifikaciji nelinearnih sistema posvećena je brojna literatura [13, 14]. U ovom radu koristićemo sledeći model

$$y(k)=\frac{a\left[y(k-1),\ldots,y(k-n),u(k-1),\ldots,u(k-m)\right]}{b\left[y(k-1),\ldots,y(k-n),u(k-1),\ldots,u(k-m)\right]}+e(k), \tag{1}$$

pri čemu je $y(k)$ mereni izlazni signal, $u(k)$ je ulaz nelinearnog sistema i $e(k)$ je poremećaj. Posebno je važan problem modelovanja poremećaja $e(\cdot)$ u modelu (1).

Vrlo često se poremećaji modeluju kao stohastički procesi [15]. Najčešće se pretpostavlja da poremećaj ima Gausovu raspodelu kao na slici 1.

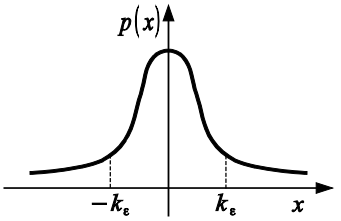


Slika 1. *Gausova gustina verovatnoće poremećaja*

U praksi, međutim, retko postoji čista normalna raspodela. Istraživanja su pokazala da u industrijskim procesima postoje i impulsni poremećaji. U tom slučaju gustina verovatnoće je negausova i ima sledeći oblik

$$p(e)=\begin{cases} \dfrac{1-\alpha}{\sqrt{2\pi}\sigma_N}\exp\left\{-\dfrac{e^2}{2\sigma_N^2}\right\}, & |e|\le k_\varepsilon \\ \dfrac{1-\alpha}{\sqrt{2\pi}\sigma_N}\exp\left\{-\dfrac{k_\varepsilon}{\sigma_N^2}\left(|e|-\dfrac{k_\varepsilon}{2}\right)\right\}, & |e|>k_\varepsilon \end{cases}. \tag{2}$$

Grafička predstava ove gustine verovatnoće je kao na sledećoj slici.



Slika 2. *Negausova gustina verovatnoće poremećaja*

U području identifikacije takav slučaj je razmatran u [16].

Često se uvodi pretpostavka da je poremećaj uniformno ograničena veličina

$$|e(k)|\le k_d, \qquad k_d\in(0,\infty). \tag{3}$$

U ovoj oblasti razvijena je posebna tehnika: tehnika invarijantnih elipsoida. Metodologija je primenjena u referenci [17].

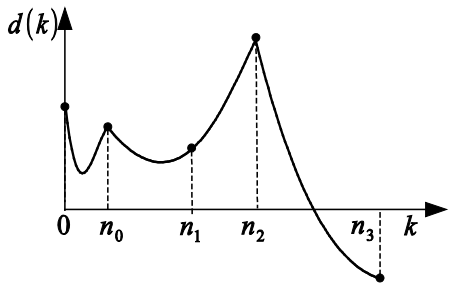
U ovom radu se razmatra na delove polinomijalni poremećaj koga ćemo označavati sa $d(k)$ i čija je analitička forma data sledećom relacijom

$$d(k)=\begin{cases} d_0(k)=d_0+d_0^1k+d_0^2k^2++d_0^{m_0}k^{m_0}, & 0\le k<n_0 \\ d_1(k)=d_1+d_1^1k+d_1^2k^2++d_1^{m_1}k^{m_1}, & n_0\le k<n_1 \\ \vdots & \vdots \\ d_p(k)=d_p+d_p^1k+d_p^2k^2++d_p^{m_p}k^{m_p}, & n_{p-1}\le k<n_p \\ \vdots & \vdots \end{cases}. \tag{4}$$

Na slici 3 je prikazan na delove kvadratni signal.

Opis sistema koji razmatramo u ovom radu ima formu

$$y(k)=\frac{a\left[y(k-1),\ldots,y(k-n),u(k-1),\ldots,u(k-m)\right]}{b\left[y(k-1),\ldots,y(k-n),u(k-1),\ldots,u(k-m)\right]}+d(k), \tag{5}$$



Slika 3. Negausova gustina verovatnoće poremećaja

3 ODREĐIVANJE PARAMETARA PREMISE

Opšta forma Takagi-Sugenovog modela je

$$R_i:\ \text{IF } \mathbf{x} \text{ IS } A_i(\mathbf{x}) \text{ THEN } \left(Reg.model\right)_i \qquad i=1,\ldots,c\,. \tag{6}$$

U relaciji (6) $A_i(\mathbf{x})$ je multivarijabilna funkcija pripadnosti, $\left(Reg.model\right)_i$ može biti proizvoljan regresioni model (na primer FIR, ARX, ARMAX i slično) a c je broj klastera (broj fazi pravila). Ako se pretpostavi da premisa zavisi samo od veličina $y(\cdot)$ relacija (6) dobija oblik

$$\begin{aligned} R_i:\ \text{IF } y(k-1) \text{ IS } A_{i,1}\left(y(k-1)\right) \text{ AND } y(k-2) \text{ IS } A_{i,2}\left(y(k-2)\right) \text{ AND } \ldots \\ \text{AND } y(k-n) \text{ IS } A_{i,n}\left(y(k-n)\right) \text{ THEN } \left(Reg.model\right)_i \end{aligned}\,. \tag{7}$$

Uvedimo veličinu stepena ispunjenosti fazi pravila

$$\beta_i\left(y(k-1),\ldots,y(k-n)\right)=\prod_{j=1}^{n} A_{i,j}\left(y(k-j)\right). \tag{8}$$

Izlaz Takagi-Sugeno model je

$$y(k)=\frac{\sum_{i=1}^{c}\beta_i\left(y(k-1),\ldots,y(k-n)\right)\left(Reg.model\right)_i}{\sum_{i=1}^{c}\beta_i\left(y(k-1),\ldots,y(k-n)\right)}. \tag{9}$$

Napomenimo da relacija (7) opisuje individualni podsistem u Takagi-Sugenovom modelu. Uočimo da u relaciji (7) premisa može da zavisi od $u(k-1),u(k-2),\ldots,u(k-m)$ veličina. Za model (7) matrica podataka je [18]

$$\mathbf{Z}=\begin{bmatrix} y_1(k-1) & \cdots & y_N(k-1) \\ \vdots & \ddots & \vdots \\ y_1(k-n) & \cdots & y_N(k-n) \\ y_1(k) & \cdots & y_N(k) \end{bmatrix},\quad \mathrm{Z}\in R^{(n+1)\times N}. \tag{10}$$

Svaka opservacija je

$$\mathbf{z}(p)=\begin{bmatrix} y_p(k-1) & \dots & y_p(k-n) & y_p(k) \end{bmatrix}^T, \quad p=1,2,\dots,N, \quad \mathbf{z}(p)\in R^{n+1}. \qquad (11)$$

Matrica fazi particije je

$$\mathbf{U}=\left[\mu_{i,p}\right]_{c\times N}, \qquad (12)$$

pri čemu $\mu_{i,p}$ predstavlja stepen pripadnosti opservacija $\mathbf{z}(p)$ na klasteru (i). Dalje se primenjuje Gustafson-Keselov algoritam čiji pseudo-kod dat u sledećoj tabeli.

Table 1. *Gustafson-Keselov algoritam*

Gustafson-Keselov algoritam

Ulazi algoritma su: matrica podataka $\mathbf{Z}$*, broj klastera* c*, težinski eksponent* m*, zapremine klastera* ρ_i

Inicijalizuje se matrica fazi particija $\mathbf{U}^{(0)}$

Do for $l=1,2,\dots$

Korak 1: Računanje centara klastera

$$\mathbf{v}^{(l)}(i)=\frac{\sum_{p=1}^{N}\left(\mu_{i,p}^{(l-1)}\right)^m \mathbf{z}(p)}{\sum_{p=1}^{N}\left(\mu_{i,p}^{(l-1)}\right)^m}, i=1,2,\dots,c$$

Korak 2: Računanje fazi kovariacionih matrica klastera

$$\mathbf{F}_i=\frac{\sum_{p=1}^{N}\left(\mu_{i,p}^{(l-1)}\right)^m \left(\mathbf{z}(p)-\mathbf{v}^{(l)}(i)\right)^T\left(\mathbf{z}(p)-\mathbf{v}^{(l)}(i)\right)}{\sum_{p=1}^{N}\left(\mu_{i,p}^{(l-1)}\right)^m}, \qquad i=1,2,\dots,c$$

Korak 3: Računanje udaljenosti podataka od centra klastera

$$\mathbf{A}_i=\left[\rho_i \det(\mathbf{F}_i)\right]^{\frac{1}{n}}\mathbf{F}_i^{-1}$$

$$d_M^2\left(\mathbf{z}(p),\mathbf{v}^{(l)}(i)\right)=\left(\mathbf{z}(p)-\mathbf{v}^{(l)}(i)\right)^T\mathbf{A}_i\left(\mathbf{z}(p)-\mathbf{v}^{(l)}(i)\right), \quad i=1,2,\dots,c, \quad p=1,2,\dots,N$$

Korak 4: Ažuriranje matrice fazi particija

For $i=1,2,\dots,c$ ***and*** $k=1,2,\dots,N$

If $d_M\left(\mathbf{z}(p),\mathbf{v}^{(l)}(i)\right)>0$

$$\mu_{i,p}^{(l)}=\frac{1}{\sum_{j=1}^{c}\left(\frac{d_M^2\left(\mathbf{z}(p),\mathbf{v}^{(l)}(i)\right)}{d_M^2\left(\mathbf{z}(p),\mathbf{v}^{(l)}(j)\right)}\right)^{\frac{1}{m-1}}}$$

Else

$$\mu_{i,p}^{(l)}=0 \text{ and } \sum_{i=1}^{c}\mu_{i,p}^{(l)}=1$$

Until $\max\left(\max\left|\mathbf{U}^{(l)}-\mathbf{U}^{(l-1)}\right|\right)<\varepsilon$

Nakon izvršavanja Gustafson-Keselovog algoritma kao izlazi dobijaju se matrica fazi particije $\mathbf{U}$, matrica centara klastera $\mathbf{V}$ kao i skup od c fazi kovariacionih matrica $\mathbf{F}_i$. Matricom $\mathbf{V}$ definisani su položaji centara dobijenih klastera, dok je kovariacionim matricama definisana geometrija klastera.

Na osnovu izlaza Gustafson-Keselovog algoritma mogu se odrediti parametri premisa Takagi-Sugenovog modela. Zbog jednostavnosti pretpostavljeno je da su funkcije pripdnosti Gausove

$$A_{i,j}\left(z_j\left(p\right)\right)=\exp\left(-\frac{1}{2}\frac{\left(z_j\left(p\right)-v_j\left(i\right)\right)^2}{\sigma_{i,j}^2}\right),\quad i=1,\ldots,c,\quad j=1,\ldots,n\,, \tag{13}$$

koje su definisane preko položaja centra i varijanse. Položaji centara su elementi matrice $\mathbf{V}$. Varijanse funkcija pripadnosti određuju se pomoću sledećeg izraza

$$\sigma_{i,j}^2=\frac{\sum_{p=1}^{N}\mu_{i,p}\left(z_j\left(p\right)-v_j\left(i\right)\right)^2}{\sum_{p=1}^{N}\mu_{i,p}}. \tag{14}$$

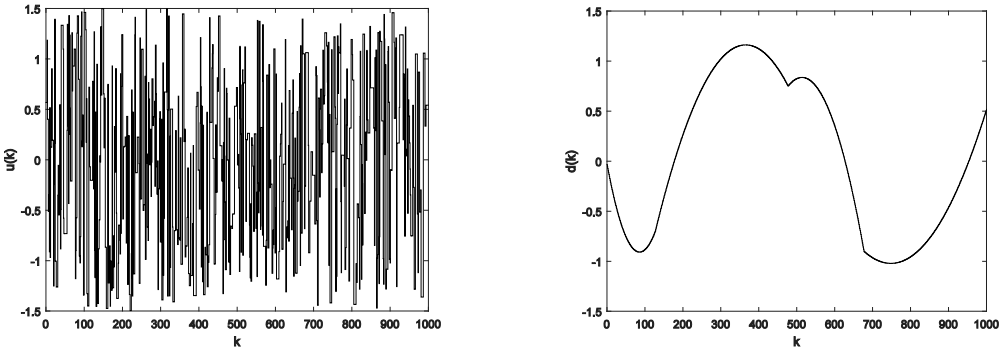
Kada se odrede svi parametri funkcija pripadnosti premisa Takagi-Sugenovog modela je potpuno definisana i može se pristiupiti ocenjivanju parametara zaključaka.

4 SIMULACIJE

Posmatra se nelinearni sistem drugog reda

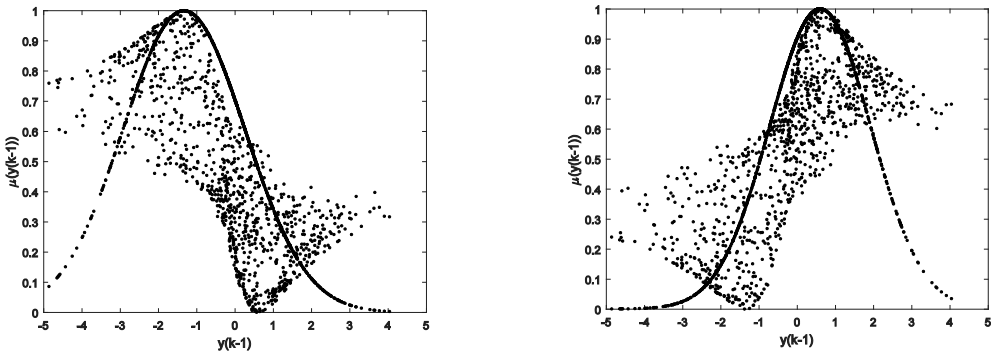
$$y\left(k\right)=\frac{y\left(k-1\right)y\left(k-2\right)\left[y\left(k-1\right)-0.5\right]}{1+y^2\left(k-1\right)+y^2\left(k-2\right)}+u\left(k\right)+d\left(k\right). \tag{15}$$

Sistem je pobuđen amplitudno-modulisanim PRBS signalom dok je promećaj na delove kvadratni signal.

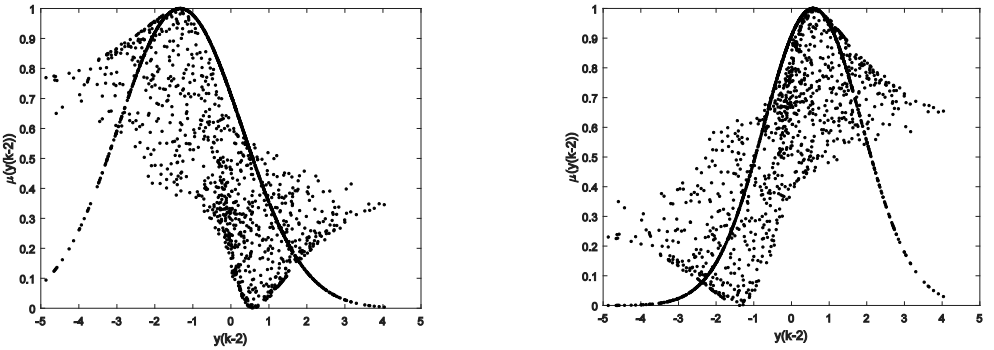


Slika 4. *Amplitudno-modulisani PRBS (levo), na delove kvadratni signal (desno)*

Ulaz Takagi-Sugeno modela je $\mathbf{x}=\left[y\left(k-1\right),y\left(k-2\right)\right]$ i on se deli u dva klastera. Na sledećim slikam prikazani su dobijeni klasteri i procenjene funkcije pripadnosti.



Slika 5. *Uporedni prikaz dobijenih klastera i procenjenih funkcija pripadnosti za* $y(k-1)$



Slika 6. *Uporedni prikaz dobijenih klastera i procenjenih funkcija pripadnosti za* $y(k-2)$

5 ZAKLJUČCI

U radu je izložen postupak za određivanje parametara premisa (funkcija pripadnosti) za Takagi-Sugoneov model koji predstavlja aproksimaciju nelinearnog racionalnog modela. Pretpostavlja se da je poremećaj na delove polinomijalna funkcija. Rezultati ovog reda mogu se koristiti za drugi stepen fazi identifikacije a to je rekurzivno ocenjivanje parametara zaključka.

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NOMENKLATURA

$A_{i,j}$	funkcija pripadnosti *j*-te veličine *i*-tom pravilu
c	broj fazi pravila (klastera)
d(k)	na delove polinomijalni poremećaj
e(k)	poremećaj

$\boldsymbol{F}_i$ fazi kovariaciona matrica i-tog klastera
N broj opservacija
$u(k)$ ulazni signal
$\boldsymbol{U}$ matrica fazi particija
$\boldsymbol{V}$ matrica centara klastera
$y(k)$ mereni izlazni signal
$\boldsymbol{Z}$ matrica podataka

Grčki alfabet

β_i stepen ispunjenosti *i*-tog fazi pravila
$\mu_{i,p}$ stepen pripadnosti opservacije $z(p)$ klasteru *i*

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ON THE DIVERSITIES OF MULTIVARIABLE CONTROL SYSTEMS

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Abstract: Successful system control can`t be achieved without taking into account system nature. Present paper contain overview of control strategies for various multivariable systems. Regarding the mathematical model, order of system and eventual presence of dead time have high influence on the choice of method, which can ensure appropriate design of decoupler and controller. All in order to ensure desired dynamical behaviour of system. Due to that, it is very important to recognize if controlled object is mechanical system or industrial process. Systems with two inputs and two outputs has been illustrated here. Consideration has been supported and presented by appropriate simulations from relevant investigations.

Key words: Decoupler, Multivariable system, PID Control.

1 INTRODUCTION

In a multitude of different industrial processes, the conditions for their functioning and the constraints on the feasibility of their control, it is a very broad field of research for adequate control algorithms that can ensure their given dynamic behavior. Regarding to multivariable systems, additional problem is mutual coupling between inputs and outputs. It disturbs both tuning of controller and functioning of system. Due to that, design of decoupler and controller have equal importance. There are a lot of investigations referring to decoupler synthesis [1-5]. Also, many methods for controller tuning, that were proved in single input single output systems, naturally try to find its application in the multivariable systems, with or without integrated decoupler [6-11]. Below is given an overview of the tipical (commonly used) industrial processes belonging to group with the two inputs and two outputs. As it shown, various kinds and combinations of decoupler and controller can be used for control of common plants in industry.

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2 ANALYSIS OF THE CONTROL STRATEGY FOR TIPICAL INDUSTRIAL PROCESSES

The possibilities of different control strategies, applied to the one mechanical system and two processes, regarding achieving their desired dynamical behavior, are shown in this chapter. Both kind of objects include their main features: mechanical system - high order and process - time (transport) delay.

2.1 Electrohydraulic servosystem for structural testing

As represent of mechanical systems, electrohydraulic servosystem for structural testing was taken here. Aim of control system is to accomplish defined load (forces) to the cantilever beam. Desired dynamical behaviour is determined by intensity and character of the forces on the piston rods. They are controlled by flow rates through the servovalves. Mathematical model of this system has been experimentally derived in [12] and shown in (1).

$$G(s)=\frac{1}{\Delta(s)}\begin{bmatrix} g_{11}(s) & g_{12}(s) \\ g_{21}(s) & g_{22}(s) \end{bmatrix}$$

$$\begin{aligned} g_{11}(s) &= 2.926\cdot 10^{2}s^{4}+1.9152\cdot 10^{4}s^{3}+1.2667\cdot 10^{7}s^{2}+5.5825\cdot 10^{7}s+4.7959\cdot 10^{9} \\ g_{12}(s) &= -3.8382\cdot 10^{4}s^{3}-1.7068\cdot 10^{7}s^{2}-8.3584\cdot 10^{7}s-6.4967\cdot 10^{9} \\ g_{21}(s) &= -4.4533\cdot 10^{3}s^{3}-3.2461\cdot 10^{6}s^{2}-1.4362\cdot 10^{7}s-1.2403\cdot 10^{9} \\ g_{22}(s) &= 2.506\cdot 10^{2}s^{4}+1.6229\cdot 10^{4}s^{3}+6.6134\cdot 10^{6}s^{2}+3.0476\cdot 10^{6}s+2.4813\cdot 10^{9} \\ \Delta(s) &= s^{5}+1.2308\cdot 10^{2}s^{4}+6.993\cdot 10^{4}s^{3}+1.5098\cdot 10^{6}s^{2}+3.5504\cdot 10^{8}s+8.2333\cdot 10^{-6} \end{aligned} \quad (1)$$

It is fifth-order system without time delay. Cancelation of mutual coupling between two control loops was carried out using inverted decoupler. It was designed based on [1]. Having in mind pretty high order of system mathematical model, mentioned kind of decoupler was utilized as static. In order to avoid unnecessary additional dynamics, transfer function of the decoupler is simple gain. Its expression is given by (2) and (3), respectively.

$$D(s)=\begin{bmatrix} 1 & d_{12}(s) \\ d_{21}(s) & 1 \end{bmatrix} \quad (2)$$

$$\begin{aligned} d_{12}(s)\Big|_{s=0} &= \frac{-g_{12}(0)}{g_{11}(0)} \\ d_{21}(s)\Big|_{s=0} &= \frac{-g_{21}(0)}{g_{22}(0)} \end{aligned} \quad (3)$$

PID controller in general case, whose equation is shown in (4) and (5), has been design using pole placement method [13].

$$K(s)=\begin{bmatrix} k_1(s) & 0 \\ 0 & k_2(s) \end{bmatrix} \quad (4)$$

$$k_1(s) = K_{p1} + \frac{K_{i1}}{s} + K_{d1} \cdot s$$
$$k_2(s) = K_{p2} + \frac{K_{i2}}{s} + K_{d2} \cdot s \quad (5)$$

Beside basic system (Example 1), the same procedure was performed on the two other perturbed models with 20% increased parameters (Example 2) and 20% decreased parameters (Example 3). They are given in [13]. Therefore, three similar mathematical models were investigated in order to show effectiveness of presented approach. Reference variables has been set as follows: sine function for first output and step function for second output. Responses are given in Figure 1., where is noticeable that P controller is the least sensitive to the model perturbations, i.e. model uncertainties, because it enables the best reference tracking.

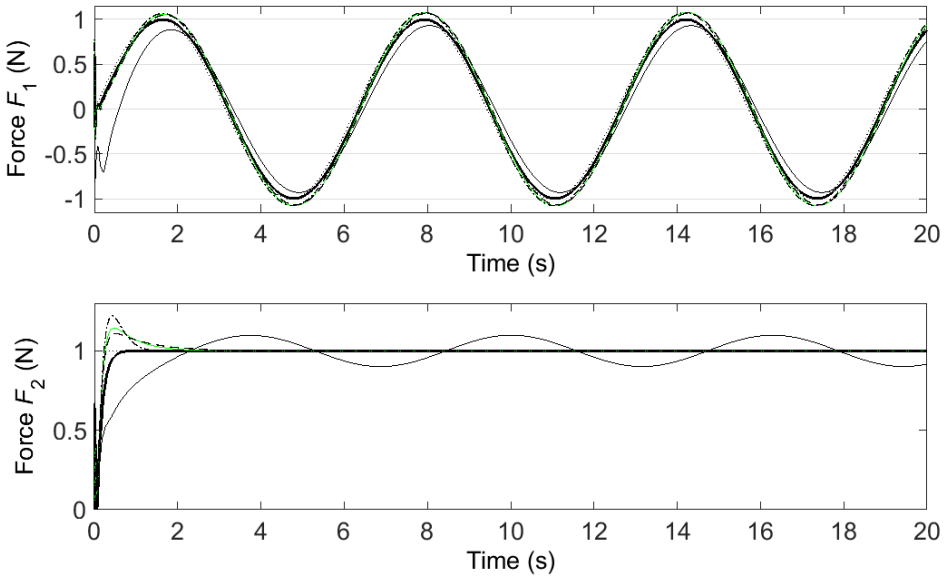


Figure 1. *Forces on the cylinders (r_1 unit sine function, r_2 unit step function) ____ Singer [12], _____ P, ____ PI$^{Ex.1}$, _._._ PI$^{Ex.2}$, _ _ _ PI$^{Ex.3}$ controllers, ... r_1,r_2 [13]*

The same object (electrohydraulic servosystem) was researched in [14]. Static inverted decoupler was applied, but controller was designed in two ways. At first, using single relay feedback test for both decoupled loops, and second using Matlab toolbox (Simulink Control Design - PID Tuner) for controller tuning. Application of relay feedback test gives only P controller that enable good system performances, as it shown in Figure 2. PI and PID controllers cause system instability and due to that they weren't shown in Figure 2. Like in diagram in Figure 1. reference values are unit sine and step functions in order to make interaction between loops more obvious. Controller tuned using Matlab toolbox gives responses shown in Figure 3. P, PI and PID controllers are feasible in this case, but the best one is P controller again. It very successfully cancels mutual coupling and enable good reference tracking.

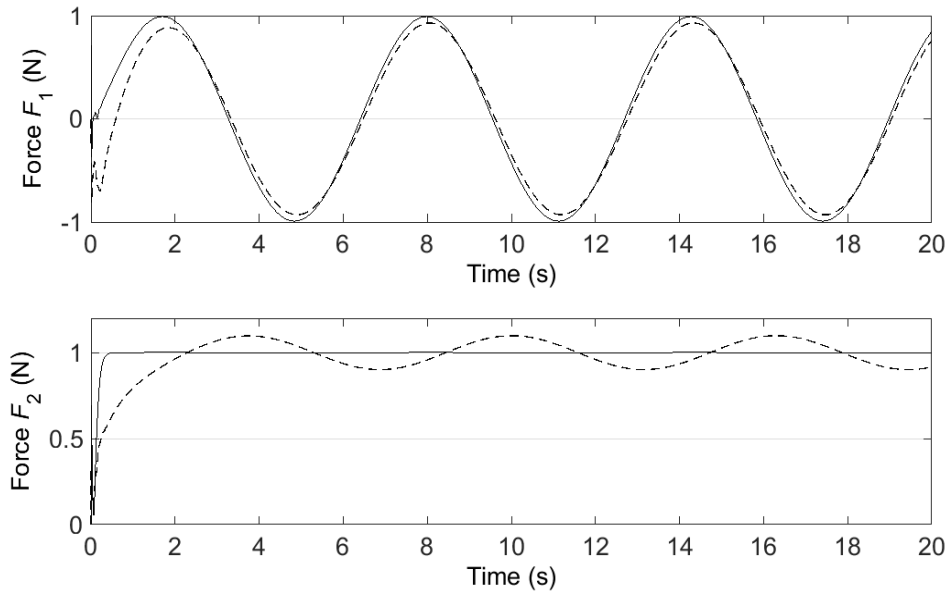


Figure 2. *Forces on the cylinders (r_1 - unit sine function, r_2 - unit step function) _ _ _ Singer [12], ___ Decoupling and P controller based on relay feedback test) [14]*

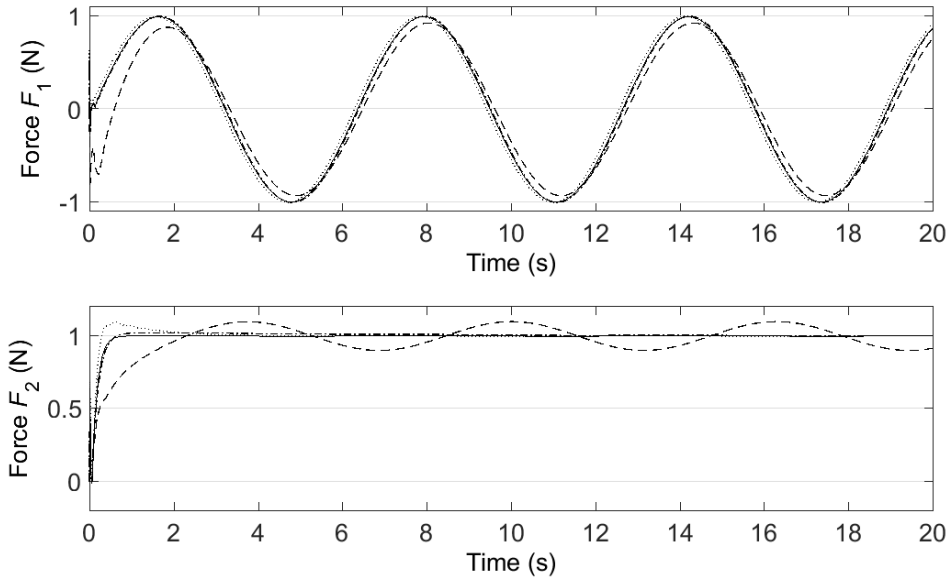


Figure 3. *Forces on the cylinders: _ _ _ Singer [12], Decoupling control (___ P, ... PI, _._._ PID controllers based on Matlab toolbox) [14]*

2.2 Flow tank

Level h and temperature t are controlled variables in this tank. Manipulated variables are flow rates Q_1 and Q_2 through the valves. Reference values are: h_r=1 m, and t_r=30 °C. Its transfer matrix follows (6):

$$G(s)=\begin{bmatrix} \dfrac{0{,}01}{63s+1} & \dfrac{0{,}01}{63s+1} \\ \dfrac{-0{,}15}{10s+1}e^{-3s} & \dfrac{0{,}4}{10s+1}\mathrm{e}^{-2s} \end{bmatrix} \tag{6}$$

Two types of decoupler (direct and inverted) are compared here. They have same transfer function matrix given by (7), but difference is in direct and inverted way of conection [2].

$$D(s)=\begin{bmatrix} 1 & d_{12}(s) \\ d_{21}(s) & 1 \end{bmatrix}=\begin{bmatrix} 1 & \dfrac{-g_{12}(s)}{g_{11}(s)} \\ \dfrac{-g_{21}(s)}{g_{22}(s)} & 1 \end{bmatrix} \tag{7}$$

Simulated responses are shown in the Figure 4. In the presented example overshoot minimization was constraint in controller design. PI controllers are tuned using method in [6]. Taking into account the other indicators of process behaviour (rise time and settling time in both outputs), it is noticeable that control structure which contain direct decoupler is better.

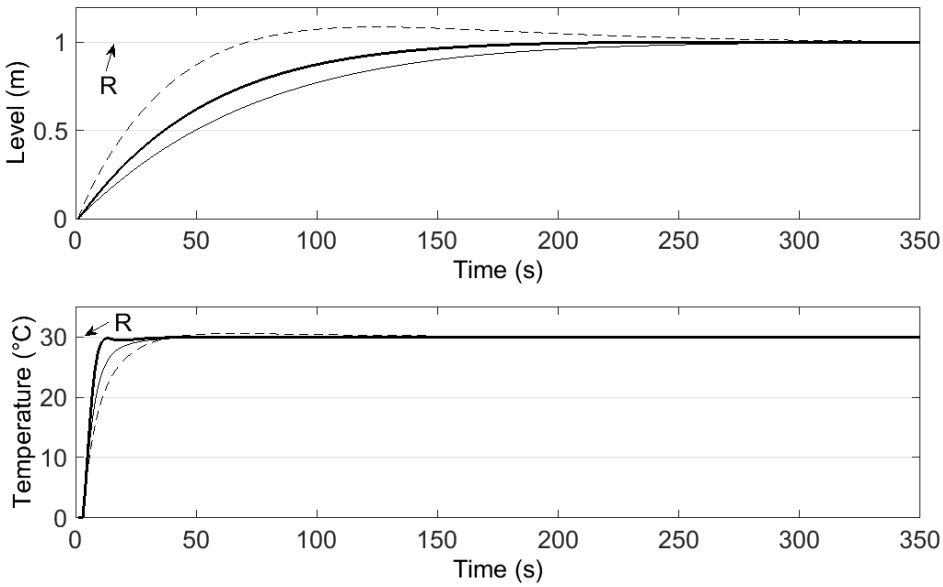


Figure 4. *Comparative display of responses under two control strategies: ____with direct and ____with inverted decoupler and _ _ _without decoupler, R - reference values [15]*

2.3 Binary distillation column (water - methanol)

Binary distillation column (water-methanol) is identified in [16]. Its transfer function matrix is given with (8). Controlled variables are: X_D – percentage of methanol in the distillate and X_B – percentage of methanol in the bottom products. Manipulated variables are: R – reflux flow rate and S – steam flow rate in the reboiler.

$$G(s)=\begin{bmatrix} \dfrac{12,8}{16,7s+1}e^{-s} & \dfrac{-18,9}{21s+1}e^{-3s} \\ \dfrac{6,6}{10,9s+1}e^{-7s} & \dfrac{-19,4}{14,4s+1}e^{-3s} \end{bmatrix} \tag{8}$$

Like in above mentioned examples, decoupler was designed in order to form two independent SISO (single input single output) systems. Direct decoupler was used because time delays mustn't be neglected contained in (8). D – decomposition method [7-10] was utilized for tuning PID controllers for separated loops, as it shown in (4) and (5). Criterion that contain minimizing of integral error was taking into account. Tuning procedure was carried out for two different additional constrains: first minimized overshoot and second faster responses. Simulated responses for these cases were compared with others from literature and shown in Figures 5. and 6, respectively. These diagrams prove that proposed method (Prodanovic et al. [7]) better satisfies specified conditions, without deteriorating other quality indicators of the system behavior.

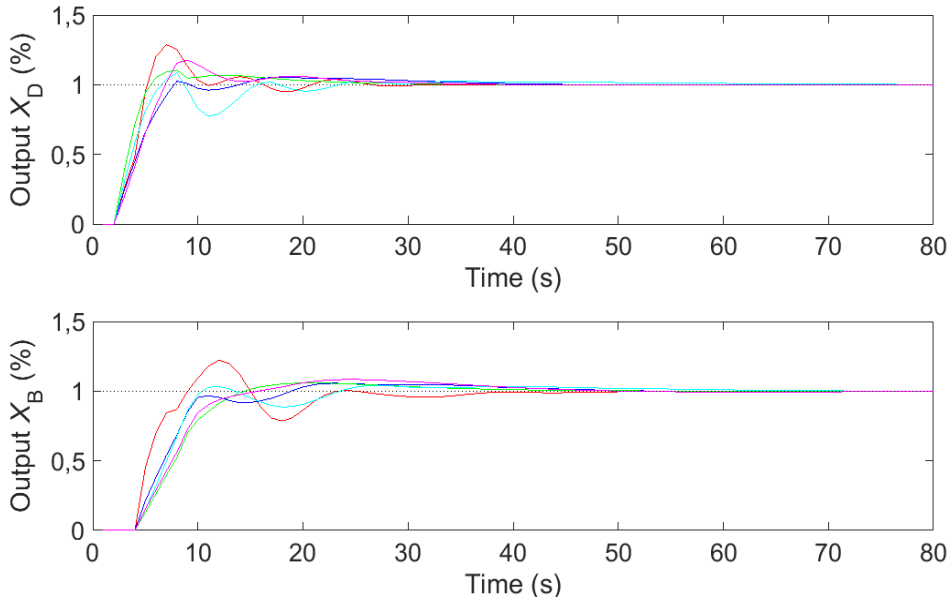


Figure 5. *Wood/Berry distillation column responses (minimized overshoot)* ____ *Atashpaz-Gargari et al. [11],* ____ *Prodanovic et al. [7],* ____ *Garrido et al. [3],* ____ *Morilla et al. [4],* ____ *Wang et al. [5],* ..... *Reference value*

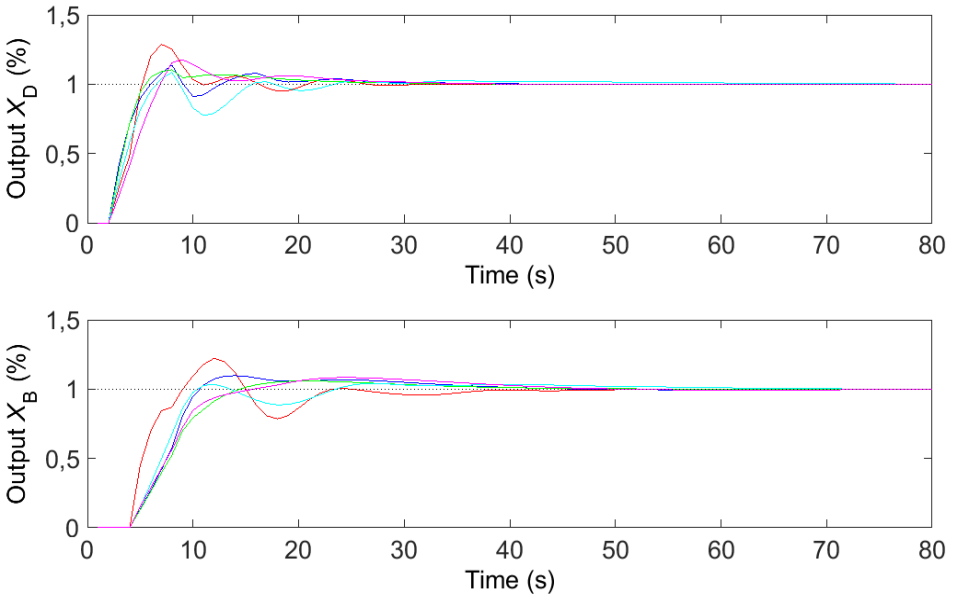


Figure 6. *Wood/Berry distillation column responses (faster responses) ____ Atashpaz-Gargari et al. [13], ____ Prodanovic et al. [7], ____ Garrido et al. [3], ____ Morilla et al. [4], ____ Wang et al. [5], ... Reference value*

3 CONCLUSION

There are presented various decoupler and controller design methods that can be applied to the particular objects. The complexity is much higher because of the different combinations between them. Some of them have aim to introduce as low as possible dynamic into control system, especially in mechanical systems. In the process industry, attention should be paid on the time delay. Decoupler effectiveness is indicated by level of influence of one control loop on the other. In other words, good decoupler prevent change in one response in the moment of changing of the other response. Control strategies are under following demands: increasing robustness to uncertainty, compensating mutual coupling, disturbance rejection and enabling as good as possible indicators of system behaviour. Therefore, mutual coupling cannot be solved using conventional methods that design controller for single loop. This problem is overcome with separately designed decoupler (like in present paper) or using controllers whose off-diagonal elements are not equal zero, i.e. contoller structure is changed. This overview lead to conclusion that derivation of universal rule or method is very difficult, but every object needs to be approached strictly with regard to its nature and the conditions it needs to fulfill.

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U/f CONTROL FOR VARIABLE SPEED THREE-PHASE AC MOTOR IN HYDRAULIC SYSTEM

Jelena Eric Obucina[1], Stevan Stankovski[2], Gordana Ostojic[3], Stanimir Cajetinac[4], Slobodan Aleksandrov[5]

Abstract: Research on how to control the electric motor, as well as the efficiency that is reflected through energy savings, is dominant in applications in hydraulic systems. In order to improve efficiency, devices that increase the overall quality of the system should be used. With the hydraulic system, electricity, electricity from an electric motor, turns into a hydraulic system, and then mechanical work is carried out. Since the operating conditions of hydraulic systems demanded a large number of variable loads on the actuator, the hydraulic components that provided this also developed. However, some simpler and cheaper components were left unattended because they did not fit into modern design and application with suitable hydraulic components. The development of electronic components for application in the hydraulic system is intensified here. Such an applicable component is a frequency converter regulating the speed of rotation of an electric motor and which is described in this paper in the application on the hydraulic system.

Key words: Control, frequency converter, hydraulic system, saving energy

1 UVOD

Within the basic functions of the hydraulic system, energy transformation, the construction of the hydraulic system must fulfill another important requirement. This requirement is that energy losses in the energy transformation path must be minimal. The total loss of energy in the hydraulic system arises as a result of: a) pressure drop, b) volume losses within the components, c) uncoordinated pump characteristics with the maximum and necessary [1, 2].

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Losses due to pressure drop can be reduced by the construction of hydraulic components that provide the necessary pressure in the system. In reducing the volume losses in the hydraulic system, in fact, the characteristics of the pump are adjusted with the requirements that occur in the system. This means that the operation of the hydraulic system must be monitored at all times and meet the requirements that are required at that moment. [1, 2], [7].

The development of electronics creates new spaces for the development of hydraulics, not only in the field of component design, but also in control systems. [2]

Today electric motors are an important standard industrial product. These motors are designed to run at a fixed speed and work has been going on for many years to optimise the control of their running speed.

Because of the ever-increasing degree of automation in industry, there is a constant need for more automatic controls, and a steady increase in production speeds and better methods to further improve the efficiency of production plants are being developed all the time.

A static frequency converter is an electronic unit which provides infinitely variable control of the speed of three-phase AC motors by converting fixed mains voltage and frequency into variable quantities. Whilst the principle has always remained the same, there have been many changes from the first frequency converters, which featured thyristors, to today's microprocessorcontrolled, digital units.

It was not until the static frequency converter was introduced that three-phase AC motors with infinitely variable speed could be used effectively. [8].

The vast majority of the static frequency converters used by industry today to control or regulate the speed of three-phase AC motors are designed according to two different principles:

- frequency converters without an intermediate circuit (also known as direct converters), and
- frequency converters with a variable or constant intermediate circuit.

Today, the frequency converter controlled, three-phase AC motor is a standard element in all automated process plants as well as in hydraulic systems. Apart from its ability to use the good properties of three-phase AC motors, infinitely variable speed regulation is often a basic requirement because of the design of the plant.

Energy can be saved if the motor speed matches requirements at any given moment in time. This applies in particular to centrifugal pumps and fan drives where the energy consumed is reduced by the cube of the speed. A drive running at half speed thus only takes 12.5% of the rated power.

2 APPLICATION OF FREQUENCY REGULATORS IN THE HYDRAULIC SYSTEM

Due to the increasing participation of automation in the industry, there is a constant need for automatic control, a continuous increase in the production rate and better methods for improving the level of utility plants are constantly evolving and improving. Electric motors are still important standard industrial product. Until they emerged drives it was not possible to fully control the speed of three-phase AC motor.

As stated, drives control the speed of the motor by changing the frequency of the motor voltage. Synchronous speed (the speed of rotation of the magnetic field of the stator in rotations per minute, RPM) is:

$$\text{Synchronous speed} = \frac{120 * \text{frequency}}{\text{number pole of motor}} \quad (1)$$

Frequency regulators are electronic devices that allow the control of the speed of three-phase AC motors by converting the input voltage and constant frequency into variable sizes. The principle of regulation and speed control characteristics of the asynchronous electrical drive function differently from the control system of the DC and servo motors.

The good characteristics of frequency regulators are known: a) programming of continuous speed control at constant torque; b) the possibility of programming a ramp; c) defining run time; d) a relatively high degree of accuracy of the recurrent state; e) allowed short-term load up to 50%; f) Increase in pump speed and capacity relative to nominal and other. The most important characteristics limiting the scope of application in the hydraulic drive are: a) delay of the response speed due to the change in the speed of the rotor mass of the electric motor and the pump; b) insufficient control over the achievement of the programmed capacity; c) limitation of the minimum permissible pump speed; d) high production price; e) narrow area of application of constant capacity pumps and others. [4, 6, 7].

2.1 Application of frequency regulator in hydraulic system for regulating capacity gear pumps

Controling of capacity of constant-volume capacities pumps rarely in hydraulic drive designs. In the last twenty years, in parallel with the development of the structure, the improvement of technical characteristics and the fall in the price per kW of power, the frequency regulators are modest, but all the glasses are used in the construction of hydraulic systems.

For such a trend, the development of the construction of gear pumps was necessary, in fact, their penetration into the area of higher operating pressures (250 to 300 bar) and larger capacities.

The following figure shows a hydraulic system with a gear pump, as a source of hydraulic energy and a frequency regulator, as an electronic component that regulates pump capacity. [4, 6, 7].

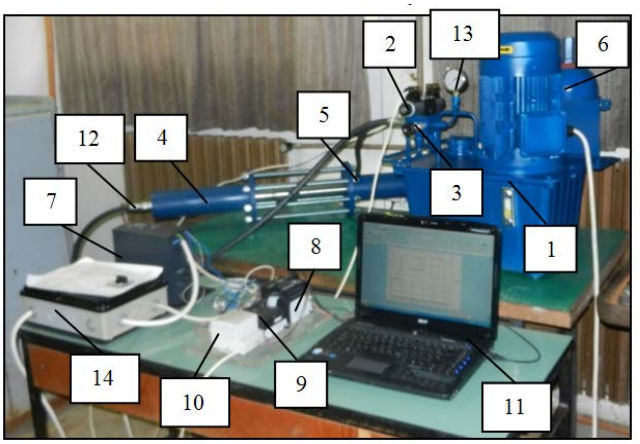


Figure 1. *The hydraulic system of regulation capacity gear pump frequency converter [4, 6, 7]*

Components of the hydraulic system are:

1 - hydraulic power pack, 2 - hydraulic valve, 3 - safety valve, 4 - hydraulic cylinder, 5 - hydraulic cylinder for load, 6 - hydraulic accumulator, 7 - frequency converter, 8 - PLC CP1L, 9 - a module for acquisition CP1W - MAD11, 10 - DC module 24V, 11 - computer, 12 - pressure transmitter, 13 - manometer, 14 - clutch.

The system works by including, at the start, an electric motor, as an energy source, and a frequency regulator on which the reference value of the pressure to be maintained in the system is assigned. The frequency controller serving as a controller has an integrated PID controller that maintains a reference pressure value.

Frequency regulator, slightly clogged pump, and then changes the rotation to keep the pressure at the set value. By activating the command to put the system into operation, the hydraulic pump is running in the order of the desired output, i.e. the reference value to be achieved on the executive body, i.e. hydraulic cylinder, maintains the set value.

The actual pressure value is obtained from a pressure transmitter mounted on a hydraulic cylinder, more precisely at a pressure measurement point in the hydraulic cylinder, and directly connected to the frequency regulator. In the event of a larger force required, the frequency regulator will refer to the speed of the electric motor, thereby pumping up the flow, as it will require a higher pressure value that is directly related to the force on the hydraulic cylinder.

Also, in case of necessary less force ie. pressure on the hydraulic actuator, this will, via the return connection, react to the frequency regulator which will reduce the speed of the drive shaft of the hydraulic pump and it will give a lower flow.

The results obtained during the experimental work are shown in Figure 2 and determine the dependence of the speed of the electric motor and pressure in the hydraulic system [4, 6, 7].

Figure 2 shows that the different speeds of the three-phase AC motor correspond to the pressure in the hydraulic system. This will confirm a theoretical consideration that the frequency regulator in the hydraulic system saves energy because the system does not always work at high pressure, but will also have the appropriate pressure, which is provided by the speeds of the three-phase AC motor, depending on the required force.

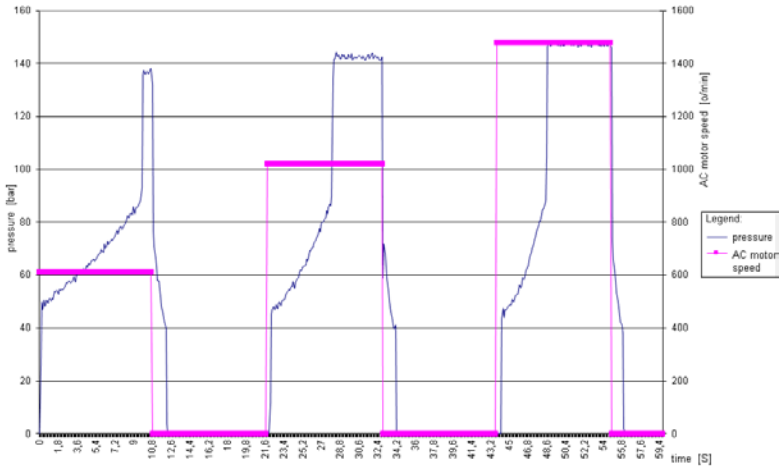


Figure 2. *Diagram depending on the pressure in the hydraulic system and the number of revolutions of electric motors [4, 6, 7]*

The second variant of this experimental part is that the frequency controller is operated via a PLC, which then receives the pressure value from the transmitter and sends the command to the frequency regulator.

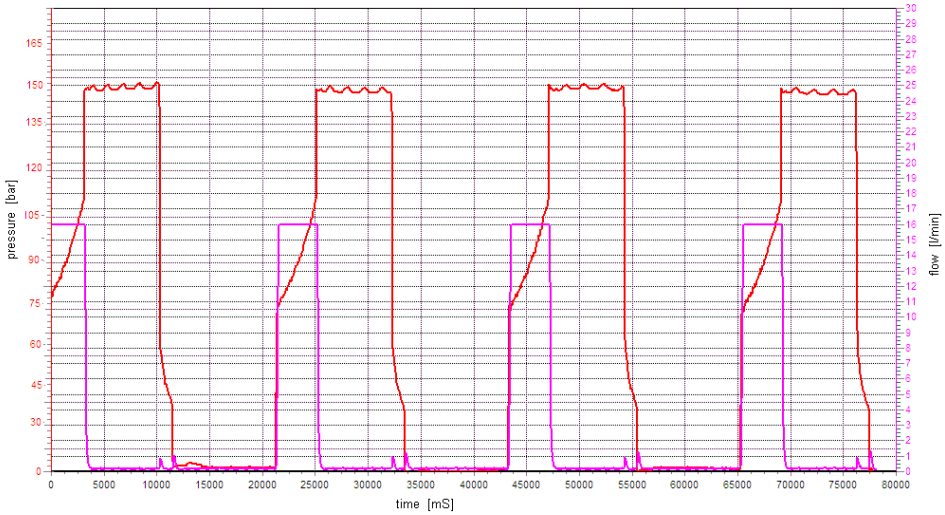


Figure 3. *Diagram of change of pressure and flow in time*

2.2 Comparison of economic parameters of regulation capacity hydraulic pumps

Comparison of economic parameters is given in Figure 4. A comparative analysis was performed for pumps and drives the program the world's leading manufacturers. With hydraulic drives in which it is possible to apply hydraulic regulator or inverter producer price continent pump and controller becomes a priority for the decision. Therefore, a comparative price analysis of axial piston pumps with hydraulic regulator and gear pumps with frequency converter in the work area capacity of 25 to 70 l/min and operating pressures of 150, 210 and 250 bar (the chart in Figure 4).

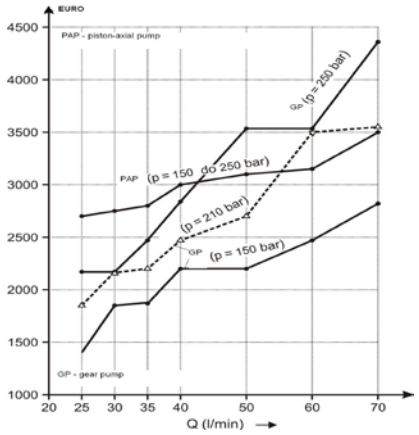


Figure 4*. Graphical display prices piston-axial pumps and hydraulic gear pumps with frequency converter* [4]

3 CONCLUSION

In this paper, data analysis and experimental data show that the use of the frequency converter in the hydraulic system useful. The diagram on figure 4. below, it is concluded that from the standpoint of economy, in the area of lower pressure, a combination of the gear pump and the frequency converter is more favorable than the piston-axial pump with hydraulic regulator. Designed hydraulic system in which the pump is replaced by a variable capacity pump whose capacity is altered by changing the number of revolutions, removes all doubt about a possible replacement of conventional hydraulic controllers with frequency converters. When the hydraulic system in which it is possible to substitute the variable capacity pump with a constant pump capacity and frequency converter, a dominant influence on the application of the system of regulation of pump capacity has a price-performance ratio and energy conservation. Area viability of the application of frequency regulator in relation to hydraulic, with the same capacity of the pump depends on the pressure and everything is on the higher range of applications of frequency converters is narrow and vice versa. There is no universal rule, so every hydraulic system and the pump must be the subject of a specific analysis or an exceptional profit for hydraulic systems where the pump can be replaced by a variable capacity pump capacity constant with frequency converter [4, 7].

Figure 3 shows a diagram of the experimentally obtained pressure dependence of the flow pressure for the hydraulic system in which the frequency regulator is installed in order to provide different speeds for different forces. This all results in energy savings in the hydraulic system.

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A CASE STUDY ON INFLUENCE OF TRAFFIC-INDUCED VIBRATIONS ON BUILDINGS AND RESIDENTS

Silva Lozančić[1], Davorin Penava[2], Mirjana Bošnjak Klečina[3], Aleksandar Jurić[4]

Abstract: Vibrations induced by traffic on irregular or damaged pavement or tracks positioned near buildings, can be a source of annoyance for residents and source of damage to structural and non-structural elements. The traffic-induced vibrations, having different frequency content, propagate through the soil towards neighbouring buildings while attenuating in the process due to damping. However, when vibrations reach the basement wall or foundation of the building they are transmitted to upper floors and can be amplified in the process depending on the eigen frequencies of the building components. In this work, described is the procedure for experimental determination of the vibration measurement in comparison with the values allowed by the code provisions. Additionally an overview of the building damage due to traffic induced vibrations is given including the unavoidable description of the annoyance experienced by its residents.

Key words: Damaged Roads, Damage To Building, Resident Annoyance, Traffic-Induced Vibrations

1 INTRODUCTION

Vibrations induced by traffic on irregular or damaged pavement or tracks positioned near buildings, can be a source of annoyance for residents and source of damage to structural and non-structural elements [1,2]. The traffic-induced vibrations, having different frequency content, propagate through the soil towards neighbouring buildings while attenuating in the process due to damping. However, when vibrations reach the basement wall or foundation of the building they are transmitted to upper floors and can be amplified in the process depending on the eigen frequencies of the building components (see Figure 1).

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In this work elaborated is the case study on the influence of traffic-induced vibrations to buidlings and residents that was a subject of a lawsuit [3,4].

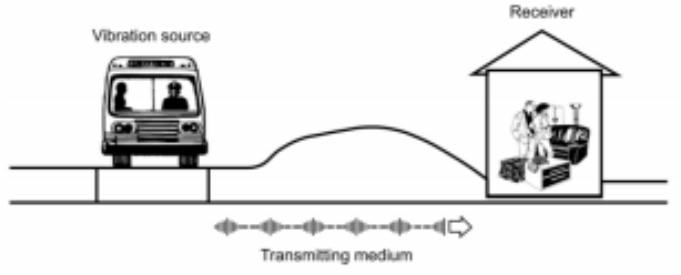


Figure 1. *Path from vibration source to the buidling*

During highway construction, the stone material used for the sub-grade and the sub-base of a future highway, was brought from a nearby quarry. The supply roads used to deliver the stone material to the construction site were partially the part of the main road system of the nearby small town. They were used over the period of three years. The traffic was intensive, having large number of trucks mostly loaded with crushed stone, passing towards the construction site and the way back. The quantity of the transported material usually had weight higher then by standards prescribed values. The traffic was ongoing whole day long, having usually the both road lanes occupied. Present was intensive breaking near the town crossroad and also unapropriate truck speed.

The town roads were deteriorated with bumps and holes even before the transport of buidling material started. The town buildings were positioned mostly very near the road. The town bulding stock consisted mostly of family houses built 50 or 20 years ago. The intensive material transport over town roads in poor condition had negative influence on them. They experienced slight or heavy damage in dependence on the buidling's age. Consequntally, present was the fear and uncertainty of the building owners due to possibility of the damage progression, vibrations and noise.

Soon after three years, the tranasport of the buidling material was shifted to another location as requested by the town residents. The roads were repaired by fixing the bumps and hoels and introducing the new base, binder and surface courses. Afterwards, the eight bulding owners had initiated a lawsuit against road maintance company for negligence. They were seeking a compensation for buidling rehabilitation due to damage caused by vibrations due to intensive traffic and unmaintened road.

The task of the court specialist in this case was to provide evidence that the damage to buildings was caused by vibrations from increased traffic in the period of highway construction, to determine the damage level and its influence on the stability and servicieabilty of the buildings, and to provide recommendations on the possibilities of building rehabilitions or to suggest demolition.

In order to complete the task the visual inspection of the buildings was conducted in order to determine the size of the damage and to grade the condition of the building. Conducted was the reconstruction of the events suspected to be the cause of the current building condition. The aim was to measure and to envisage vibrations caused by intensive traffic in the period of highway construction in order to relate them with negative effects on buildings and residents.

2 BUILDING INSPECTION AND VIBRATION MEASUREMENT

2.1 Buidling condition inspection

The visual inspection is the first to be conducted in the process of determination of the building's condition. If by visual inspection no damage was discovered, there is no need to conduct the further examinations. By visual inspection determined are locations on the structure with damage which is usually manifested through small or large cracks on e.g. foundation walls, load- and non-load bearing elements, ceilings, walls, roof, staircases, near openings, chimneys, plaster, etc.

By spotting and recording the crack locations, measured was their size and the overall building condition was assessed i.e. safe or unsafe for residents. The assessment of structural and non-structural damage and building overall condition was conducted based on comparisson of measured data with the by standard prescribed values. The procedure of damage record was conducted by using the table forms for in-situ building damage and condition assessment after an earthquake. Based on the conclusion on overall building condition, given were recommendations for building rehabilitation in order to bring them to serviceable condition.

The total number of eight buildings were examined, located in two streets where the intensive traffic was present. In all buildings spotted was damage in the form of cracks of dfferent size and shape spread over the entire building. Mostly affected were the walls, foundations, foundation walls, floors, ceilings, near openings, balcony and ceramic tiles. Additionally, observed were settlements, roof tile movements, rain leapage, even the wall buckling and ceiling collapse.

All observed building damage could have been a consequence of other irregularities such as from e.g. building construction, poor building maintenance, poor water drainage and soil settlement. Therefore, in order to relate the consequences of intensive heavy traffic-induced vibrations, it was necessary to determine the intensity of vibrations.

2.2 Traffic-induced vibrations measurement

By intensive three year traffic of loaded and unloaded trucks over the road in poor condition, the higher vibrations of the surrounding ground were contantly present. They consequently propagated towards nearby buidlings.

The traffic intensity was about 150 trucks on daily basis which can be qualified as longterm and intensive action. The intensity of excitation transmitted through the ground to the building is a function of: source excitation intensity, distance from the source to the buidling, ground type (radiation damping), ground water level, road condition, building structural system, building material characteristics, etc. Transmitted vibrations activated the inertia forces causing deformations of foundation and afterwards the rest of the building.

The task of the specialist was to provide the evidence that the traffic load caused higher dynamic excitation on buildings and consequently their damage. In order to provide such an evidence it was necessary to measure the intensity of vibrations caused by traffic. As measurement location points selected were the ground near buidling foundations and the 1st storey in multystorey buidlings.

By vibration measurement the general dynamic response of a building is determined (resonant frequencies, damping). The most important parameter governing the dynamic response is the building resonant frequency since in the case of

coincidence with dynamic excitation frequency becomes a cause of significant increase in response amplitudes. The influence of vibrations to the building is two-way, it causes damage to the building and annoyance to residents [10,11]. Based on vibration measurements, assessed was the relationship between the traffic load and the damage in the building. This was done in way that measured vibration level was compared with the values allowed for the buildings and residents as prescribed by the corresponding standards [5-9]. The hardest was to determine what and how much did it happen. In order to answer these questions, it was necessary to reconstruct the events that occurred several year ago having many characteristics changed within the period. The reconstruction was conducted by using heavy truck passage in front of the observed building.

The road condition in the period of intensive traffic was different then on the day of measurement. It was renewed thus not having bumps, holes, depressions, etc. In order to simulate the road irregularities the wooden board 24 mm thick was place on the road. The aim was to produce the effect of truck passage over the hole in the road. In the reconstruction of events used was one truck, having average speed of 30 km/h, and loaded with 77 % of nominal value, which was in compliance with the standards for cargo transports. The respondents claimed that the load in the trucks during the material transport was much higher than nominal one, and that they were passing in train formation, or by passin each other while having inappropriate speed. Therefore, much of the input parameters differs from original situation: road condition, truck weight, truck speed, traffic frequency, etc.

All of the named quantities imply that the dynamic excitation was many times higher than the measured one. This bias was tried to be overcomed by multiplying the measured quantities by the factor of 2. Vibration measurement was not conducted on all eight buildings. Only four were selected that represent the existing diversity in the building stock (age, condition, and distance to road). The selected buidlings are marked in Figure. 2 by black dots. Measured was the intensity of horizontal vibrations (in x- and y-direction) and vertical vibrations (z- direction), caused by truck loaded with 26640 kg (of possible 35000 kg) of material. The total truck mass was 41240 kg. The truck passage was repeated several times.

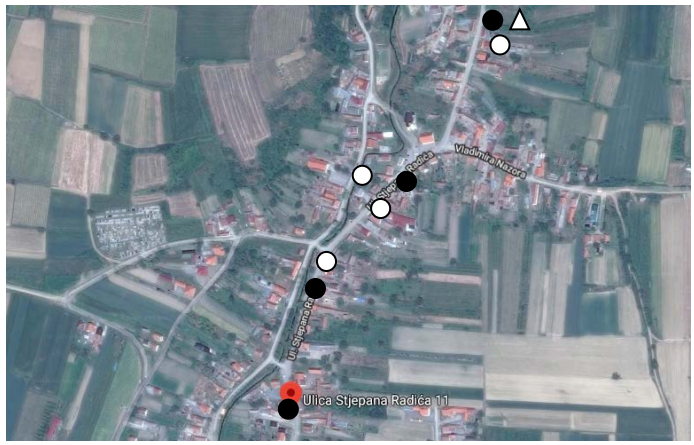


Figure 2. *Map with supply truck routes and damaged buidlings*

For the purpose of vibration measurement used were instruments of “Syscom Instruments AG” company (see Figure 3 and 4). Instruments were specially devised for civil engineering purposes, and used in buildings, tunnels, construction sites, etc. Measuring system is recording the response velocities and the date are ecorded to computer. Veleocymeters are used to measure the response in the three different directions simultaneusely (x-, y- and z-direction).

Total measurement time was 5 h.



Figure 3. *View on the measuring equipment*

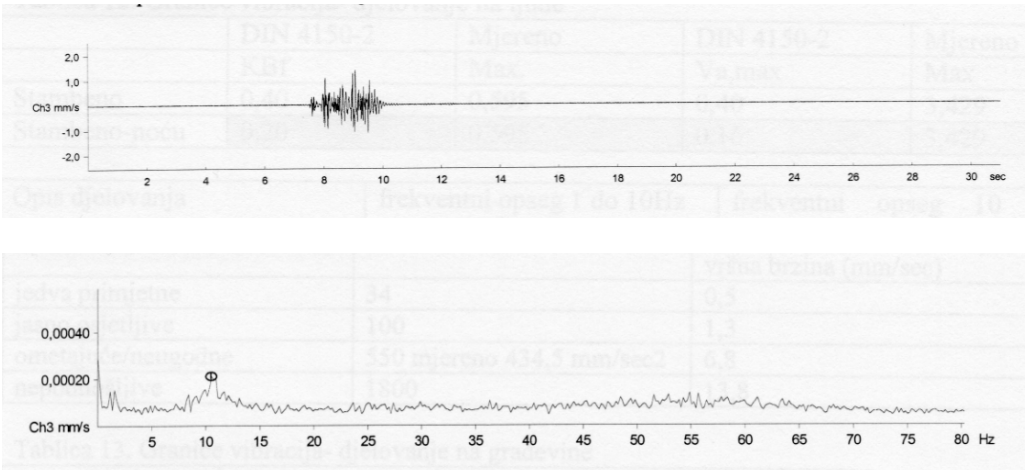


Figure 4. *Time history record of vertical velocities (in mm/sec) at foundation (above) and accelerarion data (in mm/sec^2)at various frequencies*

3 VIBRATION MEASUREMENT RESULTS

Presented are results for single building that suffered the most of the damage (see Figure 5). The building is a house with basement of dimensions 80 m^2, built in two parts (50 and 30 m^2) with solid brick masonry without confining elements. The first, old part, was built 60 years ago, and second part was built several years ago. Due to age it is considered as sensitive building. The building is placed near road with 7 m distance to its closest point, and 19 m to its farthest. The fundation soil is rock. The building experienced both, the structural (collapse of storey slab il older part, cracks in outer and foundation wall) and the non-structural damage (cracking of windows, cracked cermic tiles, displacement of roof tiles and rain water leakage).



Figure 5. *Damage to the ceiling (left) and damage to the ceramic tiles (right)*

To answer the question whether the traffic-induced vibrations caused the named building damage, measured quantities were compared to quantities prescribed by following standards: SN 64031a, DIN 4150 and ISO 2631 (see Tables 1 to 3).

The resonant frequencies of the building with structural masonry walls are usually similar for longitudinal and transversal direction, even when the ground plan aspect ration is 3 to 4. The first vibration period of the structure can be estimated based on expression T_1=0,0165*H (f_1=1/T), which applied to the observed building comes to T_1=0,084 sec (f_1=11,9 Hz) in both directions.

Vibrations besides that they cause annoyance to residents, they disrupt working ability and longterm their health. In case observed, vibrations were disrupting the residents during the days, and were unberable during night.

The increased traffic, and correspondingly the vibrations, including the initial condition of the road, its surroundings, could have lead to heavy damage to buidlings. In other buildings, the damage level was lower, due to different input parameters.

Table 1. *Comparison of measured and prescribed limits for building sensitivity to vibrations*

	SN	DIN 4150-3	Measured
$v_{a,max}$ (mm/sec) sensitive buildings	1,5-2,5	4	3,429

Table 2. *Comparison of measured and prescribed limits for resident sensitivity to vibrations*

	DIN 4150-2	mjereno	DIN 4150-2	mjereno
	f kB	max	$v_{a,max}$	max
Stambeno danju	0,4	0,595	0,4	3,429
Stambeno noću	0,2	0,595	0,16	3,429

Table 3. *Comparison of measured and prescribed limits for resident sensitivity to working ability*

Action description	Fequency range 1 do 10 Hz Peak acceleration (mm/sec^2) prescribed vs measured	Fequency range 1 do 10 Hz Peak velocity (mm/sec) prescribed vs measured
Barely noticable	34	0.5
Clearly noticable	100	1.3
Disrupting	550 434.5	6.8
Unberable	1800	13.8

4 CONCLUSION

The roads of a small town were used for the crushed stone material transport to the highway construction site from a nearby quarry. The roads were already in poor condition even before the transport started. They were used in a period of three years. During that period, the buidlings near the road and their residents experienced significant amount of traffic vibration increase.

Vibrations became constant and longterm annoyance to them. As a consequence, the damage appeared in many of the buidlings placed near the road. The damage intensity was dependent upon the building workmanship, age and type. Usually, they were classified as sensitive due to their age and the lack of proper structural integrity. While some of the damage in buildings could be considered insignificant, the other however even lead to collapse of structural elements.

After some period of time, the residents of damaged buildings initiated a lawsuit on road maintenance company. It was needed to prove that the damage in their buildings was caused by traffic-induced vibrations, and not by other causes.

In that purpose the reconstruction of the events was conducted, in which the conditions leading to damage were simulated. This was not possible in total, since the road was meanwhile repaired completely. The road was without irregularities and didn't had such extreme traffic loading. This was overcomed by introducing the wooden board to the road over which the heavy truck was passing several times. The weight of the truck and speed were in compliance with the standards for vibrations measurement.

Only on four of eight buidlings vibrations were measured.

Based on the measured vibration intensity and by comparing them with by standrds allowed values, conducted was assessment of the building condition. The effect of traffic-induced vibrations was higher on older buidlings that had less structural stiffening elements and are considered as sensitive buidlings.

The measurements confirmed the coincidence of buidling resonant frequency and dominant excitation frequency which can be served as a proof for the building damage. Additionally, the vibrations had disruptive and unberable effect on residents.

Non-maintenance of town roads and non-planned usage with significant increase of heavy truck traffic caused the damage to many buidlings near the road and annoyance to the residents. One of the most important things in planning a building construction is not to jeopardise the other buidlings.

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PRODUCT DEVELOPMENT AND MECHANICAL SYSTEMS

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FEM ANALYSIS OF GEROTOR MACHINES IMPELLER WITH PLANETARY MOTION

Lozica Ivanović[1], Miloš Matejić[2]

Abstract: This paper presents the finite element method analysis in a gerotor machine impeller. The analysis was carried out for the impeller of a gerotor machine with planetary motion. So far, a lot of has been conducted on the topic of the gerotor machines with the fixed position of the axis of the impeller element, while in the case of planetary motion of the impeller there are much less researchings. This case requires a more complicated force analysis, which is necessary for setting constraints and loads in finite element analysis. The mathematical model of the gerotor impeller force analysis with planetary motion is taken from the literature. The paper analyzes for cases with several combinations of teeth numbers with variation of materials. At the end of the paper, the results obtained by this analysis with conclusions and given further directions of research on this topic were presented.

Key words: Gerotor imppeler, Epicyclic movement, Finite element method, Load analyses

1 INTRODUCTION

Trochoid gearing belongs to the newest types of gearings. Trochoid gearing is most commonly encountered in gerotor pumps and orbital gerotor hydromotors. The usage of this type of gearing is greatly caused by the improvement of functional characteristics such as increasing the efficiency and working life, reducing the overall dimensions (since this type of toothed profile has a higher loading capacity), and so on. Its use as a consequence of the reduction of the overall dimensions reduces the consumption of materials, both for trochoid pairs and for the cases in which these pairs are installed, which further leads to significant savings in the production of devices using trochoid pairs as a working element. The increased loading capacity of this gearing type is achieved by the fact that unlike the conventional gearing (involute toothed) in the case of using a trochoidal gearing, the simultaneous coupling of a significantly larger number of teeth occurs. For example, if in the involute gearing in contact of one to two teeth in trochoid gearing, they are always in contact with more than half of the teeth of the gearing. Due to these advantages, there is a great interest in both mechanical engineers

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and researchers for the application of these gears in places where there are present significant space limits. As has been said before, this type of gearing is applicable to gerotor pumps and orbital gerotor hydro motors, but also to other rotary machines such as: compressors, blowers, etc.

One of the most important aspects of analyzing gerotor pumps is the analysis of the dynamic behavior of pump elements in operation. C. F. Heish [1] obtained such an analysis of useful data that can be further applied in the gerotors manufacturing. An important aspect of the analysis of the forces and pressures that occur on the gears with the external toothed gerotor, [2]. A very important aspect is the gerotor kinematic analysis [3], as well as the determination of the pump flow [4]. By observing and reviewing all these aspects, it is concluded that the research of the gerotor has accelerated greatly if there was an adaptive parametric CAD model, which could later be used both for the analysis of the stress conditions of the gerotor elements and for determining the contact pressures in the meshing of the trochoid gears. Some groups of authors have partly succeeded in introducing such a model into the research of gerotors [5-7]. In order for such a model to be used for practical research and experiments, it is very important to implement technological gaps in this model, [8-11].

In modern industrial applications, there are increasingly stringent demands in terms of pump performance. In addition, the environmental protection standards prescribe the development of hydraulic systems without any noise and without fluid leakage. Taking into account the quality of the gerotor pumps and the challenges they face in modern applications, as well as the requirements of the standards, the authors have developed a new concept of the gerotor pump whose prototype has been presented in the reference. [12] New topics related to gerotor pumps and cycloid gearing are generally numerical approaches supported by experimental work [13-14].

This paper is an extension of the group of author's research on the topic of automation and testing of the obtained results of parameterization of the gerotor of orbital motors. The paper presents orbital motors with planetary movement of the inner trochoid gear and determination of the pressure values that occur in the contact when the inner and outer gears are meshing. The theoretical model of determining this pressure is taken from the literature [16-17], while the result value is determined by the FEM method set up based on the theoretical model in the software package ***Autodesk Inventor*.**

2 THEORETICAL MODEL OF DETERMINING PRESSURE CONTACT IN TROCHOIDAL GEAR PAIR MESHING WITH PLANETARY MOVEMENT OF INNER GEAR

In the gerotor machines with internal trochoidal gearing, the profile of one of the gears is generated by a trochoid (curve from the family of cycloids), while the coupled profile is an appropriate inner or outer envelope. Thanks to specific geometry, the entire profile can be applied for meshing. Equivalent modification provides a profile with better functional characteristics. These advantages are used in the orbital motors design, which are presented in this paper.

In this paper, the contact pressures are considered which occur due to the meshing of the trochoid rotary machine with the planetary movement of the inner gear, for which the drive shaft is attached, while the outer gear is fixed. The main objective of this analysis is to have a closer look at the contact pressures values, which would further enable the definition of conditions for reducing the same, and thus reducing the wear, and prolonging the life of the gerotor machine. The problem of determining contact pressures is complex since the load is transmitted simultaneously at several points of contact. This means the contact (normal) force acts at each touch point, and the directions of all

normal forces goes through the current pole of rotation C. Since the number of contact points and, therefore, the number of unknown forces is equal to the teeth number of the external gear z, it is clear that it is a static indeterminate system of forces. In order to determine the size of the contact pressures, it is necessary to determine the intensity of the resulting force of the fluid pressure, which, as a concentrated force, acts in point C. In trochoid machines with planetary motion of the working elements, the shaft torque [16] balances the total moment of the fluid pressure force. The model for determining contact forces is shown in Figure 1.

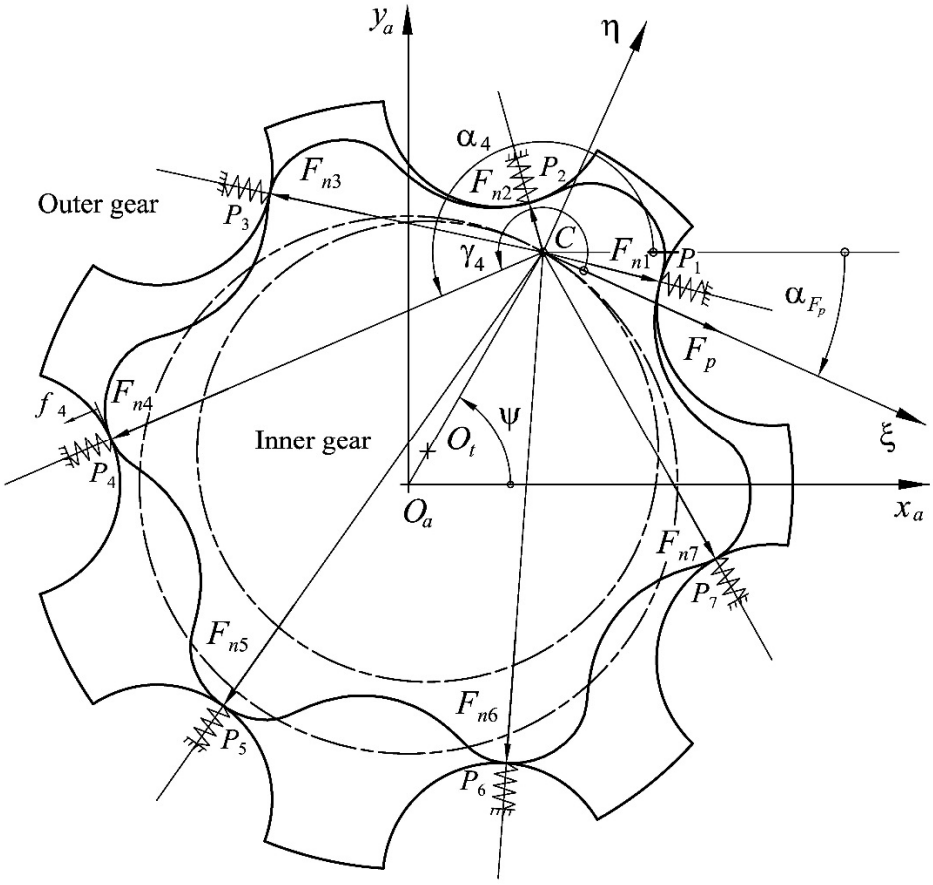


Figure 1. A model of contact forces acting on an external gear at an arbitrary point

Each contact point is modeled with a cylindrical spring, whose axis coincides with the normal direction to the surface at the touch point. Under the influence of the contact force, the F_{ni} spring is elastically deformed, and this deformation is a deflection or a shortening of the spring f_i. A well-known relationship between deformation and normal force can be written by expression:

$$F_{ni} = cf_i, \tag{1}$$

where is c spring constant stiffens. The numeric value of stiffens is c=1x10^6 N/mm.

3 SELECTION OF GEOMETRIC VALUES OF TROCHOID GEAR PAIRS AND FEM BOUNDARY CONDITIONS

In order to achieve as realistic results as possible for this investigation, the real values of the size of the three trochoidal gear pairs are taken from the catalog [18-20]. The catalog includes both geometric values and input torque values. In the variation of geometric measures, the overall dimensions of the gerotor pair have not been changed. In order to detect the differences in the use of trochoidal gears, in all cases (with 4.5 and 6 teeth) three different materials were used. The geometric characteristics of the selected trochoidal gear pairs are shown in Table 1.

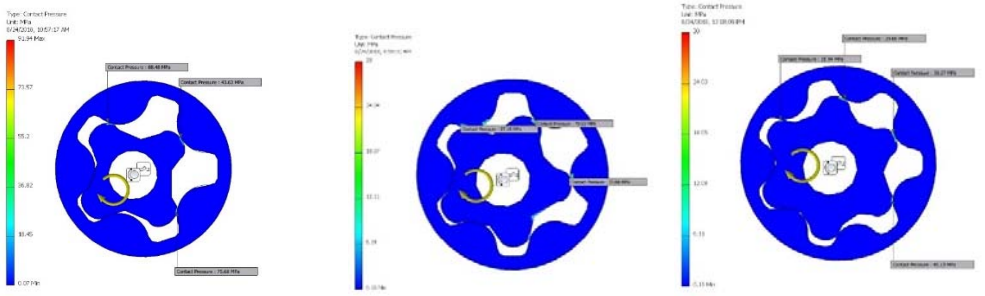
Table 1. *Geometric characteristics of selected trochoidal gear pairs*

No.	z_1	λ	e	r_c
1.	4	1,3	4,95 mm	12,375 mm
2.	5	1,3	4 mm	10 mm
3.	6	1,3	3,5 mm	8,75 mm

The FEM analysis used: steel E235, aluminum 6061 AHC and HDPE plastics for all variations in the number of teeth. A torque, 32 Nm was selected in the catalog, while the location of their action was determined in accordance with Figure 1. The outer gear in all iterations was constrained in all six degrees of freedom of movement, while inner gear was constrained by so-called *pin-constraint*.

4 FEM ANALYSIS RESULTS

As previously mentioned, FEM analysis was performed for combining all selected material variations and all previously selected teeth numbers. The results of the analysis are shown graphically and tabular for easier comparison.
Figure 2 shows the analysis for all selected teeth numbers when the steel E235 is taken into account.



a) b) c)

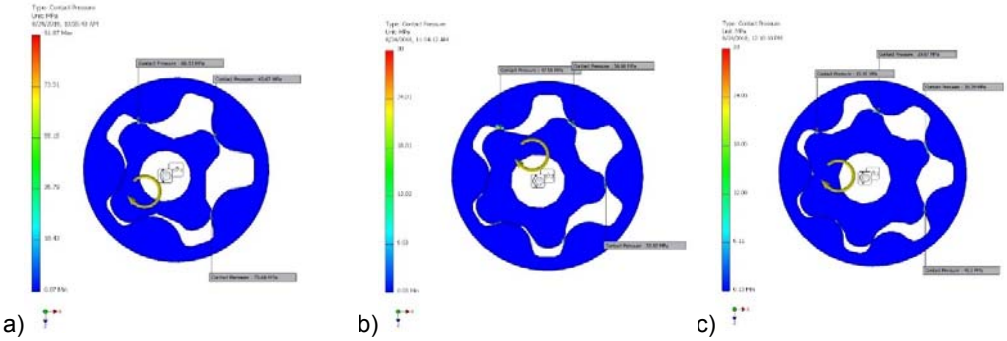
Figure 2. *The FEM analysis results in the case when the steel E235 is taken into consideration: a) trochoidal gear with 4 teeth; b) trochoidal gear with 5 teeth and c) trochoidal gear with 6 teeth*

Figure 2 also illustrates the constraints and input torque entry point. Table 2 shows the number of contact stresses between the individual teeth.

Table 2. *Meshing tooth contact pressure, MPa*

No.	*1. tooth meshing*	*2. tooth meshing*	*3. tooth meshing*	*4. tooth meshing*
1.	88,48	43,63	75,68	-
2.	27,18	70,03	33,64	-
3.	15,94	29,66	30,27	45,13

Figure 3 shows the analysis for all selected teeth numbers when the aluminum 6061 AHC is taken into account.



a) b) c)

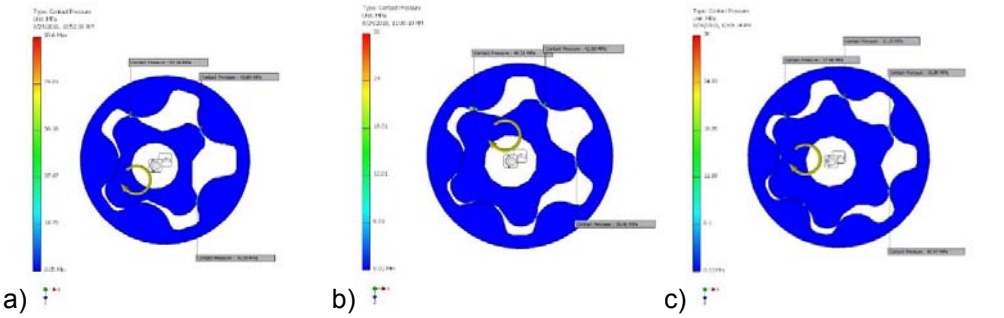
Figure 3. *The FEM analysis results in the case when the aluminum is taken into consideration: a) trochoidal gear with 4 teeth; b) trochoidal gear with 5 teeth and c) trochoidal gear with 6 teeth*

For ease of analysis results in Table 3 shows the numerical values of contact stress between the individual teeth.

Table 3. *Meshing tooth contact pressure, MPa*

No.	*1. tooth meshing*	*2. tooth meshing*	*3. tooth meshing*	*4. tooth meshing*
1.	88,53	43,67	75,68	-
2.	47,55	36,68	33,63	-
3.	15,95	29,67	30,29	45,10

Figure 4 shows the analysis for all selected teeth numbers when HDPE plastic is taken into account.



a) b) c)

Figure 4. *The FEM analysis results in the case when the HDPE is taken into consideration: a) trochoidal gear with 4 teeth; b) trochoidal gear with 5 teeth and c) trochoidal gear with 6 teeth*

Table 4 shows the number of contact stress contacts between meshing teeth.

Table 4. *Meshing tooth contact pressure, MPa*

No.	*1. tooth meshing*	*2. tooth meshing*	*3. tooth meshing*	*4. tooth meshing*
1.	93,56	48,09	76,09	-
2.	48,31	42,58	36,41	-
3.	17,68	31,25	31,89	42,47

The presented simulations were performed by replacing the action of the working fluid with concentrated pressure forces modeled on the models shown in the works [15-16].

5 CONCLUSION

In the presented paper, a multiple FEM analysis of the orbital motor trochoidal gear pairs for three different materials was conducted: steel E235, aluminum 6061 AHC and HDPE plastics and three different number of teeth of internal triode gears (z1 = 4.5 and 6). The analysis was conducted out for all combinations of different materials and teeth numbers. The results of the authors presented in the references [17] were used for the baseline analysis model. As this model is adaptive, these analyzes can be said to be universal and can be applied to any parameters of trocohidal gearing, which are physically feasible.

If, as a benchmark of these analyzes, steel is used as the material used for all combinations of teeth numbers, it can be concluded that in aluminum, there are slightly higher contact stresses compared to steel. If we consider comparative plastics and steel, considerably higher contact stresses occur in plastics. Distribution of contact stresses is very similar for all three types of materials. As expected, the greatest contact stresses occur with the smallest number of teeth for all materials, while as the number of teeth increases. The size of the contact stresses depends directly on the contact force location.

The presented research was conducted assuming that there is no working fluid in the gerotor pair, but the effect of its pressure force is taken into account through the resulting force F_p. This is the first step towards determining the critical points of the trochoidal gears. Further research will also include the simulation of the working fluid flow in the determination of the contact pressures, as well as the study of the stress-deformation state of the trochoidal gear pair. When the simulations are completed authors plans to conduct an experimental research.

ACKNOWLEDGMENT

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NOMENCLATURE

Variables:

e eccentricity, mm

F_{ni} normal force on gear tooth, N

F_p resultatnt of normal forces, N

r_c geometric characteristics of trochoidal profile, mm

z_1 tooth number of inner gear

Greek symbols

α angle between the starting and current position of the point of contact of the basic and rolling curve relevant to the center of the base curve, rad

γ angle between resultant force and component forces F_{pi}, rad

λ trochoid coefficient

Subscripts and superscripts

i number of chamber

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OPTIMIZACIJA MASE GLAVNOG NOSAČA KUTIJASTOG POPREČNOG PRESEKA DVOGREDNE MOSNE DIZALICE SA ŠINOM POSTAVLJENOM NA SREDINI GORNJE LAMELE

Goran Pavlović[1], Mile Savković[2], Goran Marković [3], Nebojša Zdravković[4]

Rezime: U ovom istraživanju izvršena je analiza i optimizacija kutijastog poprečnog preseka glavnog nosača dvogredne mosne dizalice sa šinom na sredini gornje lamele. Smanjenje mase glavnog nosača postavljeno je kao funkcija cilja. Kao metode za određivanje optimalnih geometrijskih parametara kutijastog poprečnog preseka korišćeni su metaheuristički algoritmi optimizacije primenom MATLAB softverskog paketa. Kao funkcije ograničenja uzeti su kriterijumi čvrstoće u karakterističnim tačkama preseka, kao i uticaj lokalnih naprezanja usled pritiska točka na šinu, ugibi u vertikalnoj i horizontalnoj ravni, period prigušenja oscilacija, kao i određena tehnološka ograničenja i preporuke. Opravdanost primene ovog postupka prikazana je na numeričkim primerima dvogrednih mosnih dizalica, gde se vidi ostvarena ušteda materijala glavnih nosača.

Ključne riječi: dvogredna mosna dizalica, kutijasti poprečni presek, metaheuristički algoritmi, optimalno projektovanje

MASS-OPTIMIZED DESIGN OF THE MAIN GIRDER WITH BOX-SECTION OF THE DOUBLE-GIRDER BRIDGE CRANE WITH THE RAIL PLACED IN THE MIDDLE OF THE TOP FLANGE

Abstract: In this research, the analysis and optimization design of the box-section of the main girder of the double-girder bridge crane with the rail in the middle of the top flange was performed. The reduction of the mass of the girder is set as the objective function. Methaheuristic algorithms of optimization were used as methods for determining of optimal geometric parameters of the box-section using by MATLAB software package. The constraint functions include the strength criteria in the characteristic points of the box-section, as well as the influence of local stresses due to the action of trolley wheels on the rail, deflections in the vertical and horizontal plane,

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the period of the girder oscillation, as well as some technological limitations and technical recommendations. The justification of application of this procedure is shown on numerical examples of the double-girder bridge cranes, where savings in material of the main girders are evident.

Key words: Box-section, Double-girder bridge crane, Metaheuristic algorithms, Optimal design

1 UVOD

Glavni zadatak u procesu projektovanja noseće konstrukcije dvogredne mosne dizalice jeste određivanje optimalnih geometrijskih parametara poprečnog preseka glavnog nosača.

Najvećii broj radova i publikacija se bavi problemom analize naponskih stanja i deformacija glavnih nosača dizalica, kao i njihovom optimizacijom. Analiza i optimizacija konstrukcije dvogredne dizalice sa šinom na sredini nosača izvršena je u radu [1] primenom ANSYS softverskog paketa, pri čemu se ukazalo na značaj veza između glavnih i čeonih nosača. MKE ima veliku primenu kod ovih analiza, što je pokazano i u radovima [2, 3]. U radu [2], primenom programa ANSYS i ABACUS softverskih paketa, izvršena je optimizacija kutijastih nosača mosnih dizalica u zavisnosti od različitih industrijskih ograničenja. U radu [3] je analiziran glavni nosač dvogredne mosne dizalice primenom softverskog paketa SOLIDWORKS, pri čemu su rezultati poređeni sa analitičkim rezultatima.

Pored primene MKE, sve češće se koriste različite numeričke metode optimizacije koje su naročito pogodne kod višekriterijumskih optimizacija, a sve više se primenjuju metaheuristički algoritmi optimizacije [4-6, 8]. U radu [4], primenjen je NBA metod na konstrukciji dvogredne mosne dizalice, dok je u [5] korišćen ICA metod. U radu [6], primenjeni su biološko-inspirisani algoritmi na konstrukciji mosne dizalice.

Navedeni radovi ukazuju na značaj optimizacije kako glavnih nosača dvogrednih mosnih dizalice, tako i za rešavanje sličnih inženjerskih problema primenom najrazličitijih algoritama i metoda optimizacija.

Imajući u vidu napred navedene rezultate istraživanja, cilj ovog rada jeste da se definišu optimalne vrednosti parametara geometrije poprečnog preseka kutijastog nosača dvogredne mosne ditalice koje će dovesti do smanjenja njegove mase.

2 MATEMATIČKA FORMULACIJA PROBLEMA OPTIMIZACIJE

Zadatak optimizacije je određivanje geometrijskih parametara poprečnog preseka nosača koji daju njegovu minimalnu površinu (funkcija cilja), pri čemu moraju biti zadovoljeni svi zadati uslovi (funkcije ograničenja).

Opšta matematička formulacija problema optimizacije glasi:

minimizacija funkcije cilja $f(X)$,

u odnosu na funkcije ograničenja $g_i(X) \le 0,\ i = 1,...,m,$

pri čemu važi i sledeće: $l_j \le x_j \le u_j,\ u_j > l_j,\ x_j > 0,\ j = 1,...,n.$

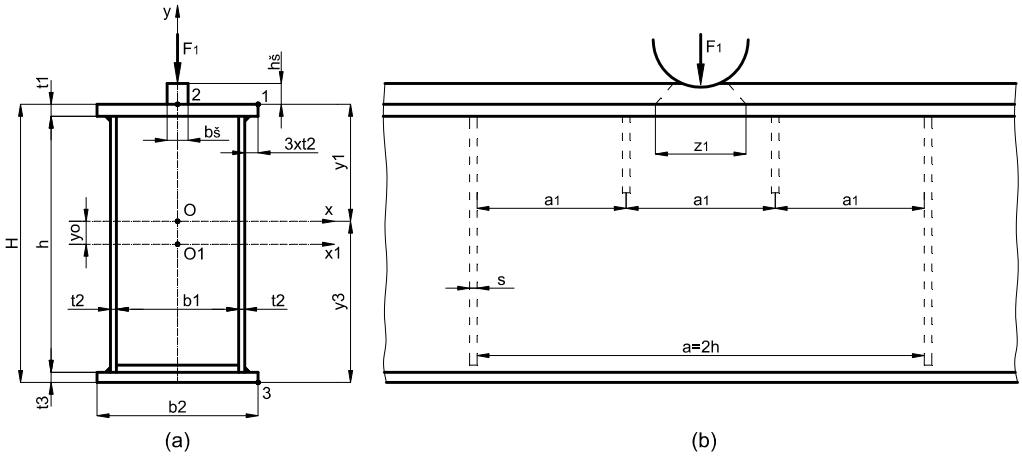
Za optimizaciju su primenjena dva algoritma optimizacije, algoritam simulacije kaljenja (Simulated Annealing - SA) i algoritam harmonijskog pretraživanja (Harmony Search – HS).

SA spada u metaheuristički metod optimizacije i zasniva se na postupku kaljenja materijala, [7]. Ovaj algoritam imitira proces kristalizacije za vreme zagrevanja ili hlađenja. Kada je materijal topao, čestice imaju visoku kinetičku energiju i kreću se slučajno u odnosu na svoje ili pozicije drugih čestica, a hlađenjem materijala se dobija da se više čestica usmeri prema pravcima koji minimiziraju energetsi balans.

HS spada takođe u grupu metaheurističkih metoda optimizacije i zasniva se na principu na kojem džez muzičari improvizuju nove melodije tražeći savršenu melodiju (harmoniju), [8].

3 FUNKCIJA CILJA

Funkciju cilja predstavlja površinu poprečnog preseka kutijastog nosača (Slika 1a), bez površine šine. Sledeće geometrijske veličine su predmet optimizacije: *h, b1, t1, t2* i *t3*.



Slika 1. *Kutijasti poprečni presek dvoogredne mosne dizalice (a) sa prikazanim položajem vertikalnih ukrućenja (b)*

Površina kutijastog poprečnog preseka, odnosno funkcija cilja, glasi:

$$f(X) = A = 2 \cdot h \cdot t_2 + (t_1 + t_3) \cdot b_2. \tag{1}$$

4 FUNKCIJE OGRANIČENJA

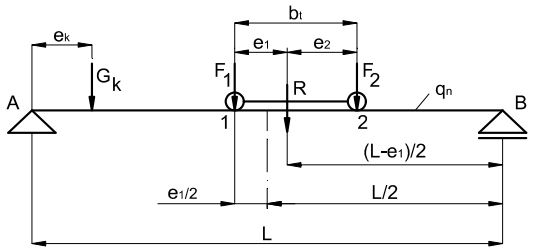
4.1 Maksimalni naponi u karakterističnim tačkama kutijastog poprečnog preseka

Provera napona se vrši u karakterističnim tačkama nosača (Slika 1a), koji moraju biti manji od graničnog napona. Kako tangencijalni naponi nisu od značaja kod ovog tipa nosača, pošto su im vrednosti reda veličine niže od normalnih napona, biće zanemareni u daljoj analizi. Posmatraju se naponi u tačkama 1 i 3 (Slika 1a), dok se naponi u tački 2 razmatraju kao poseban kriterijum.

Granični napon se određuje prema izrazu (2):

$$\sigma_{dop} = R_e / \nu_1. \tag{2}$$

Statički model po kome se vrši određivanje momenta savijanja u vertikalnoj i horizontalnoj ravni prikazan je šematski na narednjoj slici (Slika 2).



Slika 2. *Model opterećenja glavnog nosača dvogredne mosne dizalice*

Veličine neophodne za proračun napona u karakterističnim tačkama poprečnog preseka određuju se na osnovu sledećih izraza:

$$R = \gamma \cdot \left(\psi \cdot Q + m_t\right) \cdot g / 2, \tag{3}$$

$$F_1 = R \cdot \left(b_t - e_1\right) / b_t, \tag{4}$$

$$M_V = \frac{R}{4 \cdot L} \cdot (L - e_1)^2 + \gamma \cdot \left[\frac{q_m \cdot L^2}{8} + G_k \cdot \frac{e_k}{2 \cdot L} \cdot (L + e_1) \right], \tag{5}$$

$$q_m = 1{,}1 \cdot \rho \cdot g \cdot A, \tag{6}$$

$$R_H = k_a \cdot \left(\psi \cdot Q + m_t\right) \cdot g / 2, \tag{7}$$

$$F_{1H} = R_H \cdot \left(b_t - e_1\right) / b_t, \tag{8}$$

$$M_H = \gamma \cdot \left\{ \frac{R_H}{4 \cdot L} \cdot (L - e_1)^2 + k_a \cdot \left[\frac{q_m \cdot L^2}{8} + G_k \cdot \frac{e_k}{2 \cdot L} \cdot (L + e_1) \right] \right\}. \tag{9}$$

Geometrijske karakteristike (glavni momenti inercije, otporni momenti inercije za *x* i *y* osu) poprečnog preseka (Slika 1a), određuju se prema poznatim izrazima.

Maksimalni napon u tački 1:

$$\sigma_{u,1} = M_V / W_{x1} + M_H / W_{y1}. \tag{10}$$

Maksimalni napon u tački 3:

$$\sigma_{u,3} = M_V / W_{x3} + M_H / W_{y3}. \tag{11}$$

4.2 Maksimalni naponi na sredini gornje lamele nosača usled lokalnog savijanja

Usled kontakta šine i pojasnog lima pri prolasku točka kolica (Slika 1b) javlja se lokalno savijanje lima i pojava dvoosnog naponskog stanja, pri čemu se normalni naponi u podužnom i poprečnom pravcu određuju prema [9]:

$$\sigma_{zM} = 6 \cdot K_3 \cdot N / t_1^2, \tag{12}$$

$$\sigma_{xM} = 6 \cdot K_2 \cdot N / t_1^2 \le \sigma_{dop}. \tag{13}$$

Raspored položaja glavnih vertikalnih ukrućenja i kratkih ukrućenja je prikazan na slici (Slika 1b). Usvojeno je da je debljina ovih ukrućenja *s* jednaka debljini vertikalih limova glavnog nosača. Horizontalno ukrućenje nije razmatrano u ovoj analizi.

Sila *N* koja je merodavna za proračun ovih komponenti normalnih napona, i predstavlja deo sile pritiska točka koji usled krutosti šine otpada na ploču:

$$N = \frac{F_1}{1 + \dfrac{96 \cdot b_1^{\,2} \cdot I_{š1} \cdot K_1}{a_1^{\,3} \cdot t_1^{\,3}} \cdot \dfrac{1}{c_o}}, \quad a_1 \geq b_1, \tag{14}$$

$$N = \frac{F_1}{1 + \dfrac{96 \cdot I_{š1} \cdot K_1}{a_1 \cdot t_1^{\,3}} \cdot \dfrac{1}{c_o}}, \quad a_1 < b_1, \tag{15}$$

$$a_1 = a/3 = 2 \cdot h/3. \tag{16}$$

Koeficijenti K_1, K_2 i K_3 zavise od odnosa a_1/b_1, $b_š/b_1$ i z_1/b_1, i određuju se prema [9], pri čemu je:

$$z_1 = 2 \cdot h_š + 5, \ cm. \tag{17}$$

Ukupni napon na sredini gornje lamele (tačka 2) iznosi:

$$\sigma_{u,2} = \sqrt{(\sigma_{z2} + \sigma_{zM})^2 + \sigma_{xM}^{\ 2} - (\sigma_{z2} + \sigma_{zM}) \cdot \sigma_{xM}} \leq 1{,}1 \cdot \sigma_{dop}, \tag{18}$$

pri čemu mora biti ispunjen I sledeći uslov:

$$\sigma_{z2u} = \sigma_{z2} + \sigma_{zM} = M_V / W_{x1} + 6 \cdot K_3 \cdot N / t_1^{\,2} \leq \sigma_{dop}. \tag{19}$$

Pored ovih uslova, mora biti ispunjeno i da napon u ukrućenjima (vertikalnih dijafragmi i pomoćna kratka među-ukrućenja) bude u dopuštenim granicama:

$$\sigma_p = \frac{F_1}{(b_š + 2 \cdot t_2) \cdot s} \leq R_{e,p}. \tag{20}$$

4.3 Maksimalni ugibi u vertikalnoj i horizontalnoj ravni

Za ove uslove, posmatraju se ugibi glavnog nosača na sredini raspona u vertikalnoj i horizontalnoj ravni, usled dejstva točkova kolica na glavnom nosaču, preko šine, pri čemu se uzima i uticaj horizontalnih sila (kod ugiba u horizontalnoj ravni). Takođe, uzeta je u obzir i spostvena težina nosača, kao i težina kabine, ukoliko postoji (kod ugiba u vertikalnoj ravni):

$$\begin{aligned} f_V = {} & \frac{F_1 \cdot L^3}{48 \cdot B_x} \cdot \left[1 + \alpha \cdot (1 - 6 \cdot \beta^2)\right] + \frac{5 \cdot q_n \cdot L^4}{384 \cdot B_x} + \\ & + \frac{G_k \cdot L^3}{6 \cdot B_x} \cdot \left\{ \frac{L - e_k}{2 \cdot L} \cdot \left[\frac{3}{4} - \left(\frac{L - e_k}{L} \right)^2 \right] + \left(\frac{L - 2 \cdot e_k}{2 \cdot L} \right)^3 \right\} \leq f_{V,d} = K_V \cdot L, \end{aligned} \tag{21}$$

$$f_H = \frac{F_{1H} \cdot L^3}{48 \cdot B_y} \cdot \left[1 + \alpha \cdot (1 - 6 \cdot \beta^2)\right] \leq f_{H,d} = K_H \cdot L, \tag{22}$$

Ostale veličine su definisane prema [9].

4.4 Vreme gašenja oscilovanja tereta na nosaču

Kod ovog kriterijuma posmatra se oscilovanje glavnog nosača sa teretom u vertikalnoj ravni, pri čemu se posmatra jedan nosač kao prosta greda sa polovinom mase tereta i kolica sa vitlom, prema [9].

Period gašenja određuje se na osnovu izraza (23):

$$T = 6\pi \cdot \sqrt{\delta_{11} \cdot m_1} / \gamma_d \le T_d, \tag{23}$$

pri čemu specifična masa koja osciluje na sredini proste grede obuhvata i redukovanu masu nosača i određuje se prema sledećem izrazu:

$$m_1 = \left(Q + m_t\right)/2 + 35 \cdot m_n / 72. \tag{24}$$

Ostale veličine se određuju prema [9].

5 NUMERIČKI PRIKAZ REZULTATA OPTIMIZACIJE

Problem optimizacije je rešen primenom programskog paketa MATLAB. Korišćeni su pomenuti metaheuristički algoritmi optimizacije HS i SA. Takođe, optimizacija je izvršena i primenom poznatih MATLAB funkcija *fmincon* i *pattern search*, kako bi se izvršilo poređenje rezultata. Primena ovih algoritama optimizacije izvršena je na primerima dve dvogredne mosne dizalice, pri čemu jedna predstavlja izvedeno rešenje, dok je primer druge korišćen iz [9].

Pored gorenavedenih uslova (funkcija ograničenja) koji moraju biti zadovoljeni, korišćene su i određene konstruktivne i tehnološke preporuke, što predstavljaju dodatne funkcije ograničenja. U narednoj tabeli (Tabela 1) date su karakteristike mosnih dizalice, što predstavlja ulazne podatke za proces optimizacije. Obe dizalice su pogonske klase 2, i ostali ulazni podaci su usvojeni za ovu pogonsku klasu, prema [9].

Table 1. *Karakteristike dvogrednih mosnih dizalica sa šinom na sredini gornje lamele*

Pr.	*Q (t)*	*L (m)*	*m_t (t)*	*b_t (cm)*	*e_1 (cm)*	*G_k (kN)*	*e_k (m)*	*k_a*	*Materijal*	*$b_š$xh$_š$ (cmxcm)*	*A_p (cm^2)*
1	12,5	18	2,86	160	56,7	15	2,3	0,1	S355	4,5x4,5	171,68
2	10	7	4,49	186,6	78,3	/	/	0,05	S235	5x5	125,12

U narednim tabelama prikazani su rezultati optimizacije primenom navedenih metoda optimizacije, za date primere. Za primer 2 će biti prikazane dve varijante modela optimizacije, posmatraće se prvo slučaj kada ne postoje dodatna ukrućenja između vertikalnih dijafragmi (kao što je u izvedenom rešenju – Tabela 3) i slučaj kada se dodaju dodatna ukrućenja – Tabela 4. Takođe, treba napomenuti da su dobijene debljine limova zaokružene na prvi veći celi broj.

Table 2. *Ušteda u materijalu (%) i rezultati optimizacije za Primer 1*

Metod	*h (cm)*	*b_1 (cm)*	*t_1 (mm)*	*t_2 (mm)*	*t_3 (mm)*	*A_{opt} (cm^2)*	*Ušteda*
fmincon	93,68	48,27	6	5	6	156,40	8,90%
pattern.search	88,50	45,99	6	5	9	163,49	4,77%
SA	93,68	48,28	6	5	6	156,42	8,89%
HS	90,62	45,16	8	5	7	164,36	4,26%

Table 3. *Ušteda u materijalu (%) i rezultati optimizacije za Primer 2 – bez dodatnih ukrućenja*

Metod	*h (cm)*	b_1 *(cm)*	t_1 *(mm)*	t_2 *(mm)*	t_3 *(mm)*	A_{opt} *(cm²)*	*Ušteda*
fmincon	40,00	25,00	6	5	6	74,80	40,22%
pattern.search	40,00	25,00	6	5	6	74,80	40,22%
SA	40,00	25,00	6	5	6	74,80	40,22%
HS	40,00	25,00	6	5	6	74,80	40,22%

Table 4. *Ušteda u materijalu (%) i rezultati optimizacije za Primer 2 – sa dodatnim ukrućenjima*

Metod	*h (cm)*	b_1 *(cm)*	t_1 *(mm)*	t_2 *(mm)*	t_3 *(mm)*	A_{opt} *(cm²)*	*Ušteda*
fmincon	40,00	47,67	6	5	6	102,00	18,48%
pattern.search	40,00	25,00	17	5	6	106,70	14,72%
SA	40,00	25,00	17	5	6	106,70	14,72%
HS	40,00	47,67	6	5	6	102,00	18,48%

6 ZAKLJUČCI

Primena predstavljenih metaheurističkih algoritama optimizacije se uspešno pokazala na prikazanom optimizacionom problemu, što se vidi na ostvarenim uštedama (Tabela 2, Tabela 3 i Tabela 4). Na osnovu numeričkih vrednosti prikazanih u navedenim tabelama, vidi se da se primenom funkcije *fmincon* dobijaju u svim slučavima rezultati sa najvećom uštedom, dok je *patter search* dala nešto slabije rezultate. Primenjeni algoritami SA i HS u zavisnosti od slučaja, takođe daju rezultate sa najboljom uštedom.

Na Primeru 2 se vidi da sa uvođenjem dodatnih vertikalnih među-ukrućenja može znatno ostvariti ušteda u materijalu (povećenje uštede sa 14,72% odnosno 18,48% na 40,22%).

Prikazani optimizacioni problem se može dalje nadograđivati u cilju smanjivanja površine poprečnog preseka, odnosno smanjenje ukupne mase glavnog nosača. U daljim istraživanjima treba posvetiti pažnju uticaju lokalnog savijanja, odnosno pravilnom izboru i postavljanju vertikalnih ukrućenja. Predstavljeni algoritmi optimizacije mogu se uspešno koristiti i kod sličnih inženjerskih problema, pri čemu se precizniji rezultati mogu dobiti uvođenjem dodatnih ograničenja, kao što su u ovom slučaju elastična stabilnost elemenata nosača, zamor materijala i sl.

ZAHVALNOST

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NOMENKLATURA

l_j, u_j donja, odnosno gornja vrednost promenjive x_j
Q nosivost dizalice, t
L raspon dizalice, m
q_n, m_n specifična težina, odnosno masa konstrukcije glavnog nosača, kN/cm, kg
m_t masa kolica, t
b_t rastojanje između točkova kolica, cm

e_1 položaj rezultujuće sile opterećenja u odnosu na točak 1 kolica, cm
k_a dinamički koeficijent opterećenja dizalice u horizontalnoj ravni
R_e, $R_{e,p}$ napon granice tečenja za osnovni material glavnog nosača i ukrućenja, kN/cm^2
G_k težina kabine, kN
e_k položaj kabine u odnosu na početak mosta, m
R, R_H rezultujuće sile u vertikalnoj i horizontalnoj ravni, kN
M_V, M_H momenti savijanja u vertikalnoj i horizontalnoj ravni, kNcm
F_1, F_{1H} sile točka 1 kolica u vertikalnoj i horizontalnoj ravni, kN
K_1, K_2, K_3 koeficijenti za proračun lokalnih napona savijanja
z_1 dužina uticajne zone lokalnog pritiska, prema [9], cm
c_o koeficijent koji zavisi od načina vezivanja šine za nosač, prema [9]
K_V, K_H koeficijenti krutosti koji zavisi od načina upravljanja dizalicom i pogonske klase
$f_{V,d}$, $f_{H,d}$ granični ugibi u vertikalnoj i horizontalnoj ravni, cm
I_x, I_y glavni moment inercije za x osu, cm^4
$I_{š1}$ moment inercije šine za sopstvenu osu, cm^4
B_x, B_y savojne krutosti za x i y osu, kNcm^2
W_x, W_y otporni momenti inercije za karakteristične tačke za x i y osu, cm^3
T_d granični period oscilovanja, s
α, β koeficijenti za proračun ugiba, prema [9]
γ, ψ koeficijenti za proračun opterećenja, prema [9]
ν_1 koeficijent sigurnosti za 1. slučaj opterećenja
δ_{11} pomeranje grede izazvano dejstvom jedinične sile, m
γ_d logaritamski dekrement koji pokazuje brzinu gašenja oscilovanja (zavisi od odnosa visine nosača prema rasponu), prema [9]

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PRODUCT DESIGN CASE STUDY: CONCEPTUAL SOLUTION OF HAND DRILL/ANGLE GRINDER TABLE STAND

Milan Tica [1], Nikola Radulović[2], Tihomir Mačkić[3]

Abstract: Development of new products is necessary for the success of every society. Considering current situation in our country, and whole region, it is obvious that we need development of simple products, that require minimum resources. At the beginning of every development it is necessary to determine what resources are available. In addition to that, market analysis plays a crucial role in future product success. In this paper, an analysis of the market has been made regarding hand drill and angle grinder stands with analysis of their price and quality. Few different concepts have been analyzed. Product analyzed and developed in this paper represents combination of two existing products that already have good success in market. Development task is defined according to the results of the analysis. Presented conceptual solution is optimal and for the same price offers functionality of two separate products, without compromising quality.

Key words:Conseptual Design ,Drill, Angle Grinder, Stand

1 INTRODUCTION

Every development starts from an idea or from an existing product that needs to be improved. When it comes to improving existing products, it is very important to have good information about its use in practice. Also, data from market represents motivation for start of development. Market analysis should be performed by analysing the target group of potential buyers and their needs. After carefully performed analysis, new product can be designed in such a way that it can be superior to competitive products. Real price of newly developed product cannot be determined in this stage of its development. Based on calculations, an estimate of price can be done, and it represents very important factor in further process of development. Real price is determined after manufacturing process, and if it exceeds estimated price, some parts of product need to be changed, or manufacturing process needs to be adapted. Final price must be in optimal range which is determined based on target group of potential buyers. By using methods of modern product development, we form list of boundary

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conditions, which helps us to form few conceptual solutions, among which we have to choose an optimal one. Some concepts are good in terms of performance, but they are too expensive to manufacture. On the other hand, other concepts are very satisfying in terms of low price, but the quality and performance would be compromised. There are numerous ways how determine the optimal solution, based on adopted criteria. In this paper, two-factor VDI 2225 recommendation was used. This method uses economical and technical criteria to determine the proper solution. By using this method every variant gets assigned with grades, and the one with the highest grade is chosen as optimal.

2 MARKET ANALISYS

Market analysis consists from two parts, first part correlates to analysing current products available on market. Their price, quality and functionality are determined, so that new product can be placed among them. Second part deals with potential buyers and their needs.

2.1 Products available on current market

On today's market there are many tool makers, which means that prices for tools have dropped significantly. Some electric tools such as hand drills and angle grinders are followed by table stands, which are bought separately. Their price and quality varies from manufacturer to manufacturer, but they have one thing in common. All table stands are made for one tool only as shown in figures 1. and 2.



Figure 1. *Hand drill stand*



Figure 2. *Angle grinder stand*

New product should combine these two concepts, so its functionality would be increased compared to traditional table stands. Price would be someway higher compared to existing stands, which would be compensated by its functionality and the fact that it represents 2 in 1 product. As mentioned in previous text, market is flooded with different manufacturers, some of which have a long tradition in tool development and manufacturing so price and quality of their products is quite high. On the other side there is an entire group of manufacturers which offer low price and decent quality for their products. Products that have lower price are much more appealing for

potential buyers, so number of them sold is much bigger. Also, considering the fact that more expensive products made by recognizable manufacturers have their permanent buyers, new product should be in range of lower price-decent quality range, as shown in figure 3.

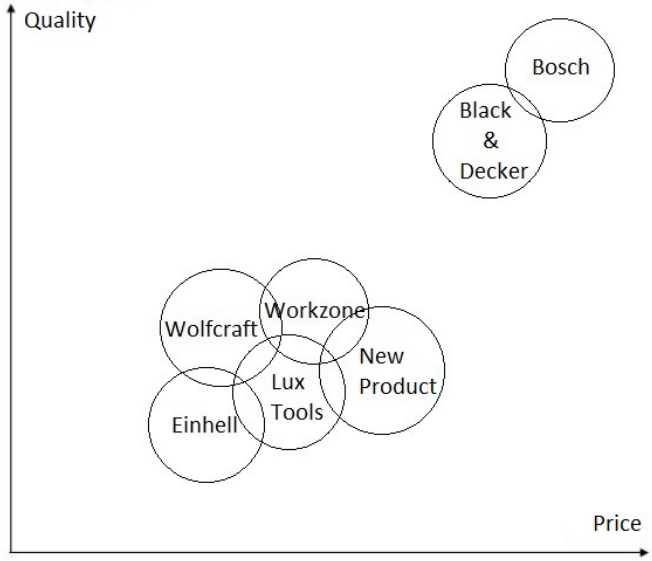


Figure 3. *Position of table stands manufacturers and new product among them*

New product would be more expensive compared to same quality products, due to fact that it represents 2 separate products integrated into one. Functionality would be way higher. Relation between price and functionality of current and new product is shown in figure below.

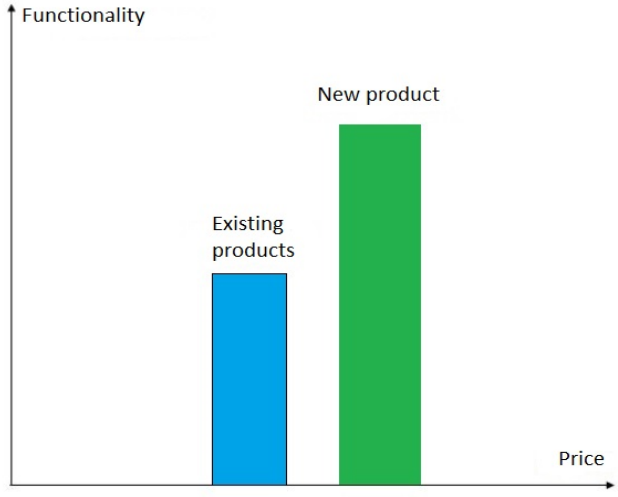


Figure 4. *Relation between price and functionality*

2.2 Potential group of buyers

Previous market analysis determined position of new product in terms of price and quality, but target group of potential buyers remains to be determined. Most of tool manufacturers offer wide range of tools, which can be used by amateurs and by professionals. Table stands for hand drills and angle grinders are mostly made for amateurs and DIY enthusiasts, and in some cases for smaller workshops. As price of tools went down, more and more people decided to try themselves in fixing and building activities. Almost every home has hand drill and angle grinder in its garage. Table stands for these tools represent very nice way to do some precision drilling and cutting. Based on these data and information, target group of buyers are DIY enthusiasts, and smaller workshops. Product should be available for purchase in tool shops, tool sections of supermarkets and on the internet (Amazon, E-bay etc.)

3 CONSEPTUAL DESIGN

The conceptual design structure represents a variant form of global arrangement of parts and components in order to achieve a specified function. The flow of table stand design consists of the following phases:

- Forming a list of boundary requirements
- Tabular description of the function perpetrators
- Selection of the optimal variant

The main function of hand drill /angle grinder table stand is acceptance of tools via standardized shapes (Euronorm Ø43 mm for drill) and two M8 bolts (for angle grinder) while allowing vertical linear movement for drilling operation, as well as angular (rotational) movement for operation of cutting with angle grinder.

3.1 Boundary requirements

Table 1. *List of boundary requirements*

1.	General functions	Acceptance of standardized shapes, and enabling of linear and angular movement with return stroke
2.	Additional functions	Possibility of bracing to table and acceptance of standard vices
3.	Working properties	To ensure stable support for tools, and enabling adequate force for drilling and cutting operation with minimum effort by user. Whole structure needs to provide good dumping for vibrations generated by electric tool.
4.	Manufacturing and economic characteristics	Using of standard parts as much as possible, non standard parts have to be made of cheap materials and easy to manufacture.
5.	Ergonomics	Easy to assemble and use ,small weight and low maintenance requirements
6.	Appearance	The impression of good quality, robust product ,that looks appealing to potential buyers

3.2 Function perpetrators and possible variants

Table 2. *Functions and their possible perpetrators*

Functions			Perpetrators		
			1.	2.	3.
	1.	Stable structure (shape and type)	Steel pipe and casted pedestal	Casted casing	Welded casing
	2.	Linear (vertical) movement	Rack and pinion (fixed rack)	Rack and pinion (fixed pinion)	Lever mechanism
	3.	Angular movement	Pin and lock	Bolt and nut	
	4.	Return stroke	Springs	Gas springs	Rubber springs
	5.	Attachment of drilling and cutting modules	Separately	Drill module attaches via cutting module	Cutting module attaches via drilling module
	6.	Acceptance of standardized shapes	Euronorm Ø43 mm and two M8 bolts		

Possible chosen variants are:

Variant V1 (1.2-2.2-3.2-4.1-5.1-6)

Variant V2 (1.1-2.1-3.1-4.1-5.2-6)

Variant V3 (1.1-2.3-3.1-4.1-5.2-6)

Variant V4 (1.1-2.3-3.2-4.1-5.1-6)

Next step is to select optimal variant based on technical and economic criteria. Each variant is assigned with grades. Based on grades, technical and economic coordinate are calculated and plotted on graph shown if figure 5. It is very important to assign adequate grades to each variant, to avoid selection of wrong variant.

3.3 Choosing an optimal variant

Table 3. *Variant grades and values of coordinates*

	Criteria	V1	V2	V3	V4	Ideal grade
Technical	Stability and precision	4	3	2	2	4
	Easy to use	3	4	4	3	4
	Mass and size	2	3	4	4	4
	Easy maintenance	3	3	4	4	4
	Sum	12	13	14	13	16
	Technical coordinate X_i	**0,75**	**0,81**	**0,87**	**0,81**	1
Economic	Number of standard parts	2	2	4	3	4
	Number complexity of non standard parts	3	3	4	4	4
	Structure complexity	3	4	4	4	4
	Assembling properties	3	3	4	4	4
	Price of materials used	2	3	3	3	4
	Sum	13	15	19	18	20
	Economic coordinate Y_i	**0,65**	**0,75**	**0,95**	**0,9**	1

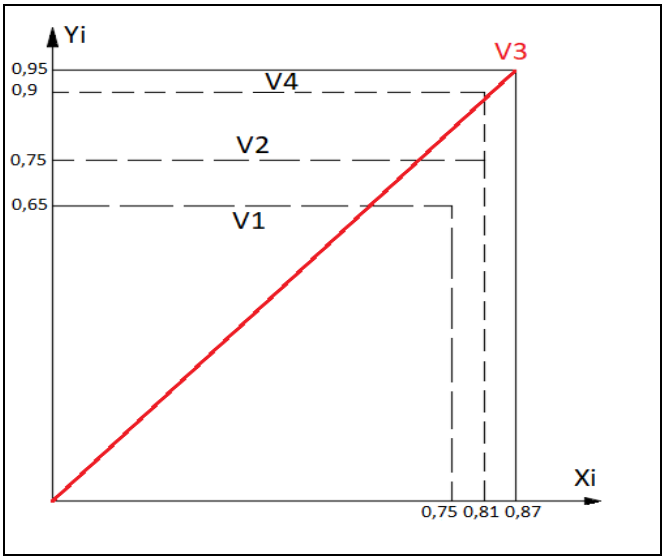


Figure 5. *Variants in coordinate system*

An optimal variant based on VDI 2225 recommendations is no.3. It is made out of casted aluminium pedestal and steel pipe pillar. Drill module uses lever mechanism to achieve vertical linear movement required for drilling operation. Cutting module used for angle grinder is attached to drilling module which is fixed during the cutting operation. Both modules are represented on sketches in figures 6. and 7.

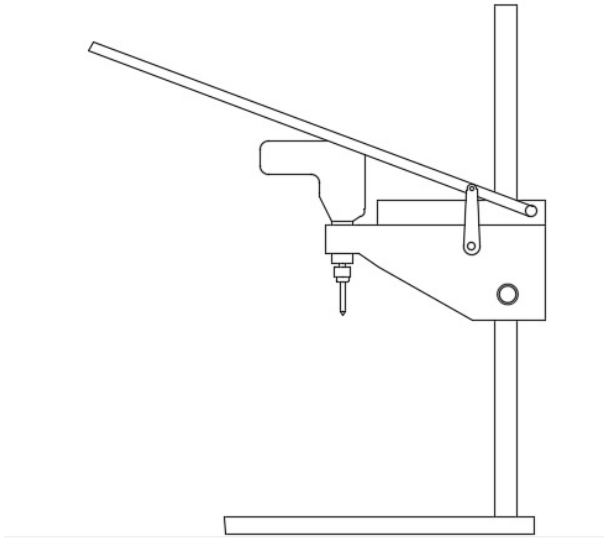


Figure 6. *Stand with attached hand drill*

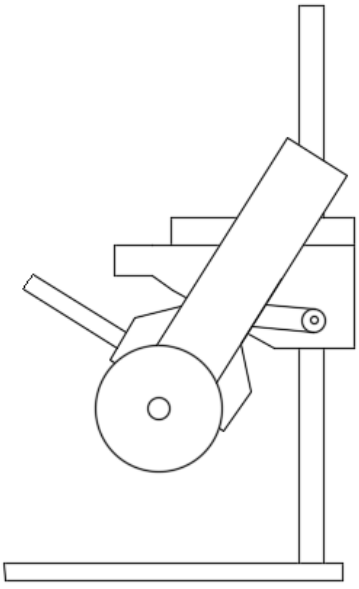


Figure 7. *Stand with attached angle grinder*

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4 CONCLUSION

This paper deals with modern ways of product development. Product design case study of table stand for hand drill and angle grinder is just a simple example of it. All stages of product development, from market analysis and defining development task, all the way to forming conceptual solutions and selection of the optimal variant are shown in proper order. At the end, sketches of chosen variant were made, and next step would be to determine geometry and materials, followed by creating CAD model of entire assembly. Selected variant represents simple tool, that uses lever mechanism to transfer force imposed by user to do required operations. Market analysis in Bosnia and Herzegovina shows that this is unique product, that has no competition. This study represents a nice way to develop simple, yet very useful products, that could have great success on market.

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GENERISANJE DINAMIČKE KOMPONENTE RADIJALNOG OPTEREĆENJA KOD ISPITIVANJA TRANSPORTNIH VALJAKA

Radivoje Mitrović[1] , Marko Tasić[1] , Žarko Mišković [1], Milan Tasić[2] , Zoran Stamenić[1]

Rezime: U cilju povećanja efikasnosti termoenegretskih postrojenja, posebna pažnja se posvećuje povećanju pouzdanosti sistema za snabdevanje termoelektrana ugljem sa površinskih kopova. Usled otkaza nosećih valjaka trakastih transportera dolazi do zastoja u transportu i značajnog povećanja troškova u radu sistema. Zbog toga se uvode metode laboratorijskih ispitivanja pouzdanosti transportnih valjaka. Postojeći probni stolovi se uglavnom zadovoljavaju ispitivanjima valjaka pod delovanjem nepromenljivog radijalnog opterećenja. U radu je prikazana konstrukcija uređaja za generisanje dinamičke komponente radijalnog opterećenja na postojećem probnom stolu za ispitivanje transportnih valjaka u laboratoriji LIMES na Mašinskom fakultetu u Beogradu. Uređaj se odlikuje svojom jednostavnošću, robusnošću i univerzalnošću. Omogućuje izbor različitih amplituda, inteziteta i frekvencija radijalnog opterećenja.

Ključne riječi: transportni sistemi, transportni valjci, laboratorijsko testiranje

GENERATION OF DYNAMIC RADIAL LOAD COMPONENTS IN TESTING OF TRANSPORT ROLLERS

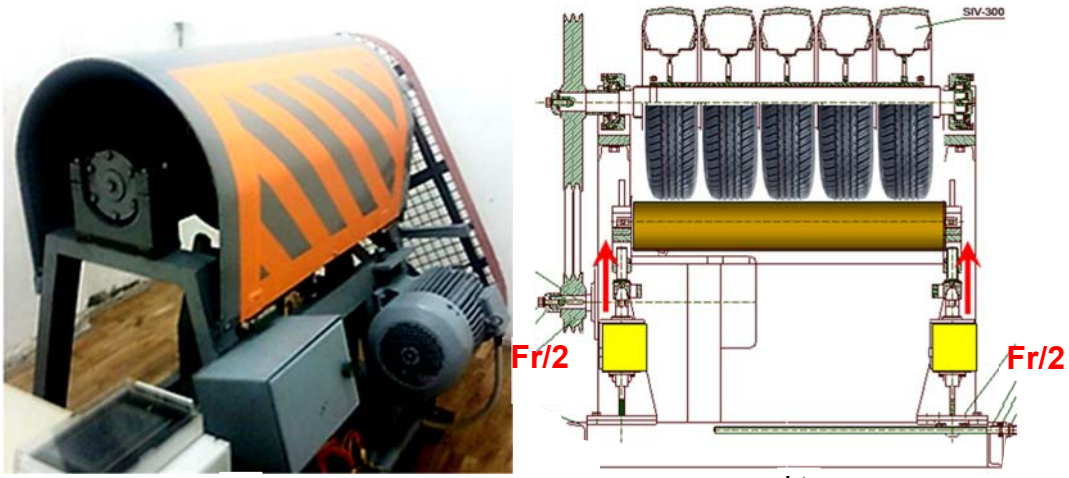
Abstract: In order to increase the efficiency of thermal power plants, special attention is paid to increasing the reliability of the system for supplying thermal power plants with coal from open pit mines. Due to the failure of the conveyor belt rollers, there is a delay in transport and a significant increase in the costs of the system. Therefore, methods of laboratory testing of the reliability of rollers are introduced. Existing test stands are mostly satisfied with tests with an unchanging intensity of radial load. The paper presents the construction of a device for generating a dynamic component of radial load at the existing test stand for testing the conveyor rollers at the LIMES Laboratory at the Faculty of Mechanical Engineering in Belgrade. The device is distinguished by its simplicity, robustness and universality. Allows you to select different amplitudes, intensity and frequency of radial load.

Key words: conveyor belt systems, laboratory testing, transport rollers

1 UVOD

Rad predstavlja prikaz konstrukcije uređaja za generisanje dinamičke

komponente radijalnog opterećenja na probnom stolu za ispitivanje transportnih valjaka. Probni sto je razvijen u laboratoriji LIMES na Mašinskom fakultetu u Beogradu u okviru rada na projektima TR14033 i TR3529 Ministarstva prosvete, nauke i tehnološkog razvoja (Sl.1a). U njegovoj osnovnoj varijanti, radijalno opterećenje ispitivanih transportnih valjaka je generisano pomoću pneumatskih cilindara (Sl.1b) i imalo je zadati - konstantni intezitet tokom ispitivanja.



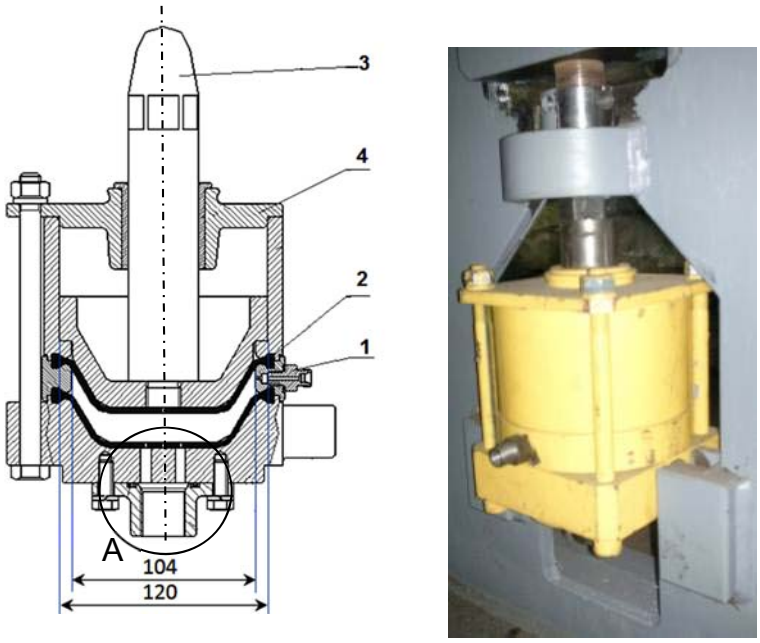
Slika 1. *Probni sto za ispitivanje transportnih valjaka radijalnim opterećenjem (laboratorija LIMES – Mašinski fakultet u Beogradu)*

Radijlano oterećenje koje deluje na cilindrični omotač transportnog valjka se generiše pomoću dva pneumatska cilindra sa donje strane. Sa gornje strane se nalazi pogonsko vratilo sa setom pneumatskih točkova, koji preko kaišnog prenosnika dobijaju pogon od elektromotora. Promenom pritiska u svakom od pneumatika u setu, moguće je ostvariti neravnomernu raspodelu pritiska duž izvodnice cilindra transportnog valjka, čime se ostvaruje simulacija neravnomernog rasporeda težine transportovanog materijala.

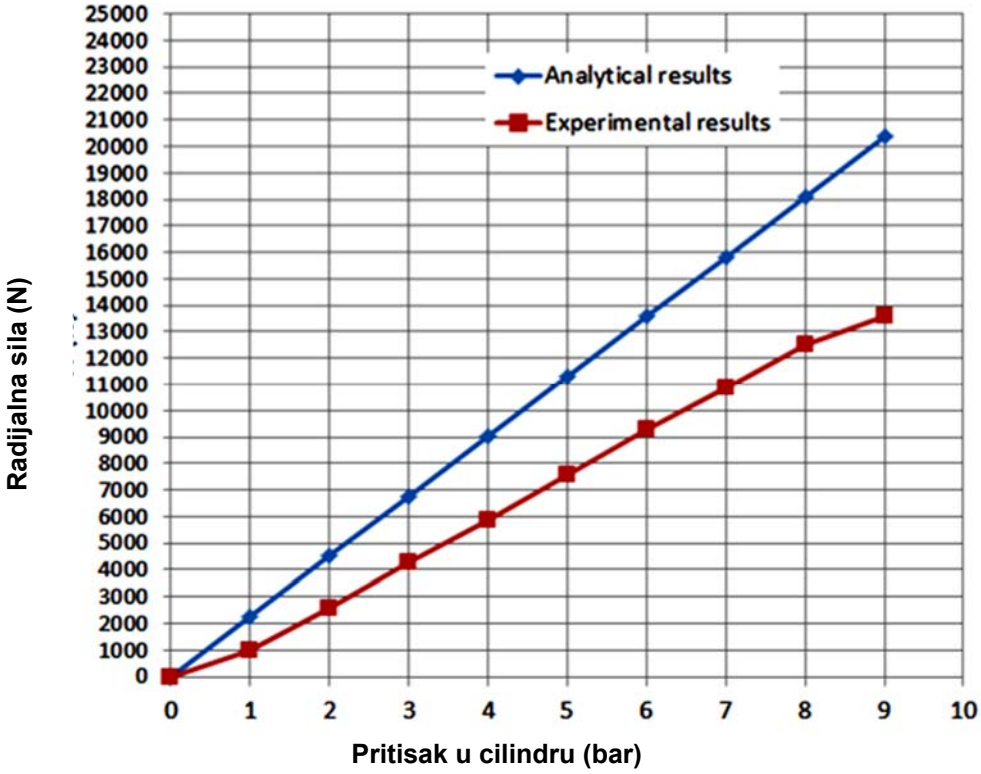
2 GENERISANJE RADIJALNOG OPTEREĆENJA

Radna sila se ostvaruje pomoću pneumatskog cilindra, čiji je presek prikazan na slici 2. Konstrukcioni elementi pneumatskog cilindara su: priključak za dovod vaduha pod pritiskom (1), gornja i donja gumena membrana (2), klip (3) i kućište cilindra (4). Elastična svojstva pneumatskog oslajnjanja omogućuju amortizaciju udara u radu probnog stola. Prema prečniku klipa od 120mm i raspoloživom pritisku od 9bar u pneumatskoj instalaciji cilindri mogu ostvariti radijalnu silu 20kN.

Eksperimentalna istraživanja [1,2] sprovedana u cilju etaloniranja pneumatske instalacije na ZWICK ROELL HB250 hidropulzatoru u okviru laboratorije LIMES su pokazala da maksimalna vrednost radijalne sile iznosi oko 13kN (eksperimentalna kriva na dijagramu na sl. 3).



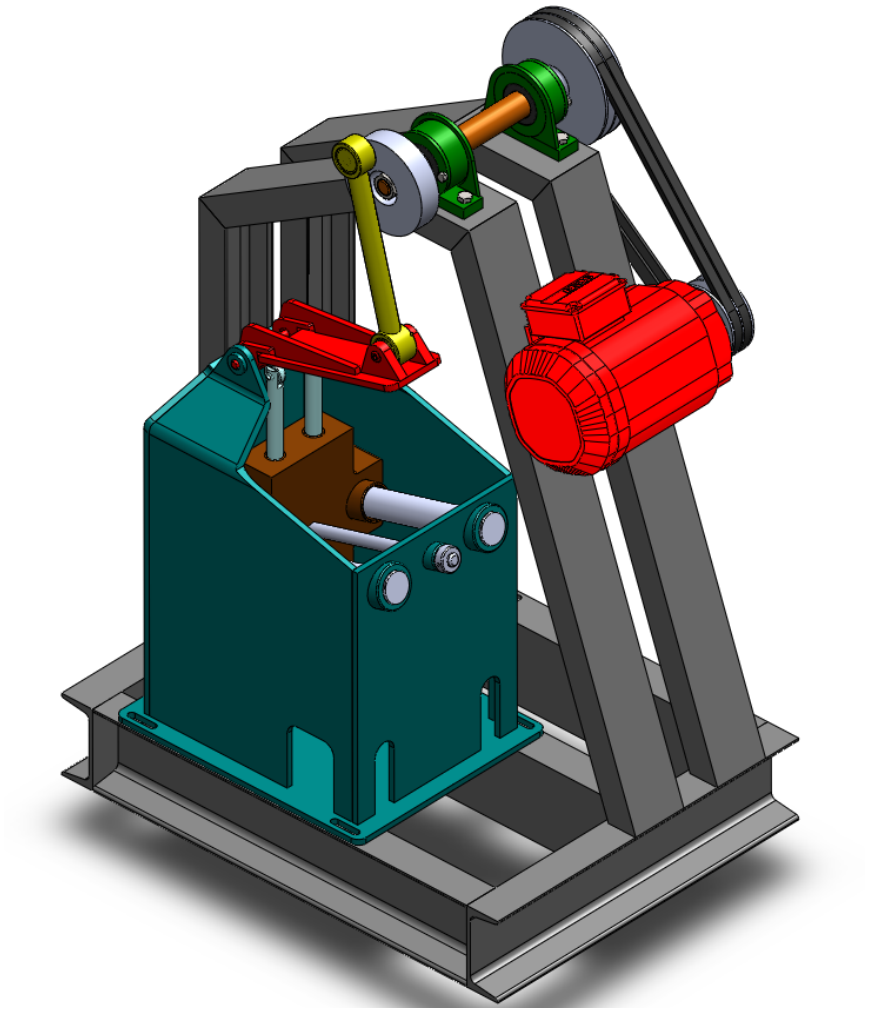
Slika 2. *Izvršni pneumatski cilindar na probnom stolu za ispitivanje transportnih valjaka*



Slika 3. *Radne sile i pritisci u pneumatskoj instalaciji*

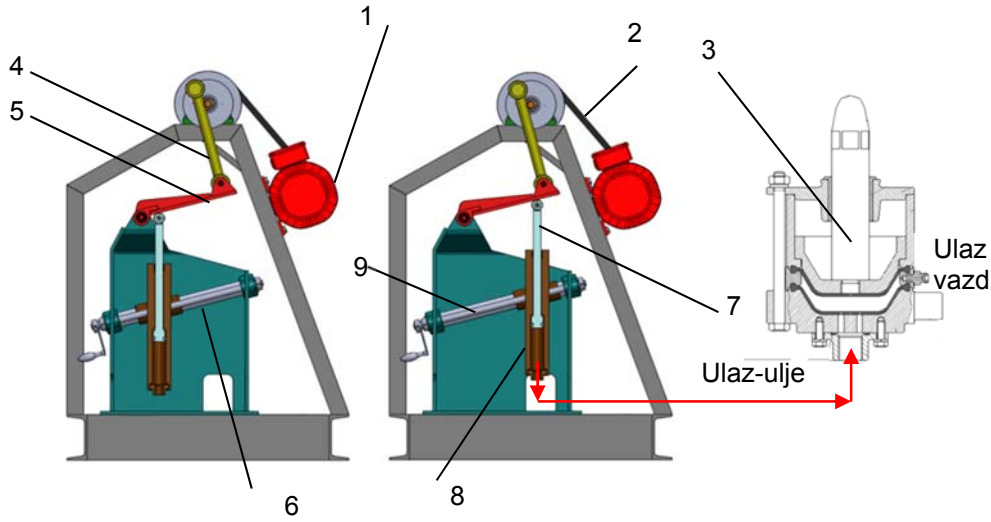
2.1 Generisanje dinamičke komponente radijalnog opterećenja

Na slici 4 je prikazan 3D model uređaja za generisanje dinamičke komponente radijalnog opterećenja na probnom stolu za ispitivanje transportnih valjaka. Uređaj je izveden kao posebna konstrukcija generatora promenljivog hidrauličkog pritiska i kao takav se može koristiti i u drugim instalacijama za dinamičko ispitivanje različitih mašinskih elemenata ili sklopova.



Slika 4. *Izgled 3D modela uređaja za generisanje dinamičke komponente opterećenja*

Da bi se omogućilo stvaranje dinamičke komponente radijalnog opterećenja na dnu pneumatskog cilindra, ispod donje gumene membrane, napravljeni su otvori za dovod ulja iz hidroagregata (detalj “A” na slici 2). Na slici 5 su prikazani preseci kroz 3D model uređaja za generisanje pulsirajućeg hidrauličkog pritiska sa položajima za minimalni i maksimalni hod klipnjače hidrocilindra.



Slika 5. *Preseci 3D modela uređaja za generisanje hidrauličkog pritiska 1-elektromotor, 2-kaišni prenosnik, 3-pneumatski cilindar, 4-oscilatorna poluga, 5-oscilatorna ploča, 6- kose vođice, 7-klip, 8-hidrocilindri, 9-navojno vreteno*

Pogon od elektromotora 1, se preko kaišnog prenosnika 2, prenosi do oscilujuće poluge 4, koja potiskuje oscilujuću ploču 5. Ploča sa svojom donjom stranom preko točkića, potiskuje klipove 7, dvaju paralelnih hidrocilindara vezanih u jedan blok 8. Položaj bloka se pomoću navojnog vretena 9, menja kretanjem duž kosih vođica 6. Ovim pomeranjem se menja položaj klipnih poluga u odnosu na oscilujuću ploču, odnosno menja se hod klipnjača u cilindrima. Na ovaj način se vrši promena amplitude dinamičke komponente radijalnog opterećenja. Promena frekvencije se obezbeđuje promenom učestanosti obrtanja elektromotora pomoću frekventnog regulatora napona napajanja.

Maksimalni hod klipa hidrocilindra prečnika 40mm, iznosi ±50mm. Njegov položaj h u trenutku t se menja po sinusnom zakonu srazmerno ugaonoj brzini remenice ω:

$$h = 0.050 \sin \omega t \tag{1}$$

Promena (smanjenje) zapremine vazdušne komore u pneumatskom cilindru, zbog nestišljivosti ulja, odgovara njegovom dotoku sa donje strane donje gumene membrane i iznosi:

$$\Delta V = A_h \cdot h = \frac{0.040^2 \cdot \pi}{4} \cdot 0.05 \cdot sin(\omega \cdot t) = 6.283 \cdot 10^{-5} \cdot sin(\omega \cdot t) \tag{2}$$

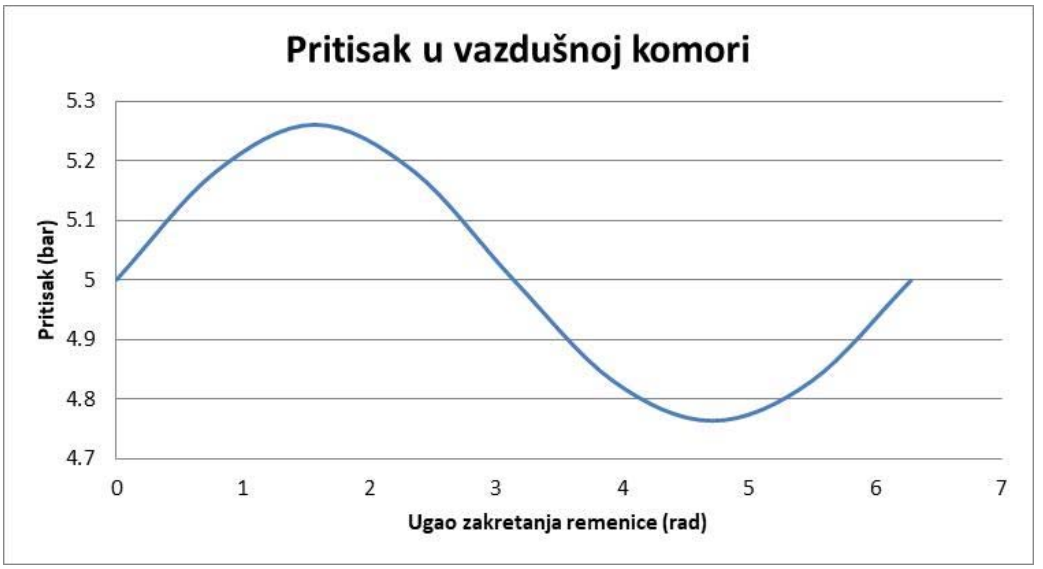
U prvom približenju se može prihvatiti da se promena stanja gasa u vazdušnoj komori pneumatskog cilindra odvija pri konstantnoj vrednosti temperature. Izotermalna promena stanja daje vezu između pritisaka i zapremina u vazdušnoj komori pre i nakon dotoka ulja iz hidrocilindara u sledećem obliku:

$$p_0 \cdot V_0 = p_1 \cdot V_1 \tag{3}$$

odnosno periodična promena vrednosti pritiska u pneumatskom cilindru iznosi:

$$p_1 = p_0 \cdot \frac{V_0}{V_0 - 6.283 \cdot 10^{-5} \cdot sin(\omega \cdot t)} \quad (4)$$

Za vrednosti srednjeg pritiska u pneumatskom cilindru od 5bar, zapreminu vazdušne komore od 0.001268m^3 i hod hidrauličnog klipa od ±50mm ostvaruje se promenljiva vrednost pritiska, prikazana na dijagramu sa slike 6.



Slika 6. *Radni pritisak u pneumatskom cilindru*

Na dijagramu je prikazana promena pritiska koja odgovara jednom punom obrtaju remenice, odnosno hodu oscilujuće poluge.

3 ZAKLJUČCI

Prikazana konstrukcija uređaja za generisanje dinamičke komponente radijalnog opterećenja je nezavisna konstrukciona jedinica koja se može koristiti za dinamička ispitivanja različitih elemenata i sklopova mašina i uređaja.

Uređaj se u laboratoriji LIMES na Mašinskom fakultetu u Beogradu koristi kao dodatak probnom stolu za ispitivanje transportnih valjaka pod dejstvom radijalnog opterećenja radi generisanja njegove dinamičke komponente.

Zbog svoje mehaničke konstrukcije uređaj se odlikuje jednostavnošću, robusnošću i univerzalnošću. Ne zahteva posebnu obuku operatera za montažu primenu i rukovanje u toku ispitivanja.

Omogućuje izbor različitih amplituda, inteziteta i frekvencija radijalnog opterećenja bez potrebe za upotrebom elektronskih ili hidrauličkih upravljačkih jedinica.

NOMENKLATURA (10 PT BOLD, UPPERCASE, Spacing Before 18 pt, After 6 pt)

A_h površina klipa hidrocilindra, m^2
h hod klipa hidrocilindra, m
p_0 pritisak u vazdušnoj komori pre dotoka ulja, bar
p_1 pritisak u vazdušnoj komori posle dotoka ulja, bar
t vreme, s
V_0 zapremina vazdušne komore pre dotoka ulja, m^3
V_1 zapremina vazdušne komore posle dotoka ulja, m^3

Grčki alfabet

ω ugaona brzina remenice, rad/s

Subskripti i superskripti

0 početno stanje
1 krajnje stanje
h hidraulički
p pneumatski

LITERATURA

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OPTIMIZATION OF RAVIGNEAUX PLANETARY GEAR SET

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Abstract: The advancement of the automotive industry tended to replace classical gears with fixed axes, with planetary gear set with movable axes. Planetary gear sets have many advantages over classical gears, but their design is more complex. One of the planetary gear sets, which is highly applicable in the automotive industry, is the Ravigneaux planetary gear set. This planetary gear set consists of gears with external and internal toothing, which for different cases of movement of gears provides different output speeds and torques. The optimization of the module and the gear width of the the Ravigneaux gear set in order to reduce its mass, and taking into account the values of the safety coefficient, was carried out in this paper. Observed optimization factors are: three materials (37Cr4, Ck15 and 15CrNi6), three modules (1mm, 1.25 mm and 1.5 mm)and three gear widths (20 mm, 22 mm and 25 mm).These values satisfy the conditions of the planetary gear kinematics. By optimizing the Ravigneaux planetary gear set saving of the mass of around 28% was achieved.

Key words: optimization, planetary gears, Ravigneaux planetary gear set, safety coefficient.

1 INTRODUCTION

Transmissions are necessary part of every machine in the industry. The advancement of technology tends to reduce the losses as well as the mass of the gear set, but the transmission structure is becoming more complex. Nowadays planetary gear transmissions are widely used. The increased use of planetary gear set is because of the advantages that this type of gear set brings into the machine systems in which it is built, which are: large transmission ratios, the possibility of sharing power on the drive shaft to a multiple driven shafts and vice versa, the possibility of achieving different transmission ratios, compactness and other.

These gears, as already said, can achieve large transmission ratios, but it should be noted that this reduces the efficiency. The possibility that the space between the

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[4]MSc, Stefan Milojević, Faculty of Engineering University of Kragujevac, Serbia, stefanmilojevic94@hotmail.com

central gears is filled with more satellites ensures good use of the interior space and allows a compact construction of planetary gears.

The use of multiple satellites allows the load to be transmitted simultaneously with a large number of teeth, which leads to a reduction in load and selection of smaller modules.Thanks to these features, planetary gears are two to three times lighter than conventional gear sets of the same power and transmission ratio. Equitable mass reduction requirements and dimensional dimensions correspond to drives with planetary gear units.

Although planetary gears have a number of advantages, they, also, have important shortcomings: more complicated than conventional gears, they have complex kinematics, they are sensitive to the change in distance between axes, additional forces may occur due to the insufficient accuracy of the load distribution between satellites,require high accuracy in construction and assembly, as this can also contribute additional loads on gears.

There is a lot of types of planetary gears. The simplest planetary gear consists of two central gears and one row of satellites [1].

One type of planetary gear that is the subject of numerous research is Ravigneaux's planetary gear set that arose as a result of the improvement of previous gear sets, such as Simpson (patented in 1944). Ravigneaux's planetary gear set is a double planetary gear patented by Paul Ravigneaux in 1949 in France. It consists of two central gears with an external toothing and one central gear with internal toothing, between which there are two satellites connected by one carrier [2-5].

In this paper, based on the calculation of the complete Ravigneaux's planetary gear set in the Autodesk Inventor 2016 software given in [6], optimization of the obtained safety coefficient for surface durability for one gear pair was performed. Optimizing first gear pair of Ravigneaux's planetary gear set is affecting the whole gear set in terms of its dimensions and mass.

The implementation of experiments can not be imagined today without applying some of the optimization methods. Among a lot of optimization methods widely used are Taguchi method and Artificial Neural Network (ANN).

Taguchi method is an optimization method consisting of a limited number of experiments. Within this method there are two tools used: the orthogonal array and the S/N ratio that allow the function to be optimized within the experiment limits. Optimization methods are used to reduce the number of experiments and thus save time and expenses necessary for conducting of experiments [7]. In [8] performed design optimization of planetary gear combining Taguchi method and Computer Aided Engineering. Taguchi method was used for obtaining a linear regression model in order to predict a nominal safety factor value. Regression model for prediction of safety coefficient was based on the simulation data obtained from ANSYS software. The conclution that was drawn from this paper was that this kind of approacch can be used for optimisation of the system with certainty that the component will perform with efficiency under assigned conditions. Another optimization of planetary gear with the help of Taguchi method was performed by S. Miladinovic et.al. in [9]. They investigated influence of material, module and gear width on the safety coefficient for surface durability by varying two types of material, three modules and three gear widths. This optimization gave the best combination of factors, and has shown that the most influential factor was module. Combination of Taguchi method and ANN for optimization of safety coefficient for surface durability of internal gear of planetary gear set was used in [10]. Influence of module, material and gear width was investigated. With the help of ANOVA analysis it was found that most influential was module, than gear width and the least influential was material. ANN was used for prediction of safety coefficient for

surface durability of internal gear of planetary gear set.

In this paper, the Taguchi method was used to determine the percentage influence of the factors considered as well as to determine the optimal level of factors for the safety coefficient for surface durability of gear pair of Ravigneaux planetary gear set (in the text below safety coefficient), while the ANN method was used to predict the values of safety coefficient.

2 DESIGN OF EXPERIMENTS USING TAGUCHI METHODOLOGY

Taguchi method was developed by Dr. Genichi Taguchi in the 1980s and represents a statistical method of quality engineering. This method is a method of experimental design that attempts to minimize the variability of products and processes by selecting the best combination of level of factors that can be controlled using orthogonal arrays. This method's approach is a very useful for determining the best combination of different factors for an objective function [7].

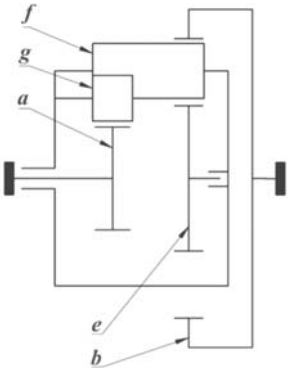
In the last few years, this efficient and systematic way of optimizing design for performance, quality and expences has been used for numerical and theoretical research.

In this study, for the optimization of the level of safety coefficient of planetary gear, an analysis of the material, the module and the gear width was performed. Due to the complexity of this type of planetary gear set in this paper, optimization for one pair of gears was made more precisely for the pair a-g (Figure 1).

Table 1 shows the factors and their levels used to optimize the safety coefficient.

Table 1. *Levels for various control factors*

Factor	Units	Level 1	Level 2	Level 3
(A) Material	/	37Cr4	Ck15	15CrNi6
(B) Gear width	mm	20	22	25
(C) Module	mm	1	1.25	1.5



a - first central gear
g, f - satellites
e - second central gear
b - third central gear

Figure 1. *Scheme of Ravigneaux planetary gear set*

Using the Taguchi technique and using the ANOVA analysis, the influence of the considered factors on the safety coefficient of the Ravigneaux planetary gear is found. Orthogonal arrays, in the Taguchi method, are used to design the experiments. In this case, the orthogonal array L27 was selected for the experiment plan (Table 2). The safety coefficients of the Ravigneaux planetary gear set are obtained in the Autodesk Inventor software and are shown in Table 2. These results are transformed into signal-

to-noise ratio which is a measure of quality characteristics deviating from the desired values. Different quality characteristics may be chosen, depending on the experimental objective. In the Taguchi methodology, the quality of any particular design solution is quantified using a ratio. Three different S/N ratios can be used for the calculations, i.e., the smaller is better, the higher is better and nominal is better [8]. In this study, because minimum safety coefficient is the objective function, the smaller is better situation has been selected. The S/N ratio of the-smaller the better can be expressed as follows [11, 12]:

$$S/N=-10\log\frac{1}{n}\left(\sum y^2\right). \tag{1}$$

wherein *n* is the number of repetitions of the experiment and yi is the average measured value of experimental data i. Unit of S/N ratio is decibel (dB). S/N ratio is used to select the optimum levels of parameters based on the minimum deviation. The optimal is the combination of factors that has the highest S/N ratio.

Table 2. *Safety coefficient and S/N ratios for the L27 orthogonal array*

	Material	Gear width	Module	SHa – safety coefficient	S/N ratio of the safety coefficient	ANN
1	37Cr4	20	1.00	1.000	0.00000	1.000
2	37Cr4	20	1.25	1.259	-2.00051	1.339
3	37Cr4	20	1.50	1.533	-3.71084	1.648
4	37Cr4	22	1.00	1.021	-0.18051	1.021
5	37Cr4	22	1.25	1.312	-2.35868	1.312
6	37Cr4	22	1.50	1.601	-4.08783	1.601
7	37Cr4	25	1.00	1.065	-0.54699	1.059
8	37Cr4	25	1.25	1.399	-2.91635	1.399
9	37Cr4	25	1.50	1.696	-4.58852	1.696
10	Ck 15	20	1.00	1.060	-0.50612	1.026
11	Ck 15	20	1.25	1.351	-2.61311	1.351
12	Ck 15	20	1.50	1.644	-4.31804	1.699
13	Ck 15	22	1.00	1.097	-0.80413	1.097
14	Ck 15	22	1.25	1.408	-2.97205	1.408
15	Ck 15	22	1.50	1.717	-4.69541	1.717
16	Ck 15	25	1.00	1.144	-1.16852	1.213
17	Ck 15	25	1.25	1.501	-3.52761	1.501
18	Ck 15	25	1.50	1.819	-5.19665	1.819
19	15CrNi6	20	1.00	1.112	-0.92210	1.112
20	15CrNi6	20	1.25	1.418	-3.03352	1.418
21	15CrNi6	20	1.50	1.725	-4.73578	1.725
22	15CrNi6	22	1.00	1.151	-1.22151	1.229
23	15CrNi6	22	1.25	1.478	-3.39349	1.446
24	15CrNi6	22	1.50	1.802	-5.11510	1.802
25	15CrNi6	25	1.00	1.201	-1.59086	1.201
26	15CrNi6	25	1.25	1575	-3.94561	1.575
27	15CrNi6	25	1.50	1.909	-5.61612	1.909

The calculation of the S/N ratio (Signal to Noise Ratio) with the use of equation 1 depends on the results obtained by the experiments. By analyzing the S/N ratio, the optimal level of each factor can be determined along with an optimized set of factors. Then, an optimal combination of factors that can affect the degree of security can be

predicted. In Table 3, are shown values for S/N ratio "Smaller is better" and Figure 2 shows the Main Effects Plot for the safety coefficient.

Table 3. *Response Table for Signal to Noise Ratios "Smaller is better"*

Level	Material	Gear width	Module
1	-2.2656	-2.4267	-0.7712
2	-2.8668	-2.7587	-2.9734
3	-3.2860	-3.2330	-4.6738
Delta	1.0204	0.8064	3.9026
Rank	2	3	1

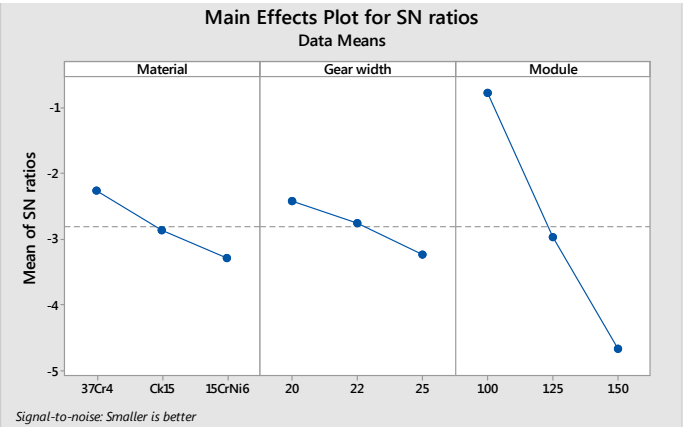


Figure 2. *Main Effects Plot for the safety coefficient*

The optimal combination of the factors considered is A1B1C1, while the influence of each factor individually cannot be determined by the S/N ratio, and for that ANOVA analysis is used.

For determining influence of significant process factors the statistical method called Analysis of Variance (ANOVA) was used [8, 13]. ANOVA is used for finding how much the contribution of the most influential factor has changed in the generated design. The results presented in Table 4 show that all factors are primary factors because the p-value is less than 0.05.

Table 4. *Analysis of Variance for S/N ratios of the safety coefficient*

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pr %
Material	2	4.7355	4.7355	2.3677	566.77	0.000	6.17
Gear width	2	2.9563	2.9563	1.4781	353.83	0.000	3.85
Module	2	68.9147	68.9147	34.4573	8248.13	0.000	89.86
Residual Error	20	0.0836	0.0836	0.0042			0.11
`Total	26	76.6900					100.00
DF - degree of freedom, Seq SS - Sequential sum of squares, Adj SS - Adjusted sum of squares,Adj MS - Adjusted mean square, F – value, Pr percentage of contribution							

According to ANOVA, the most important and influential factor on the safety coefficients of planetary gear set, for 95% confidence level, is the module with 89.86%, followed by the material with 6.17% and the gear width with 3.85% influence.

Figure 3 shows the 2d contour plot of material and module dependency on safety coefficients of planetary gear set.

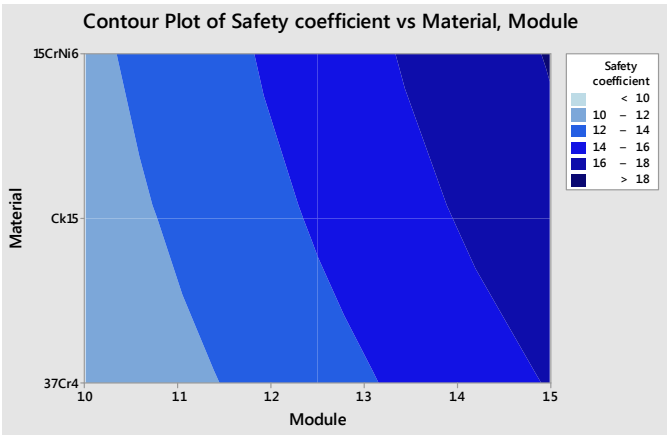


Figure 3. Contour plot of safety coefficient dependance of material and module

3 ARTIFICIAL NEURAL NETWORKS

For reducing of number of experiments, also, can be used ANN. ANN is artificial intelligence system inspired by information processing of a human brain. It is a system which consists of number of interconnected neurons. Each neuron has memory where are stored information that are processed. Simple neural network consists of three layers: input layer, hidden layer and output layer [12, 14, 15].

ANNs are not programed they are trained, and for that have been designed training algorithms; the mostly used is back-propagation Levenberg–Marquardt algorithm, which was used in this paper. ANN with 3 input factors, one hidden layer, with 15 neurons, and one output was developed for predicting safety coefficient (Figure 4). As transfer function was used log-sigmoid (logsig) transfer function. ANN output is given in Table 2, and regression diagram which shows regression coefficients for training, validation, testing and overall is shown on Figure 5.

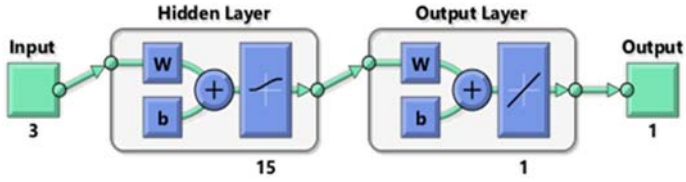


Figure 4. *Shematic representation of developed ANN*

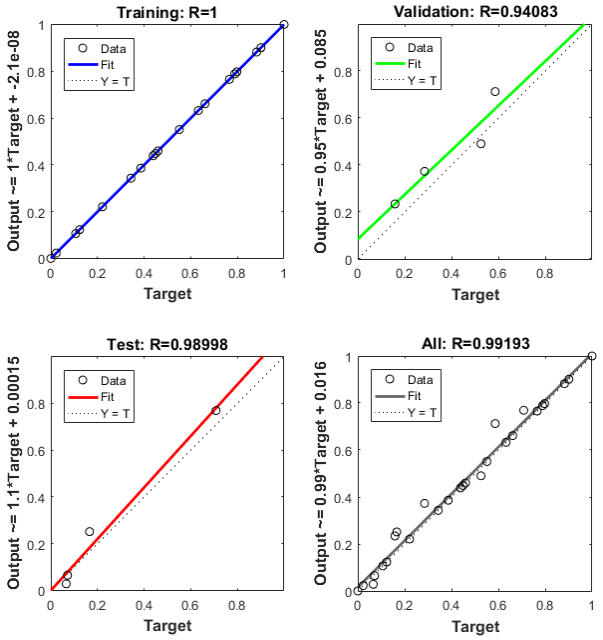


Figure 5. *Regresion diagram obtained for trained network*

It can be noticed that overall regression coefficient is 0.99 which shows very good corelation between experimental results and ANN's output.

4 CONCLUSION

Optimization of one gear pair of Ravigneaux planetary gear set was performed in this paper in order to notice the behaviour of safety coefficient when material, module and gear width are changed. Based on Taguchi and ANOVA analysis, it is concluded that the greatest influence on the safety coefficient has module with 89.86%, while the least influence has the gear width with 3.85%. The optimal variant of the factors (A1B1C1) is obtained by the Taguchi method. The optimization of safety coefficient has shown that all the factors are on the first level, which means that the material is 37Cr4, the module is 1 mm and the gear width is 20 mm. The ANN model was, also, developed with regression coefficient of 0.99 which means that this model can be used for prediction of safety coefficient with great reliability. Difference in the mass between Ravigneaux planetary gear set with max and min value of safety coefficient is 4.921 kg which is around 28% of mass of whole gear set.

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LIFTING TABLE DESIGN IN A LEARNING FACTORY AT UNIVERSITY OF MOSTAR

Nebojsa Rasovic[1], Adisa Vucina[2], Remzo Dedic[3]

Abstract: Today industry faces challenges such as shorter time-to-market, high number of product variants and limited resources. Learning factories as close-to-industry environments for education have proven to be an effective concept addressing these challenges. The analysis of mechanical engineering curriculums at Faculty of Mechanical Engineering, Computing and Electrical Engineering has showed that product design and development has no proper practical learning. This paper presents new education approach in product design and development and a case study of lifting table development through the concept of Learning Factory at the University of Mostar.

Key words: learning factory, lifting table, product design

1. INTRODUCTION

The term “Learning Factory“ was first coined in 1994. in USA when the National Science Foundation (NSF) awarded a consortium led by Penn State University a grant to develop a learning factory. Thanks to that grant a college-wide infrastructure and a 2000 square meters facility equipped with machines, materials and tools was established and utilized to support hundreds of industry-sponsored design projects since 1995. [1]. This early model of learning factories emphasizes strong link between design projects gained through engineering education at faculty and real industry in order to make a close approach for students to real problems in industry [2–4]. Regarding Europe the Institute of Production Management, Technology and Machine Tools (TU Darmstadt) had one of the early learning factory implementations in 2007. Recently the use of learning factories has increased in Europe. The term “Learning Factory“ literally assumes system concept which includes elements of learning or teaching as well as a production environment [5]. These two words “learning“ and “factory“combination emphasizes the importance of experiential learning in high education and research institutions. Learning factories provide a real production environment where processes and technologies are based on real industrial sites. Learning factory concept offers a good environment for education and also resourses for technological and organizational innovation if it is used for research [6, 7]. In recent years, learning factories have been

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established in manufacturing education and research as promising learning and innovation platforms [8].This concept can be implemented in a lot of different ways. This paper presents new education approach in product design and development (PDD) through the concept of learning factory. Lifting table is designed in order to complement the learning factory configuration at Faculty of Mechanical Engineering, Computing and Electrical Engineering (FSRE), University of Mostar.

2. LEARNING FACTORY CONCEPT AT UNIVERSITY OF MOSTAR

The initiative of introducing of learning factory at FSRE, University of Mostar, has started in January, 2018. Faculty applied the project co-financed by European Union and implemented by Deutche Gesellschaft fur Internationale Zusammenarbeit (GIZ) and received a certain amount of funds for project Increasing Competitiveness of Small and Medium Enterprises (SMEs) through Creating Business Associations and Establishing a Learning Factory, within the EU ProLocal programme.

Faculty is leader and nine local metal and plastic industries are partners in this project. The main goal of the project is the development and realization of the learning factory concept in collaboration with enterprises, development of curricula and support to enterprises in the field of education and research. The role of enterprise in the project is a contribution to the development of lifelong learning curricula and the transfer of knowledge in the field of practical training in the learning factory. Local community plays important role in project supporting the building of infrastructure, fostering better cooperation between the academic community and SMEs, as well as raising awareness of innovation among citizens through activities and workshops on the project.

2.1 New education approach in product design and development

Learning factories have been widely spread in Europe, and have created many concepts and forms of facilities varying in size, function, and equipment sophistication in order to improve the learning outcomes of students in one or more areas of engineering knowledge. Competency development is generally seen as a learning factory key objective. Aiming to enhance learning experiance of students on PDD, FSRE has taken a new model of education approach. A new model of education approach in PDD is presented by algorithm on Figure1. In the learning factory, product development process begins with the generation of ideas that can be driven by market conditions and the needs of a local environment, coming from educational needs or as a result of academic research. Students go through four characteristic phases of the product development process from the idea to final product. The process is systematic and at the same time flexible to the type of product being developed. With this approach, students are provided advanced training of integrated product development in real industrial environment where they recognize the need and opportunities for industry to address and overcome problems using academic and scientific approach. This workflow model enables students a systematic approach to the integrated products design and their related processes including manufacturing and support, which is emhhasized by the pillars of the algorithm. Namely, during the design process, they will take into account the process of production, testing, and packaging. At the same time, they will gain experience in organizing the integrated product development process and working in interdisciplinary parallel teams. The goal is that each phase in development process is strengthened by pillars in each individual step, depending on the needs and requirements. This model enables the strengthening and enhancement of the students in the synergy of academic and industrial environments. Benefits resulting from this learning approach in PDD

through the learning factory concept are reflected in the following:

- Education in Realistic Industrial Environment,
- Learning Process Modernization,
- Adoption of New Technology,
- Improving Innovation Capabilities.

This process in learning factory is realized within an open two-way information circuit between the academy and industry. This allows permanent teaching process improvement and keeping up the academic community with a modern industrial sector.

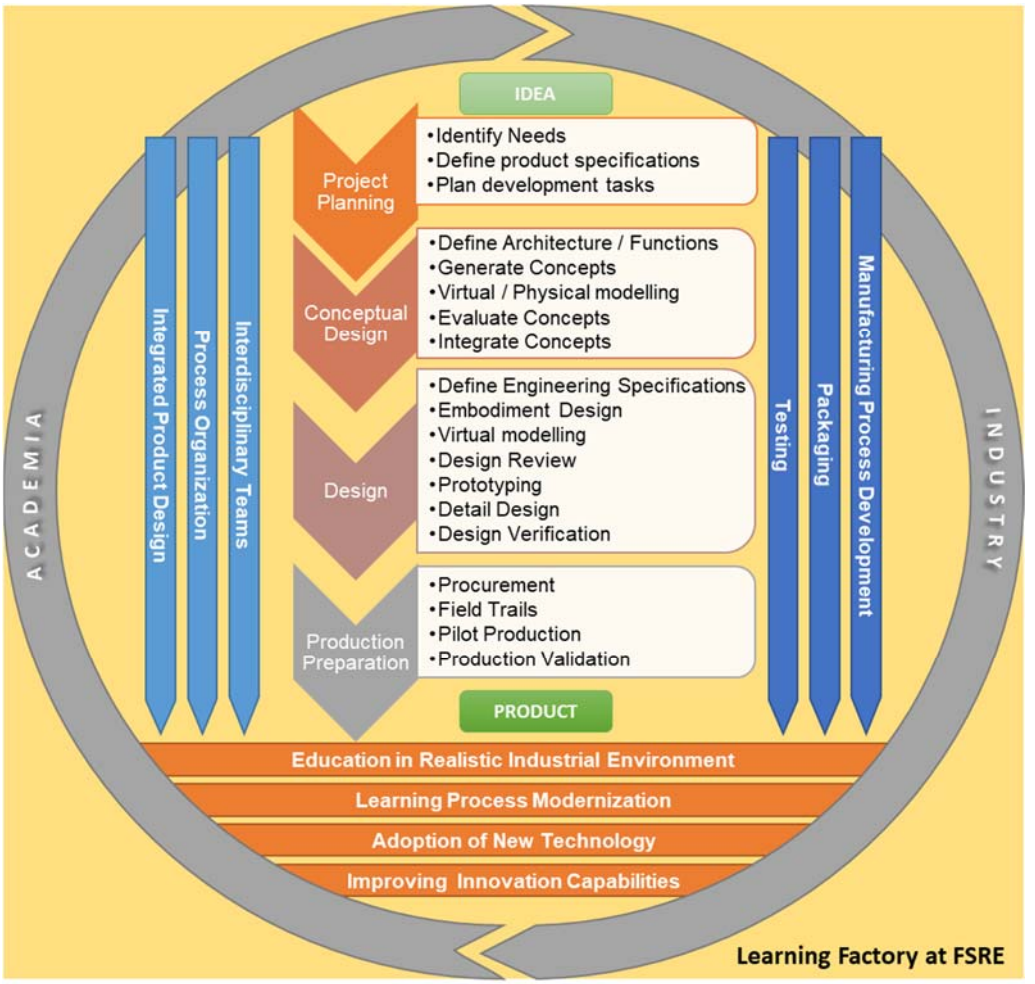


Figure 1. *The new education approach in product design and development through Learning Factory concept*

Working in learning factory environment students are able to focus on industry requirements and possibillities. Students are referred to the technology to be applied in specific processes and platforms that allow learning under market conditions of production. This is very important since it is known that the industry permanently monitors the latest technology and the latest information based on "know-how" philosophy. Students through education and practical work in learning factory are able

to improve their professional, social, methodical and personal competences and also skills for cooperation and comunication in interdisciplinary groups such as:

- Problem solving abilities,
- Indepedency,
- Interdisciplinary expertize,
- Knowledge of production/testing/packiging proceses,
- Knowlge on crucial technologies,
- Project management,
- Communication skills.

From all of the above, it can be concluded that the proposed approach to academic learning in PDD ensures a correct understanding of engineering as much as computer technology at the same time. A modern engineer uses information and communication technology to better manage the design process and other processes including production and support processes.

2.2 Lifting table design

The idea for the lifting table design has come from the local industry needs for a lifting platform that should lift a man and/or load at a certain height. From the analysis, the requirements for design are defined:

- Table dimensions are 600x300mm,
- Maximum lifting height is 550mm,
- Minimum height is 200mm,
- Maximum lifting weight is 300kg,
- Total weight of the structure is up to 30kg,
- Easy to handle,
- Easy assembly of parts,
- Maximum Costs 300KM,
- Easy dismantling,
- Adopt to available manufacturing technology at the learning factory,
- Adaptable to different conditions of exploitation.

In the first design phase it is also very important for students to know the essential steps of the product planning process. This will help them to understand the origin of the requirements and if necessary to add to the list. Product planning and clarifying the task are consciously combined into one main phase. This is to emphasise the importance of integrating both activities.

After defining the product specifications, the conceptual design phase is methodically carried out. Different design concepts are developed, modeling is performed, the concepts are evaluated and the optimal design concept is selected for further development. Based on the requirements the manually driven lifting table is selected. In a design phase detailed embodiment design was done, focusing on the use of CAD tools (Figure 2). Detailed design and verification were carried out, followed by the purchase of required parts, production and assembly in order to make a prototype of the lifting table. Figure 3 presents parts and subassemblies of the lifting and final lifting table prototype is presented in Figure 4.

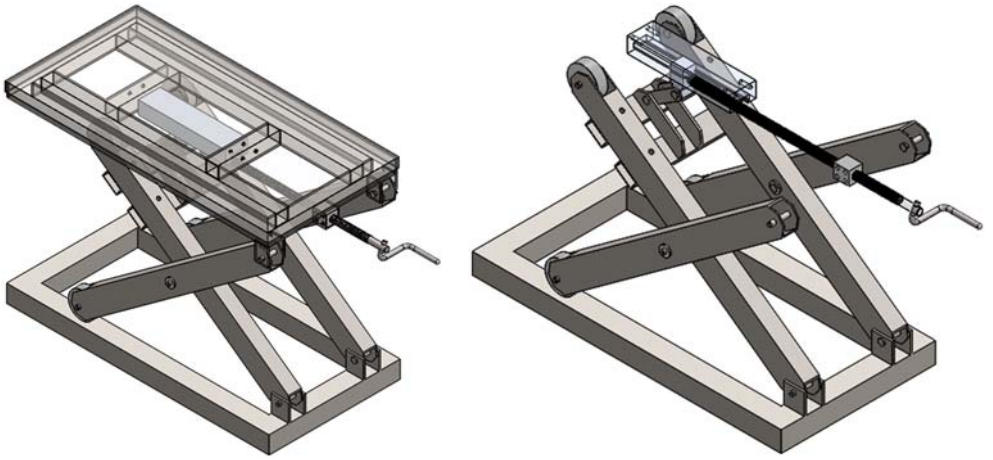


Figure 2. *Selected conceptual design*



Figure 3. *Parts and sub-assembiles of the lifting table*



Figure 4. *Lifting table prototype*

3. CONCLUSION

In this paper, an algorithm of transformation an idea to the final product design for manufacturing technology. It presents a systematic approach to learning and knowledge linking with the trends in various fields of engineering, from design to production and exploitation. The design of the lifting table through the concept of learning factory is intended to strengthen the competencies of students studying the product design and development. At the same time, in parallel with the design transformation, the algorithm model provides the development of student competencies in a real industrial environment. The advantage of introducing the learning factory algorithm is primarily due to the synergy of academic knowledge and the real industry sector. This model of student education can be used to strengthen competencies in other study programs at FSRE such as production engineering and mechatronics, as well as in electrical engineering and computing. In addition to the core engineering competencies, students will be able to strengthen their skills to work in interdisciplinary teams. In the coming years, the learning factory concept will be faced by significant challenges since manufacturing technology, industrial settings, engineering problems etc., are changing rapidly. The learning factory concept has to keep pace with these changes in order to be up to date or even proactively innovative in the years to come.

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ASSESSMENT OF THE SERVICE LIFE TO DESTRUCTION OF THE GEARS PLANETARY GEAR UNITS

Predrag V. Živković[1]

Abstract:Failure to gears of the planetary gear due to fatigue can cause catastrophic damage to the equipment, taking into account that the speeds are important elements in power transmission systems in many modern machines. Therefore, effective procedures for the evaluation and information carrying capacity and the life of the gear needed to those skilled in the several fields of engineering applications, including those involved in the preparation for a disaster monitoring and management in the field of transportation, power generation, and mechanical industry. In engineering practice in order to increase the working speed in the current gear applications, requires better knowledge of the specification of the fatigue behaviour of steel, of the number of cyclic changes for the stress greater than 10^6 or 10^7. In this regard, the DIN standard was introduced useful information to consider capacity and fatigue damage of steel gear in the event of a large number of changes in the cyclic stress. In this presentation, a method and formula for the assessment of the capacity and the service life for a large number of cycles are shown. The procedure takes into account the pitting resistance (the surface damage of the fatigue) with gears and helical gears. The formulas are based on the DIN standard for capacity calculation of cylindrical gears.

Key words: Failure, gears, service life, load capacity

1 INTRODUCTION

Planetary transmissions are specific complex structures. The gear parts are burdened with the high specific load. Such loads in the work leading to damage of tooth flank and/or tooth breakage, as the most important component parts of the planetary gear unit. Planetary gear system has the advantages of lightweight, small size, high transmission ratio, a strong load bearing capacity and high-efficiency transfer of [1-3]. Therefore, they are widely used in various mechanical equipment, and even to run the excavator, working as construction machinery. The current situation and data experience have shown that the reliability of the main gears (such as the sun gear, planet gears and ring gear) has a significant impact on the reliability of the entire transmission system [4]. In the article [5] presented a long-term reliability fatigue damage the method of analysis for the tooth root bending in the wind turbine drivetrains. The planetary gear system, the

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movement state of each gear very complicatedly and their working environment is generally worse [6]. Therefore, the validity of the method for predicting the ease of how to establish a model, and how to input variable for the model should be in the spotlight. A large number of scholars have established the reliability model of the planetary gear system based on dynamic theory, which makes the shape of the model is too complex or difficult to ensure accuracy. Field or accelerated speed test system can effectively get life or reliability of the information, or the planetary gear system, a long time and high costs, it is difficult to understand [7].In order to estimate the lifetime of the planetary gear system easily and efficiently in this work will be displayed in the process, based on the DIN standard and ISO recommendations contained, and the results will be compared with AGMA recommendations in one of the next works. Therefore, life prediction is guaranteed, and its complexity is reduced.

2 THE STRESS-LIFE METHOD

The distinguishing characteristic of materials associated with the loss of resistance under the action of repeated or fluctuating stresses is called fatigue failure. The study of fatigue failure is not an exact and absolute science, of whichprecise results can be obtained. The prediction of fatigue fracture is very often approximate and relative, with many components of the statistical calculation, and there are a great many factors to be considered, even for very simple load cases.

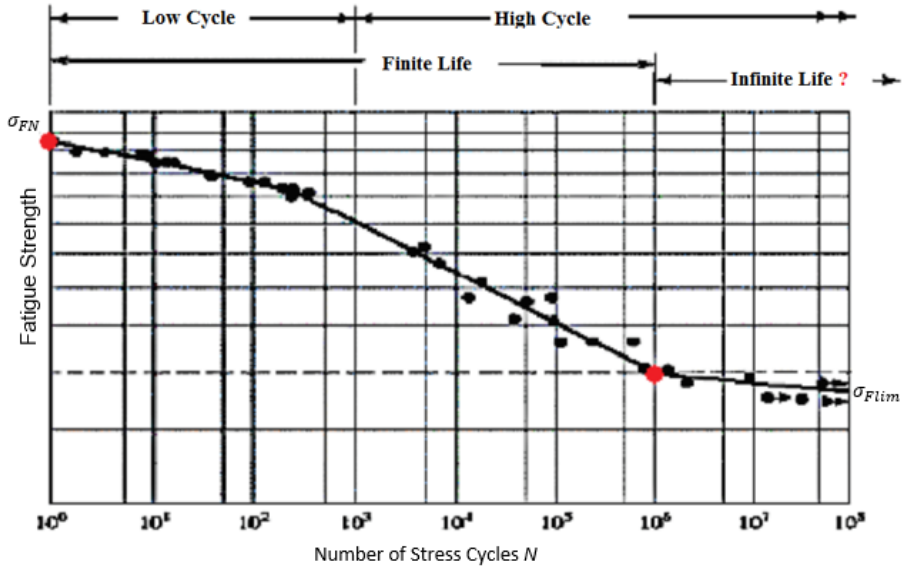


Figure 1. *Diagram of Whöler with the actual appearance of gear steel behaviour. The Graph provides the corresponding fatigue strength for steel reported at a specific number of stress cycles*

In this sense, the determination of the fatigue limit for materials with industrial purposes, in particular, the steeldemands a great variety of test to define the magnitude of fatigue limit reported at a specific number of cycles. In practice, gears are mostly operated under variable loads. Even in a continuous process the load acting on gear teeth is fluctuating due to the tooth contact process and operational conditions under which the gears shall perform.

Under these variable loads a tooth breakage, which most often results in a total gear failure, must be taken into account during the stages of gear design or load capacity calculation. This fact has demanded that new fatigue tests for gear materials be carried out and the fatigue resistance behaviour with a high number of load cycles be analyzed.

As it is known, there are a great many factors to be considered during the study of fatigue phenomena. The methods of fatigue failure analysis are inexact and only approximate results can be obtained. Thus, more-exact methods require that more data be derived from practical testing and statistical calculation. A Whöler's, or strength-life ($\boldsymbol{\sigma_{FN} - N}$) diagram is the most widely used graph to provide the corresponding fatigue strength of a material reported at a specific number of stress cycles (see figure 1).

In the Whöler diagram, it is usual to represent the logarithm of the fatigue strength ($\boldsymbol{log\sigma_{FN}}$) in the function of the logarithm of the number of cycles ($\boldsymbol{logN}$). The fatigue failure analysis based on stress-life method is especially useful for a wide range of gear design applications and represents high-cycle applications adequately. In particular, the steel for gears requires a great variety of tests to define the fatigue strength versus the number of load cycles. In theory, it is often accepted that the line in the case of stress cycles greater than 10^6 or 10^7 cycles behaves with slope zero and failure will not occur, no matter how great the number of cycles. The stress value corresponding with the point of inflextion in the graph is declared fatigue limit or endurance limit.

Figure 1 shows the actual appearance of gear steel behaviour with a small and very significant modification: the graph becomes not totally horizontal after the steel has been stressed for a number of cycles greater than the basic number of cycles for established typical fatigue strength (N = 10^6 …10^7). Moreover, it is possible to distinguish a significant change in the slope of the line near to 10^6 cycles. It is different than the classical infinite life appearance of steel behaviour. Gear performance required the capacity to more stress cycles greater than the default number of cycles for fatigue. In such situations, it is useful to take into account the level of fatigue resistance in case of a large number of stress cycles. The need for greater precision in determining the fatigue limit of steel with applications in high-speed transmission and led to the testing of new studies in the zone of high-stress cycles. DIN and standard AGMA 2105-D04 is a good example of the precision and speed behaviour of steel. Formulas for estimating the permitted strength of volume and superficial fatigue steel with applications on Involute cylindrical gear with external gear teeth are placed on the DIN standard 3991,1,2,3 follows.

$$|\boldsymbol{\sigma_H}| = \frac{\sigma_{Hlim}}{S_H} \quad (1)$$

$|\sigma_H|$Permissible contact stress taking into account fatigue strength, [N/mm^2].

σ_{Hlim}: Fatigue limit taking into account contact stress, [N/mm^2].

$\boldsymbol{S_H}$: Safety factor for pitting.

In particular, the factors of stress cycles to take into account the characteristics of life force gear material. Factor $\boldsymbol{Z_N}$, adjust the fatigue limit stress for the required number of cycles of operation in comparison with the fatigue limit stress determined by testing for the number of basic cycles (N = 10^6- 10^7 cycles). In the case of gears, the number of stress cycles is defined as the number of networks of contacts under a load of gear teeth are analyzed. At this time there is insufficient data to provide correct wrong stress cycles for all types of gears and gear applications. Experience, however, indicates that a new cycle of stress curves for pitting resistance and bending of steel gear as presented in the DIN 3991 Standard. Taking into account current information about the behaviour of fatigue load capacity of steel gears,

The aim of this study is to establish the procedures and formulas for assessing the value of the speed of life expectancy for a large number of cycles. The procedure takes into account the decay resistance (surface fatigue failure) gear with straight teeth, as integral components of the planetary gear train. The equations presented are redefined in accordance with the formulas for the calculation load capacity of the DIN standard and ISO recommendations for Gear Fatigue Life Estimation.

2.1 Determination of Stress Cycle Factors

Rating methods accepted by standards to evaluate the load capacity of external spur and helical involute gear teeth operating on parallel axes are based on the contact stress resistance and bending strength [8, 9, 10, 11]. The formulas evaluate gear tooth capacity as influenced by the major factors which affect progressive pitting of the teeth and gear tooth fracture at the fillet radius. The pitting and fracture of gear teeth are considered to be a fatigue phenomenon depending on stress cycles. Certification of gear load capacity is based on the confrontations of stress calculated by gear-tooth rating formulae with the bending and contact permissible stresses for gear materials.

The actual cylindrical gear-tooth rating formulae for pitting resistance are based on Hertz's results for the calculation of contact pressure between two curved surfaces. They have also been improved with modifications in the new standards to consider load sharing between adjacent teeth, the load increment due to external and internal dynamic loads, uneven distribution of load over the face with due to mesh misalignment caused by inaccuracies in the manufacture, and elastic deformations, etc.

The formula for the calculation of tooth contact stress for pitting resistance, the calculating of tooth root strength takes into account load sharing between adjacent teeth, an increment of nominal load due to nonuniform distribution of load on the tooth face, and some external and internal dynamic load. According to ISO recommendations and DIN 3991 provides the following rating formulas and permissible stresses applicable for calculating the pitting resistance and bending strength of external cylindrical involute gear teeth operating on parallel axes.

$$\sigma_H = Z_H \cdot Z_E \cdot Z_\varepsilon \cdot Z_\beta \cdot Z_B \cdot \sqrt{\frac{F_t}{d_{a_1} b_{a1}} \cdot \frac{u_{a1g1}+1}{u_{a1g1}} \cdot K_A \cdot K_v \cdot K_{H\alpha} \cdot K_{H\beta} \cdot K_\gamma} \le \sigma_{H1,2} = \frac{\sigma_{Hlim1,2} \cdot Z_L \cdot Z_V \cdot Z_R \cdot Z_W \cdot Z_X \cdot Z_{N1,2}}{S_{Hmin}} \quad (2)$$

Where:σ_H - Contact tooth-flank stress, N/mm^2, $Z_E = 189{,}8\frac{\sqrt{\mathrm{N}}}{\mathrm{mm}}$ - Elastic coefficient, F_t- Transmitted tangential load, N, K_A - Overload factor, K_v -Dynamic factor, $K_{H\alpha}$ - Transverses load factor, $K_{H\beta}$ - Face load factor, K_γ - Factor of uneven distribution load between satellites, $Z_{\varepsilon a1} = 0{,}939$ and $Z_{\varepsilon a2} = 0{,}943$ - Contact ratio factor, $Z_H = 2.314$, $Z_\beta = 1$ - Helix angle factor, $Z_B = 1$, $Z_L = 1{,}052$ and $Z_L = 1{,}023$ - Lubricating oil factor, $Z_{Va1} = 0{,}968$ and $Z_{Va1} = 0{,}946$ – Speed factor , $Z_R = 0{,}971$ – Roughens factor, $Z_W = 1$ -Work hardening factor,$Z_X = 1$ – Size factor.

The allowable stress values for both contact and bending stresses must be determined, where the endurance limits are derived from the testing of reference gears under reference test condition. The pitting and bending endurance limits obtained there should be applied when material composition, heat treatment and inspection method are appropriately chosen for the size of the gear. In order to obtain the allowable stress values, these endurance limits have to be divided by the minimum value of the safety factor and multiplied by the correction factors, taking into account the difference between the conditions in which the endurance limit tastings were carried out and the operating

conditions and circumstances of the gear of interest. Those are Z_N factor for contact stresses and $Y_N$factor for bending stresses.
Thus, the contact stress calculated by Equation 3 must be less than or at least equal to the allowable value $\sigma_{H1,2}$, at the flanks of mated gears.

$$\sigma_H \leq \sigma_{H1,2} = \frac{\sigma_{Hlim1,2} \cdot Z_{N1,2}}{S_{Hmin}} \cdot Z_L \cdot Z_V \cdot Z_R \cdot Z_X \cdot Z_W = \frac{\sigma_{HG1,2}}{S_{Hmin}} \quad (3)$$

Where:$\sigma_{Hlim1,2}$. Is the pitting endurance limit of the gear tested which has same material and heat treatment as the gear 1 or 2 or interest, S_{Hmin} is the required minimum value of the safety factor against pitting, Z_N factors are correction factor for the pitting endurance limit and $\sigma_{HG1,2}$ is the pitting endurance limit of the gear of interest.By means of mathematical processing of formulas (3), it is possible to determine the stress cycle factor for pitting resistance an according to equations (4).

$$Z_{N1,2} = \frac{S_H \cdot Z_H \cdot Z_E \cdot Z_\varepsilon \cdot Z_\beta \cdot Z_B \cdot \sqrt{\frac{F_t}{d_{a_1} b_{a1}} \cdot \frac{u_{a1g1}+1}{u_{a1g1}} \cdot K_A \cdot K_v \cdot K_{H\alpha} \cdot K_{H\beta} \cdot K_Y}}{\sigma_{Hlim1,2} \cdot Z_L \cdot Z_V \cdot Z_R \cdot Z_W \cdot Z_X} \quad (4)$$

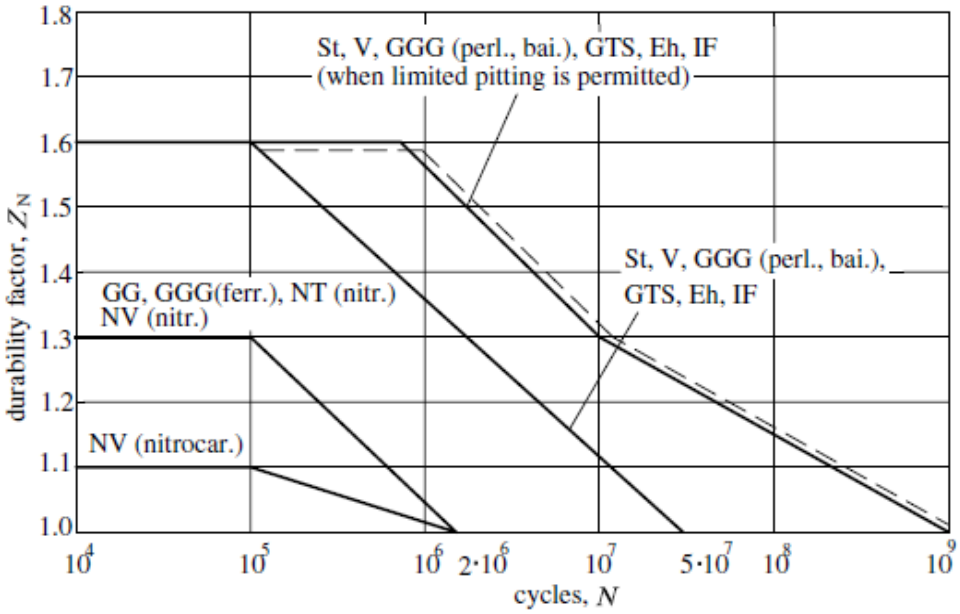


Figure 2. *Pitting resistance stress cycles factor,* Z_N. [8]

2.2 Determination of the Expected Fatigue Lifetime

Determining the expected Fatigue Lifetime Understanding the factors Z_N with a stress fatigue limit equivalent to a certain number of cycles, it is possible to determine the expected useful fatigue shelf life in a state of contact stress in the teeth with the corresponding allowable stress for the failure. Under these conditions, the number of cycles expected pitting (n_{Lh}) can be estimated with a cycle stress factor Z_N determined by a formula (4) and graphical information presented on the DIN 3991 (see Figure 2).When we are sure that the number of load cycles corresponds to the calculated value factors Z_N sate the expected fatigue life (H_{σ_H}) can be known by the equation (4).

$$H_{\sigma_H} = \frac{n_{Lh}}{60 \cdot n \cdot q} \text{ (hours)} \quad (5)$$

Where: n_{Lh} - Number of expected load cycles by pitting and corresponding with stress cycle factors Z_N in figure 3,n - Rotational speed $(\min^{-1})$, q - Number of load application by 1 turn of gear. It can be different for bending stress or contact stress.

2.3 *S*ample Case of the calculation

With the intention of demonstrating the procedure to estimate the useful expected fatigue lifetime of cylindrical gears, the calculation of the expected useful life of the pinion is presented (see table 1). Specifically, the transmission speed corresponds to the phase analysed by the speed reducer is applied to the transfer speed of the gear unit for the movement of excavator BGH600, which are used as mining and construction machines.Kinematic scheme gear unit shown in Figure 3.

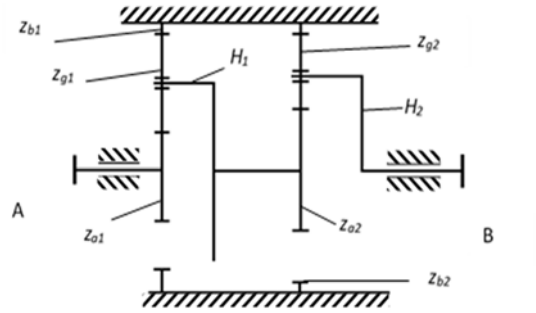


Figure 3. *Kinematic scheme gear unit for moving excavator BGH600*

It should be noted that the calculation of the speed capacity of confronting the resistance was sufficient in the case of the classical theory of fatigue-life. The results that take into account the new fatigue resistance level with a precision of stress cycle factors are more real (see table 1). In general, safety factors must be established from a thorough analysis of the service experience with a particular application. A minimum safety factor is normally established for the designer by specific agreement between the manufacturer and purchaser. When specific service experience is not available, a thorough analytical investigation should be made. It is certain that the magnitude of safety and reliability factors can condition the value of estimating life, for good designs with proven values of safety and reliability are important (see table 1).Calculate the operating stress on the flanks of gear teeth for the first and second planetary set. The computational load was a high value so that the input torque $T_{in} = 538$ Nm. Stresses on the flanks of the first planetary set are: $\sigma_{HGI} = 1421$ N/mm^{2}in the second $\sigma_{HGI} = 2412$ N/mm^2. The load has been taken, with the intention to examine the destruction of parts of the planetary gear to destruction. So, the same value minus took and assessing the service life of gear teeth, with the intention that the obtained values are compared according to ISO recommendations, and the mechanical characteristics of the materials obtained according to DIN standard. Thanks to the formula 4, to calculate the value of the factor Z_N=0.964.From Figure 2, established the dependence between Number of load cycles $n_{Lh}$and factors Z_N. then is

$n_{Lh} = \sqrt[0.056]{\frac{2{,}466}{Z_N}} = \sqrt[0.056]{\frac{2{,}466}{0.964}} = 20.7 \cdot 10^6$cycles, which corresponds lifetime of $L_H = \frac{n_{Lh}}{60 \cdot n \cdot q} = \frac{20.7 \cdot 10^6}{60 \cdot 1108 \cdot 1} = 311$ hours.

Recommendation by the ISO 6336 factor for Haigh number cycles $n_{Lh} > 10^7$.

$Z_N = \frac{\sigma_{HGl}}{\sigma_{Hlim}} = \frac{1421}{1680} = 0.845$, and $n_{Lh} = \sqrt[0.056]{\frac{2,466}{Z_N}} = \sqrt[0.056]{\frac{2,466}{0.845}} = 202.3 \cdot 10^6$

Cycles, which corresponds lifetime of $L_H = \frac{n_{Lh}}{60 \cdot n \cdot q} = \frac{202.3 \cdot 10^6}{60 \cdot 1108 \cdot 1} = 3043$ hours.

What shows that for the lesser load of the planetary gears, the expected lifetime would be much higher. A load of high values is given intentionally to indicate the defects of some parameters for determining the factor Z_N, which according to the DIN standard for $n_{Lh} = 10^9$ has the value $Z_N = 1$ (see Fig. 2). And according to ANSI / AGMA 2105-D04 standard [10], the value is less than 1. These values leave space for discussion and further consideration.

Table 1. *Initial data to estimate the useful expected fatigue lifetime of cylindrical gearsconsidering pitting resistance of the teeth*

Description	Value					
	I plan. set			II plan. Set		
Number of teeth in pinion	z_{a1}	z_{g1}	z_{b1}	z_{a2}	z_{g2}	z_{b2}
	12	30	72	13	26	65
Operating pitch diameter of pinion, mm	$d_{a1} = 42{,}867$			$d_{a2} = 53{,}333$		
Module (m_n), mm	3.5			4		
Face width, mm	40			60		
Pressure angle, α_n	20°			20°		
Helix angle at standard pitch diameter,	0			0		
Transmitted tangential load	$F_{ta1} = 8369$ N			$F_{ta2} = 47075$		
Rotational speed	$n_{a1} = 1108$ min^{-1}			$n_{a1} = 158{,}285$ min^{-1}		
Overload factor	$K_A = 1$					
Dynamic factor, K_v	1,041			1,003		
Face load factor, $K_{H\beta}$	1,445			1,124		
Transverses load factor, $K_{H\alpha}$	1,304			1,1		
Factor of uneven distribution loads between satellites, K_γ	1.05			1.05		
Fatigue limit taking into account contact stress, σ_{Hlim}	1680 N/mm^2			1680 N/mm^2		
Safety factor for pitting, S_{Hmin}	1			1		

3 CONCLUSION

An efficient procedure, formula, and information on the valuation of the expected service life in the case of steel cylindrical gear with a large number of cycles are given. The formulas are based on the DIN Standard for calculation of the load capacity of cylindrical gears. In this paper, the factors of stress cycles to take into account the characteristics of life force gear materials, and to employ the only factor to adjust Z_N fatigue limit stress for the required number of cycles of operation. The procedure is fixed taking into account the decay and gears with straight teeth.Understanding the factors Z_N with a fatigue stress limit equivalent to a certain number of cycles, it is possible to determine the useful service life of fatigue-awaited in the state of contact stress in the teeth with the respective allowable stresses for the failure. Under these circumstances,

the number of cycles expected pitting (N_{Lh}) can be estimated from the duty cycle factor Z_N. The load is selected very high value that will be used to check the service life and the destruction of parts of the planetary gears on the bench.And the results will be published in one of the next works.

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COMPUTATIONAL MODAL ANALYSIS OF PLANETARY GEAR UNITS

Predrag V. Živković[1]

Abstract: To describe the dynamic behaviour, Sun planetary gear, planet carrier, and three Planet gear, models with real boundary conditions were developed. The methodology for determining Eigen frequencies and Eigen modes of oscillation of the basic constituent components of planetary gear trains using the Finite Element Method is shown. Conducted model analysis method results in a large number of modal shapes of Eigen mode oscillation. In real conditions, only some of them are induced. The aim is to determine its own frequency and the main forms of oscillation in order to identify the influences that affect the reliability of parts of the planetary gear, which can be used to develop new forms of constructive and avoiding the appearance of modal oscillation. The work is important because the applied methodology can be used to analyze any planetary gears which working in dynamic conditions, regardless of their design. Subspace algorithm frequency analysis was executed using the CAD software COSMOS - M. The results, at the level of the basic dynamic behavior of parts of planetary gear with real boundary conditions, refer to the Eigen frequencies and Eigen modes of oscillation, which are presented in graphic form.

Keywords: The Eigen forms of oscillation, the carrier of the planet gear, a natural frequency

1 INTRODUCTION

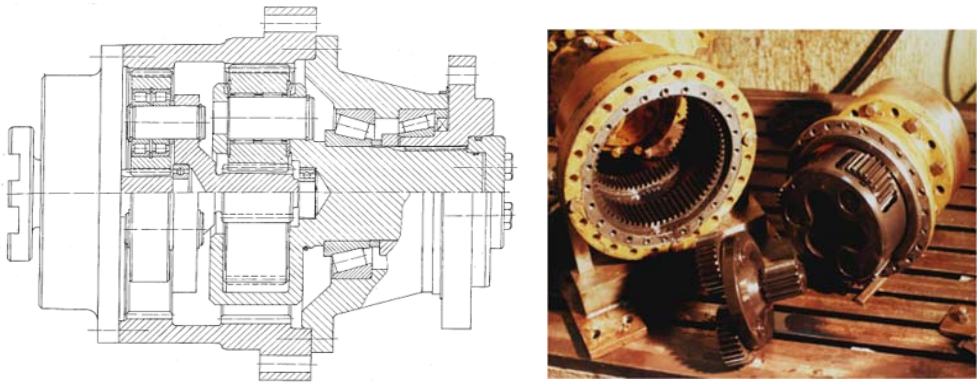
Planetary Gears are excellent mechanisms for the transfer of mechanical energy, thanks to the components of the high degree of efficiency, high capacity and reliability in the work which they are intended for. Developmental research of planetary gears is necessary to improve the efficiency and compactness in order to reduce vibration, noise and prices. Most studies have been devoted to the steady state in which the load and speed are constant. However, in operation, the load and speed are changing, which is frequent in many industrial applications of planetary gears that include non-stationary operating conditions. If we add excessive changes of the applied torque and power, manufacturing or assembly errors, the transfer will be subject to instability at work and high levels of vibration.

The vibrations of mechanical systems are adverse events that occur in the

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planetary transmissions. They are caused by changed conditions of work, and in parts of the planetary gear causing undesirable wear and damage, when the gear teeth flanks cause failure[1], which may be caused by inaccuracies of the gear-cutting process [2,3], and the operating conditions which they are subjected to operation [4].

In the design phase of machines, in addition to modelling and defining forms, the designer explores the optimal technical conditions of work, and among other things, to solve the problem of vibrations, which are the result of working conditions, the occurrence of unexpected load, inaccuracies making and/or improper assembly of parts of planetary gear. The parts which are used in aircraft and motor vehicles, maritime transport, construction and mining machines and other mechanical systems can have undesirable dynamic behaviour and the occurrence of noise and vibration.



(a) *(b)*

Figure 1. *a) Two-stage planetary gear unit which is the subject of research, b) Considered planetary gear disassembled*

Vibration and noise in mechanical systems, even in the planetary gears, occur as side effects, caused by inaccuracies and the occurrence of errors during the processing of parts, defects in the conclusion, the instability of energy transfer from the occurrence of unforeseen forces and moments, and other unforeseen factors and working conditions (stationary or non-stationary). [2-9] The intensity and frequency of excitation depends on the loading level of geometric precision, the material characteristics and operating conditions. Many other authors were interested in the dynamic behavior of planetary gears. In [10], the author presents the experimental studies in order to describe the effects of certain errors that occur Planet gear, the load and stress at the planetary gear train with ($n = 3 - 6$) - Planet gear. In [11], the author presented experimental and theoretical studies to determine the impact of certain key factors in planetary gears to stress and load distribution to parts of the planetary gear train. In [12], the author developed a model for predicting the load distribution on a gear of planetary gear under quasi-static conditions. In [13], the author has examined the impact of several important factors in the level and rate of occurrence of stress. In [14], the author presented the Theoretical and experimental investigation of the modulation sidebands of planetary gear sets.

In this paper, we are interested in an analysis of the dynamic behavior of parts of the two-stage planetary gear (Fig.1,a), and an expanded state in Figure 2,b. Firstly, the finite element model was developed under consideration of parts of planetary gear. Simulation of the dynamic behaviour of parts of the planetary gear being represented by the Finite Element Method, stressing that it is in steady state and without the influence

of damping. Finally, the correlation between the numerical and experimental results will be compared with the already obtained data of the works. [15,16]

2 THE FINITE ELEMENT METHOD

The Finite Element Method - FEM, is a modern numerical method widely applied in calculating, designing and constructing machine components. Contrary to other numerical methods based on mathematical discretization of boundary value equations, the FEM relies on physical discretization of the considered continuum of the parts of finite dimensions and simple shapes called finite elements. The FEM is based on the continuum mechanics postulates. Essential postulates of continuum mechanics are well known and can be found in various resource books. [17,18] This work encompasses a brief account of the FEM basic equation formulation, the description of elements that are used and the procedure of modeling contact conditions.

2.1 The basic theoretical equations

This will set the basic analysis of the dynamic parameters of the real structure of general material and geometric configuration. First will be set up to identify the relation of the dynamic behaviour of the structural system, then the relation to determine Eigen frequencies and Eigen modes of oscillation. Based on theoretical considerations, according to the [17, 18], as the basic model of the static model is a suitable number and type of the finite element and formed of the stiffness matrix, and the inertia of the damping elements and at the level of the whole structure.

Under conditions where the vector of nodal force a function of time, $F(t)$, the dynamic analysis of the finite element is performed on the basis of Eq. (1), which is the result of the equality of the works of the external forces in the virtual displacement, [17,18].

$$[m]_{(k)} \cdot \frac{\partial^2}{\partial t^2} \cdot \{\delta\}_{(k)} + [b]_{(k)} \cdot \frac{\partial}{\partial t} \cdot \{\delta\}_{(k)} + [b]_{(k)} \cdot \{k\}_{(k)} = \left\{F_{(t)}\right\}_{(k)} \quad (1)$$

Where: $[m]_{(k)}$ – element inertia matrix; $[b]_{(k)}$ – matrix damping structural elements; $\{k\}_{(k)}$ – stiffness matrix elements; $\{\delta\}_{(k)}$– element displacement; $\frac{\partial^2}{\partial t^2}, \frac{\partial}{\partial t^2}$ – Partial derivatives; $\left\{F_{(t)}\right\}_{(k)}$– load matrix. The scheme for composing matrices of inertia –$[M]$, stiffness –$[K]$, structural damping –$[B]$, displacement – $\{\delta\}$ and load – $\{F\}$ at the level of the whole structure is known [17, 18]. After the formation of these matrices, one can write down the equation definitely forced oscillations of the support structure, the finite element discretized, $[M] \cdot \frac{\partial^2}{\partial t^2} \cdot \{\delta\} + [B] \cdot \frac{\partial}{\partial t} \cdot \{\delta\} + [K] \cdot \{\delta\} = \{F\}$ (2)

Since in the general case, the basic equation of the problem of determining the parameters of the oscillation of its own system structure [17, 18]

$$[M] \cdot \frac{\partial^2}{\partial t^2} \cdot \{\delta\} + [K] \cdot \{\delta\} = \{0\} \quad (3)$$

And relations for characteristic node displacement are,

$\{\delta_i(t)\} = \{\delta_i^0\} \cdot e^{i\omega t}$, Where: ω – Eigen angular frequency, and t – time, then it may be written, $(-\omega^2 \cdot [M] + [K]) \cdot \{\delta_i^0\} = 0$ (4)

And solutions for Eq. (5) are found from the condition of the determinant value$= 0$,

$$D = det|-\omega^2 \cdot [M] + [K]| = 0 \quad (5)$$

Relations that connect solutions of Eq. (6) are known from the Theory of oscillations.

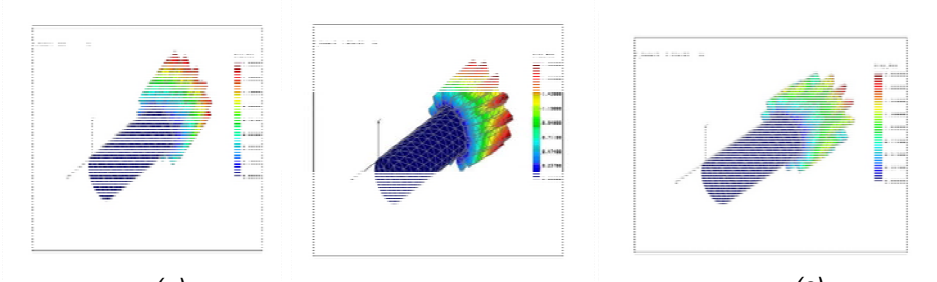
By assigning calculated values to some Eigen frequencies ω_i in Eq. (5), and when the system of homogeneous algebraic equations is normalized, e.g. with displacement δ_1 = 1, the modal matrix [μ] is obtained, that allows a graphic representation of Eigen modes of oscillation, as $[\mu] = \begin{bmatrix} 1 & 1 & \dots & 1 \\ \mu_{21} & \mu_{22} & \dots & \mu_{2n} \\ \mu_{n1} & \mu_{n1} & \dots & \mu_{nn} \end{bmatrix}$ (6)

Every oscillating mode may be written as $\{\mu_i\} = \{1\ \mu_{2i}\ \mu_{3i}\ \dots\ \mu_{ni}\}$ (7)

2.2 Results and discussion

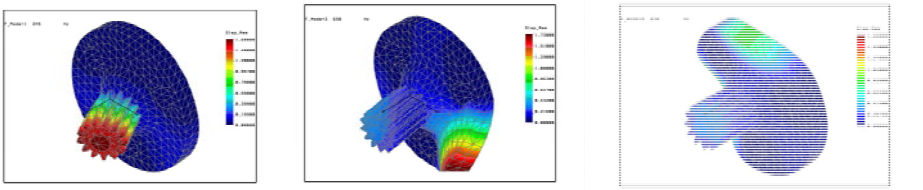
Parts of planetary gear such as carriers of the planet gear, housing, shaft and others. Are continuous systems (elastic body) which oscillate the excitable energy which is also generated by the meshed teeth. Discrete and continuous systems are mutually engaged and the drive is coupled with discrete and continuous systems. Modelling of the discrete system and continuous system using Finite Element Method allows the analysis of dynamic behaviour. Determine the Eigenfrequencies and Eigenmodes of oscillation to determine the sensitivity of the system to excitation. In addition, the application of this procedure shall be determined and additional dynamic load, i.e., Internal dynamic forces of the meshed gear teeth and in its entirety. The subject of this paper is not a study of internal dynamic forces and still does not go into this matter.

The paper considered the gears and the carriers of planet gears (elasticity modulus $E = 2.1 \cdot 10^5$ N/mm^2, Poisson's ratio - $\nu = 0.3$ and density - $\rho = 7850$ kg/m^3), as component parts of the planetary gear to move the excavator (where the gears module is $m_n = 3.5$ mm, $m_n = 4$ mm, gear width $b_1 = 40$ mm, $b_2 = 60$ mm, number of teeth of Sun gear are $z_{a1} = 12,\ z_{a1} = 13$ teeth number of Planet gears are$z_{g1} = 30,\ z_{g1} = 26$ and teeth number of ring is$z_{b1} = 72, z_{b1} = 65$). Planetary gear (Fig. 1, a and 1, b) used to start the excavator BGH600. To assess the dynamic behaviour of parts of the planetary gear, it is necessary to know the natural frequencies and modes of oscillation. This was a modal analysis using finite element method. A large number of modal forms of natural oscillation was obtained. In real conditions only, some of them are induced. Determination of Eigen frequencies and Eigen modes of oscillation are determined by using a computer package *COSMOS - M*, which offers the possibility of determining the frequency analysis by subspace algorithm. The application of the Finite Element Method allows the analysis of dynamic behaviour.



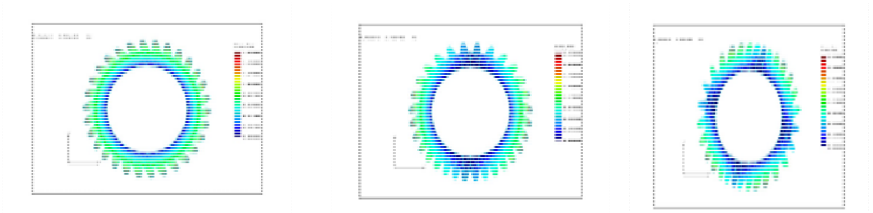
(a) *(b)* *(c)*

Figure 2. *Modes of oscillation the Sun gear in the first planetary stage, F_Mode_1= 668H_z, b) F_Mode_3=1032H_z, c) F_Mode_5=2238 H_z*



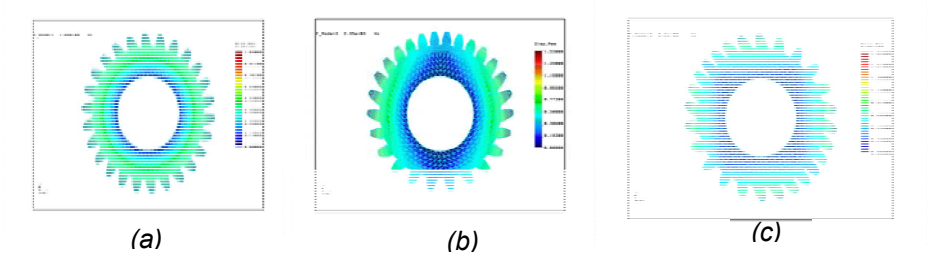
(a) (b) (c)

Figure 3. *Modes of oscillation the carrier planet gear in the first planetary stage a) F_Mode_1= 345H_z, b) F_Mode_3=657H_z, c) F_Mode_5=676 H_z*



(a) (b) (c)

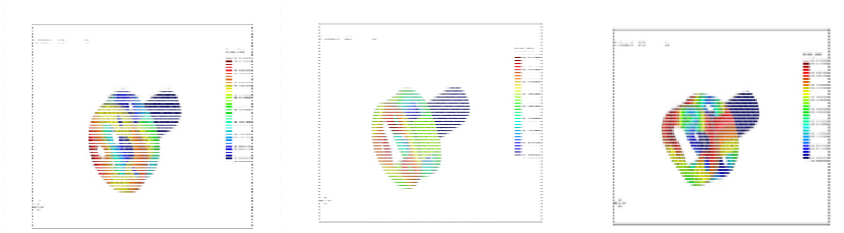
Figure 4. *Modes of oscillation Planet gear in the first planetary stage, a) F_Mode_1= 3519H_z, b) F_Mode_3=3720H_z, c) F_Mode_5=4220 H_z*



(a) (b) (c)

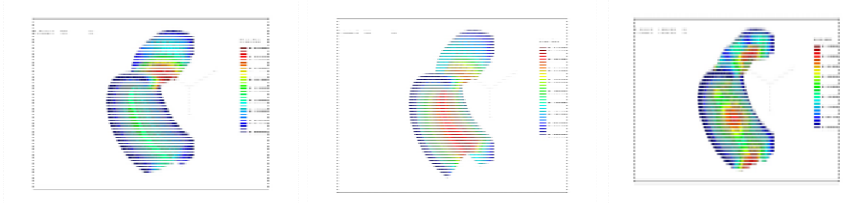
Figure 5. *Modes of oscillation Planet gear in the second planetary stage, a) F_Mode_1=1924H_z, b) F_Mode_3=2349H_z, c) F_Mode_5=3204 H_z*

Certain have their natural frequency and main vibration mode shapes to determine the sensitivity of the system to excite. In addition, the application of this approach can be determined and additional dynamic load, i.e., internal dynamic forces of the meshed gear teeth and in its entirety. The subject of this paper is not a study of internal dynamic forces and still does not go into this matter. Figures 3-7 shows some results of the modal analysis of planetary gear that is the subject or the object of our examination, which is shown in figure 1a, and 1, b. The forms of oscillation, i.e., displacement in its origin modes of oscillation are shown in Figures 2-7. For these frequencies in Figure 2-7 shows the displacement distribution and the Eigen modes of oscillation for, 1, 3 and 5 modes of oscillation.



(a) (b) (c)

Figure 6. *Modes of oscillation carrier Planet gear in the second planetary stage, a) F_Mode_1= 118H_z, b) F_Mode_3=207H_z, c) F_Mode_5=278 H_z*



(a) (b) (c)

Figure 7. *Modes of oscillation of the Ring gear, a) F_Mode_1= 723H_z, b) F_Mode_3=729H_z, c) F_Mode_5=1054 H_z*

The lowest natural frequency of the considered gear is: the central drive - Sun gear is 668 H_z (Figure 2), for the first planetary gear set of planet gear is 3519 H_z (Fig. 4), of the second 1924 H_z (Fig.5), for the carrier of the Planet gear 345 H_z for the first planetary gear set (Fig. 3), of the second 118 H_z (Fig.6), with a Ring gear is 723 H_z (Fig.7). The said Eigen frequency of the input central gear-Sun gear of planetary transmission frequency is close to design parameters (the operating speed 1100min^{-1}) or its higher harmonics ($f_{za1} = 664.8\ H_z$). For this reason, the analysis of interactions of the driving force in the meshed gear teeth on the occurrence of vibration is significant. Moreover, this design of planetary gear provides a compact solution in which the coupling teeth represent the critical point. This is one reason why the need to focus on the strength of tooth flank, in the design stage and the calculated with respect to the reliability and the generation of vibration and noise. Under load, the gear parts suffer deformations. If it passes the limit of elasticity it would result in immediate termination of operation of the planetary gear.

And those strains which have been in the field of elasticity achieved certain effects on the function and life of speed reducer. Variable elastic deformation along with the stress they make lead to fatigue of gearing parts. Increased elastic deformation, particularly of a carrier of the planet gear and they increase the unevenness of the load distribution in the meshed gear teeth and the Ring gear. Due to the change of load change representing the deflection forced vibration system. Under the influence of variable forces, natural vibrations are induced. The gear unit is shown in Figure 1, which was subject to an analysis, should be directed to a process of determination of the fracture of teeth flanks so that unfavorable situations would not appear in this respect. The deformations are relatively small, i.e., Construction is sufficiently rigid and vibration levels low. By using the Finite Element Method are determined by the deformation of gear, the carrier of the planet gear support for both planetary sets, and housing - internal gearing (Ring gear). The results show that the effect of the elastic deformation of the

housing - ring gear, is small. [15, 16] This is another reason that the planetary gear is selected for the dynamic analysis of Eigen frequencies and Eigen modes of oscillation gears and the carrier.

The subject dynamic analysis of the parts of planetary gear trains, according to a benefits application in solving problems of various mechanical structures.

3 CONCLUSION

Simulation of the dynamic behaviour of parts of the planetary gear being represented by FEM, stressing that it is in steady state and without the influence of damping.

Based on the implemented modal analysis a number of conclusions can be made:

1. The applied method is of importance as:
   - A modal analysis solves an equation for which there is no applied load,
   - A modal analysis gives us specific information on the characteristics of the structure instead of reporting a response,
   - A modal analysis tells us at which frequency the structure will absorb all the energy applied to it, and what the shape looks like which corresponds to this frequency, and
   - There is a range of uses for a modal analysis varying from finding mistakes in models up to providing information on how to change a structure in order to move a node.

2) A Dynamic structural analysis is based on the principles of isotropic structure analysis, with real configuration and 3D elements. Obtained results present the realistic behaviour of the considered construction for the given boundary conditions.

3) These analyses are determined to the potential failure of possible places, which directly influence the reliability of parts of the planetary gear, and guidance is provided for avoiding them. What can serve in the creation of new products.

4) The applied methodology can be used to analyse any structures operating in dynamic load conditions.

5) The analysis may be useful in the design of new solutions in terms of reliability or reconstruction carried out in terms of improving the dynamic behaviour in the process of exploitation.

6) FEM (Finite Element Method) compared to the expensive laboratory methods has greater justification application in solving this type of problem.

For another time Topic. Finding out exactly how the structure will respond requires some other type of analysis.

ACKNOWLEDGMENT

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IMPROVEMENT OF THE SYSTEM OF SAFETY OF TECHNOLOGICAL MACHINES WORKING ON THE POLYGONS OF THE DISPOSAL OF MUNICIPAL WASTE

Pugin Konstantin Georgievich [1]

Abstract:The landfills of municipal waste disposal are places of increased danger. Technological machines that ensure the movement and compaction of waste must have an additional system that will ensure the safety of their operation. In the article the question of modernization of the existing system of safety of technological machines used on solid municipal waste landfills is considered. Based on the analysis of hazards arising from work on compactors at landfills, a safety system scheme is proposed that includes a thermal imager, an inclination sensor, an approach detection system for reverse motion and a ground penetrating radar. The proposed safety system of the compactor allows you to respond in a timely manner to the emergence of hazardous factors, which will significantly reduce the number of accidents when it is used in solid municipal waste landfills.

Key words: compactor, sensor, system, safety, exploitation.

1. INTRODUCTION

Ensuring occupational safety is one of the most important tasks for the solution of which great attention is paid by enterprises engaged in the production operation of special equipment. This problem is most acute wherever heavy equipment is used in difficult production conditions. For example, the construction, maintenance and repair of roads, the construction of unique construction, land reclamation and hydrotechnical facilities, on the landfills of industrial and municipal waste. The most part of ensuring safe operation is reduced to compliance with the set of operating rules, in which all the dangerous factors that arise during operation are not always stated [1 -5].

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2. ANALYSIS OF SAFETY EQUIPMENT FOR SOLID MUNICIPAL WASTE

The safety of construction equipment is often decided by the use of sensors that enable us to assess in advance the changes in the conditions of the production process. These systems are able to identify the signs of a particular hazard and to give a signal, for example, to the controls of the machine, thereby preventing human casualties or damage. Often, developments are also being made for machine designs created earlier. For example, the possibility of using a load limiter in road construction machines is considered. The prospects of introduction of the security and control system with the help of liquid crystal graphic displays intended for instant information output from security sensors have been revealed. Optimal zones for securing safety sensors for this technique are provided. A lightweight way of laying asphalt is also provided by installing sensors of various types on road construction equipment. These sensors control the density of asphalt pavement, its temperature, detection of obstacles in the way of movement. There is also a thermal imager for constructing an optimal trajectory for laying a road.

But one of the types of equipment was left without the introduction of any modernization in terms of security systems - these are compactors for stacking and compacting solid municipal waste, operated at landfills. This type of equipment is subject to several hazardous effects:

- mechanical impact - getting into the dips, hitting a large-sized garbage or a person, tipping the machine;
- thermal - impact on the sites of the landfill site, covered with open fire or falling into an array of waste, susceptible to decay;
- chemical - the presence in the waste of hazardous reagents, adversely affecting the metal, paint and varnish coatings, rubber products of the machine.

The analysis of the action of dangerous factors allowed to determine a set of hardware that allows to minimize the negative impact on the compactor and the person. To prevent accidents when working on a compactor, it is proposed to install additional equipment that includes: a thermal imager; tilt sensor; proximity sensor; geological radar. One of the options for placing additional sensors on the compactor that increase safety is shown in Fig. 1.

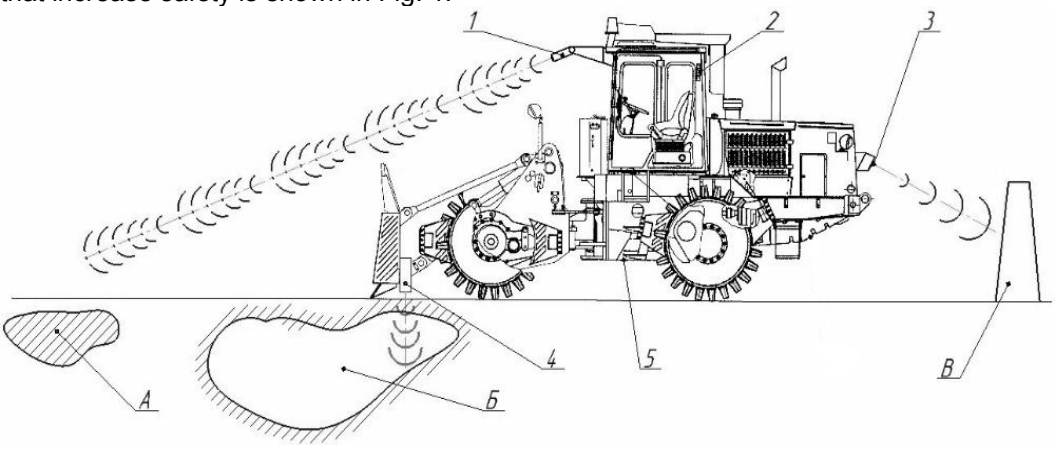


Figure 1. *Compactor with additional equipment.1 - thermal imager, 2 - tilt sensor, 3 - proximity sensor, 4 - georadar, 5 - protection of the lower part of the machine, A - glowing area of the test site, B - dip, B - obstacle (person, large object).*

To select the instruments installed on the compactor, it is necessary to determine a number of criteria that ensure the formation of a safe operation of the compactor: the range of the thermal imager; Range of operation of parktronics; the maximum angle of inclination of the compactor; the depth of the georadar.

Let's consider each of the parameters in more detail. The required range of the thermal imager can be determined based on the distance necessary for the stop of the compactor producing the working operations at a given speed. To determine the characteristics of the device for determining such places, it is necessary to determine the minimum safe distance that will be traversed by the machine before the driver-mechanic stops it.

To do this, you need to determine the horizontal distance from the axis of attachment of the device to the area of the source of ignition. Using the technique of determining the distance of visibility for cars, it was determined by calculation that to stop the machine it is necessary to determine the fire area for 14.5 m.

Similarly, the distance for the effective operation of proximity sensors is determined. It is equal to 1.65 meters.

Often happens that the technique loses stability, moving along the transverse slopes of the terrain. This depends on many factors, the end result of which is the ultimate transverse stability angle. The slope angle is calculated for each machine individually, so it is necessary to take this into account. For example, for some compactor models, the limiting transverse angle is 25 °. Hence, the system should begin to notify the driver of the approach to the critical angle when the sensor detects an inclination angle of 20^{o}.

Installation of GPR on this type of machine is difficult due to the need for vertical direction of the device. There are two possible ways to install the instrument on a compactor:

- on the back of the blade;
- on a specialized hinge in front of the machine.

Installing it on the back of the blade makes the device ineffective because the machine is already in the danger zone at the time of detection, and installation on a special hinge is not possible because it overlaps the driver's view and will be damaged when the compactor is working directly repulsion of waste. Therefore, it is proposed to use this device in conjunction with multicopters. That is, before the work begins, "aerial reconnaissance" is performed - the operator flies the entire territory of the test site with the help of a drone, to which the ground-penetrating radar is fixed. Certain places of possible dips are marked on the map, then loaded into the PC in the cab of the compactor. This increases the safety when working with the machine, as well as the problem with its attachment to the machine.

Thus, we have a number of key parameters that the proposed sensors for the safety system must provide. The range of the thermal imager is not less than 15 meters. The range of the obstacle detection system is not less than 1.65 meters. Limit angles of the tilt sensor from 0 to 45 degrees. The action of the georadar is up to 4 meters.

However, in addition to the main parameters, it is necessary to introduce a number of additional criteria for the choice of instruments:

- protection from vibration, shock and chemical influences;
- providing easy access for maintenance and repair;
- Long service life;
- Possibility of power connection with the electric circuit of the machine;
- good operating temperature range;
- light weight and small overall dimensions;

- the way the device is powered.

Based on the above limitations and criteria, we select devices.

To determine the centers of internal decay of domestic waste, we suggest using the PathFindIR system. This system is a thermal imaging camera for mounting it directly into a vehicle. This device was selected for the following properties:

- operating temperature range (from -40 to +80 ° C), which allows to operate in difficult climatic conditions;
- there is protection against chemical, vibration and shock effects;
- small overall dimensions do not interfere with the survey;
- There is a heating of the protective lens that allows the device to work even in severe frosts;
- Long service life (10 years) and low weight (360 grams);
- The voltage of the network is from 6 to 16 V, the power consumption is less than 2 W (with the heater turned on - 8 W).

To prevent the machine from colliding with large-sized waste or a person, an installation is proposed for the compactors of the parking system SPARK-8-M.

The choice of this system is based on the following properties:

- a large range of operating temperatures (from -30 ° C to + 70 ° C), which allows them to operate in difficult natural conditions;
- sufficient range (up to 2.5 meters);
- system response time - 0.25 sec;
- mains voltage - 12 V, power consumption -2 W;

To determine the slope value, it is recommended to use the DN-P02M angle sensor.

This device has small overall dimensions (37.5x18x30mm), a magnetic stand for mounting on metal surfaces, which allows it to be installed anywhere in the cabin of the compactor so that it will not be any to interfere with the operator of the machine in operation. The device has the following characteristics:

- Operating temperature range from -40 C to +80 C
- Device power - battery independent, battery life - 7 years
- Angle detection range up to 180 degrees
- Data can be written to its nonvolatile memory or the same is output to compatible devices.

All information received from the systems of parameter determination (parktronics, thermal imager, tilt sensor) is fed to the electronic unit via the bus, where it is processed, if necessary, the interface convenient for visual perception is stored and converted. The same block is loaded with a map of the landfill with the centers of ignition and decay noted after "air reconnaissance". All the information received is displayed on the monitor located in the cab of the car. All parameters are monitored by the unit and the parameter is approached to the critical one. An appropriate warning is displayed on the screen accompanied by an audible signal.

Based on the analysis of the hazards that arise when working on compactors on landfills, a safety system scheme including a thermal imager, an inclination sensor, approach to the obstacle when driving in reverse and georadar. This system allows you to monitor in real time the state of the environment around the machine and its to warn about approaching the site of fire, smoldering or failure, the risk of collision with large-sized debris or human, thereby reducing the chances of damage to the machine or injury to people.

3. CONCLUSION

The proposed safety system of the compactor allows you to respond in a timely manner to the emergence of hazardous factors, which will significantly reduce the number of accidents its operation on the TKO landfills.

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DISCRETE METHOD OF DOSING FREE-FLOWING CONCENTRATED FEED WITH SPIRAL-SCREWED FEEDER

Lyalin E. A.[1], Trutnev M. A.[2]

Abstract: A fundamentally new scheme for dispensing free-flowing concentrated feed with spiral-screwed feeder is described in the paper. The volume of a specified feed portion is achieved due to a certain number of revolutions of the spiral. A schematic and general view of the spiral-screw feeder for implementing the proposed dosing system is presented as well as the optimal design and technological parameters of the feeder. As the result, dosing inaccuracy amounted 1-3.5 % for compound feed and 1.2-5.5 % for granulated feed with 5 mm of granule diameter. The optimum parameters for qualitative work of spiral-screwed feeder are defined as following: helix diameter – 49 mm, helix pitch distance 1d and 5 mm gap. With these parameters, the relative inaccuracy of dosing does not exceed 1.7%, two times lower compared to dosing at the continuous operation mode of spiral-screwed feeder.

Key words: Discrete mode, Dosing accuracy, Spiral-screwed feeder, Free-flowing concentrated feed

1 INTRODUCTION

Free-flowing granulated materials feed as a continuous flow or as a slug is an important part of technological process operations in agriculture and other industrial branches. A sustainable feed supply (dosing) with modulation capacity designates the choice of technical device that enables to implement a related stage of technological process. Dispensing feed units as a spiral-screwed feeder (the SSF) are applied for a regular and uniform feed supply of machinery [1, 2].

An indicated kind of feeder falls into a category of volume-type dispensing devices. The volume of output dose depends on the following parameters and factors of the feeder: helix diameter, pitch distance, and section; gap between helix and shroud; helix rotation frequency and feeder operating time; filling ratio of interturn space and friction ratio of dosing material to helix and shroud.

The majority of indicated parameters are designed and remain unchanged during the exploitation, therefore, they do not influence on dosage accuracy. However,

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helix rotation frequency is a relative factor that can change over time, for example, with a voltage fluctuation in the supply mains or increase in helix load under change in physical and mechanical properties of dosing material that leads to an error of output dose.

2 DESCRETE METHOD OF DOSING WITH SPIRAL-SCREWED FEEDER

In order to exclude the mentioned factor, V.V. Platonov offered the method of dosing with screwed feeder relied on the number of screw revolutions, not on its operation time [3]. We suggest to dispense free-flowing material with spiral-screwed feeder according to the number of helix complete revolutions, when helix consistently stops in a strictly particular position in the end of dose output.

2.1 Control Circuit for Spiral-Screwed Feeder

The following SSF control circuit is defined to implement the method (Fig. 1) [4].

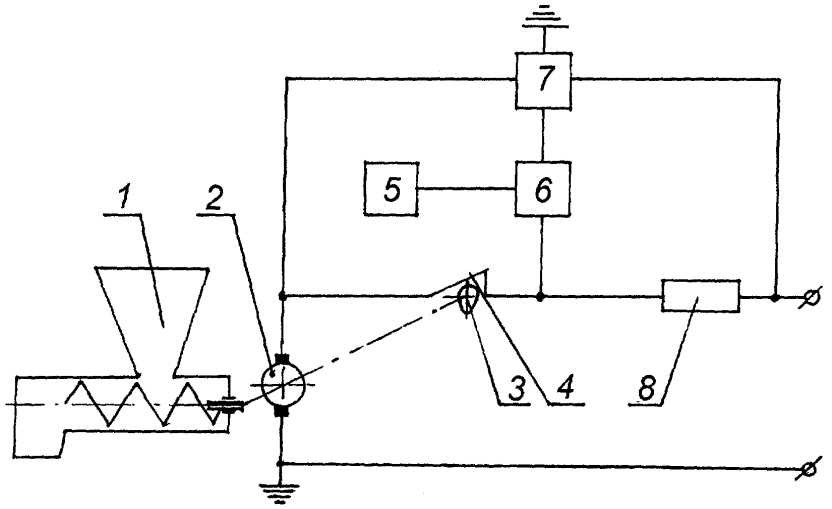


Figure 1. *Control circuit for spiral-screwed feeder; 1 – spiral-screwed feeder, 2 – drive, 3 – eccentric, 4 – normally closed contacts, 5 – control unit, 6 – revolution counter, 7 – relay, 8 – additional resistance*

The installation consists of spiral-screwed feeder 1, on a drive shaft 2, the eccentric 3 with normally closed contacts 4, control unit 5, revolution (dose) counter 6, relay 7, and additional resistance 8.

2.2 Operation Description of Spiral-Screwed Feeder

Spiral-screwed feeder works as follows. The number of material doses dedicated for distribution (i.e. the number of revolutions of feeder drive shaft) is set on the control unit 5, then feeder 1 is turned on by means of relay 7. When the drive shaft 2 runs, eccentric 3 periodically opens the contacts 4 and dose counter 6 rates the number of fodder portions given out. After the set portions were dispensed, counter 6 resets to zero and turns off relay 7 of electric drive power 2. Since the contacts 4 are closed and additional resistance 8 is connected, the drive continues to run at a reduced angular velocity, and stops only when the contacts 4 are opened, in a strictly

particular position providing a stringency of material dose formation. Therefore, an accuracy and stability of dosing process increases regardless of change in helix rotation frequency. After that, the new number of revolutions is set on the control unit and cycle repeats [4].

3 PRACTICAL METHODS

The scientists of the Department of Agricultural Machinery and Equipment of the Perm State Agro-Technological University developed and produced a laboratory installation (Fig. 2) in order to implement the given method of dosing. Gear motor of KAMAZ windshield viper is used as a drive. An implemented automobile control circuit allows a helix shaft to stop always in one (initial) position regardless of the complete revolution number. The helix is oriented in a such way that the last whorl is located in a lower position and on the end of cylindrical body, that provides a stringency of fodder dose formation [5].

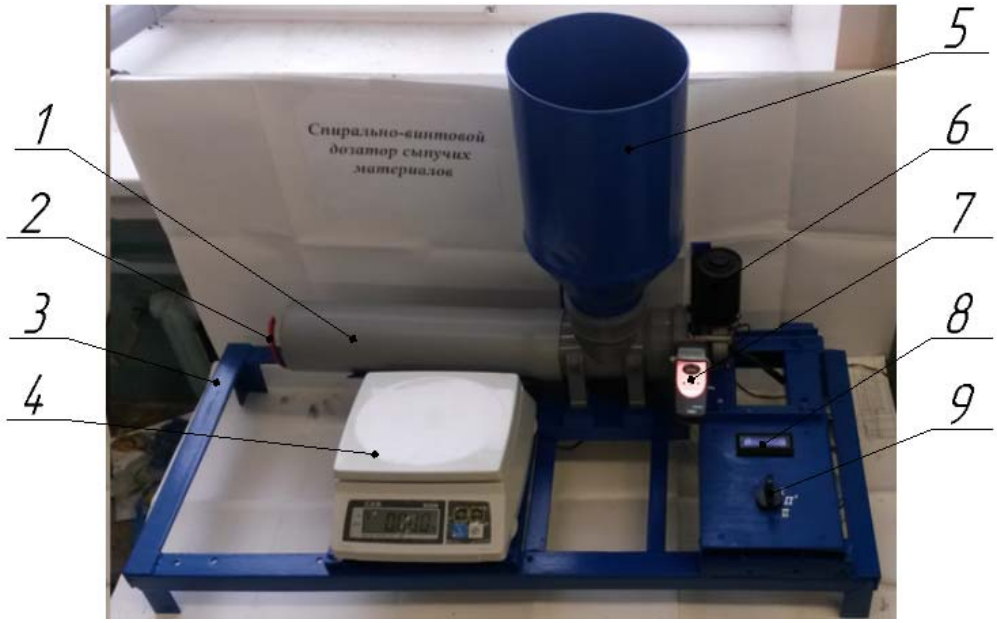


Figure 2. *General view of experimental laboratory installation; 1 – cylindrical body, 2 – helix, 3 – frame, 4 – scales CAS SW-05, 5 – hopper with a charging neck, 6 – gear motor 16.3730, 7 – tachometer SM8238, 8 – measuring system MYLB-G.T.Power RC 130A, 9 – switch*

4 RESEARCH RESULTS

A dependence diagram of spiral-screwed feeder supply Q (kg/min) vs. rotation frequency n (rpm) of helix drive shaft (Fig. 3) is made on the basis of research data.

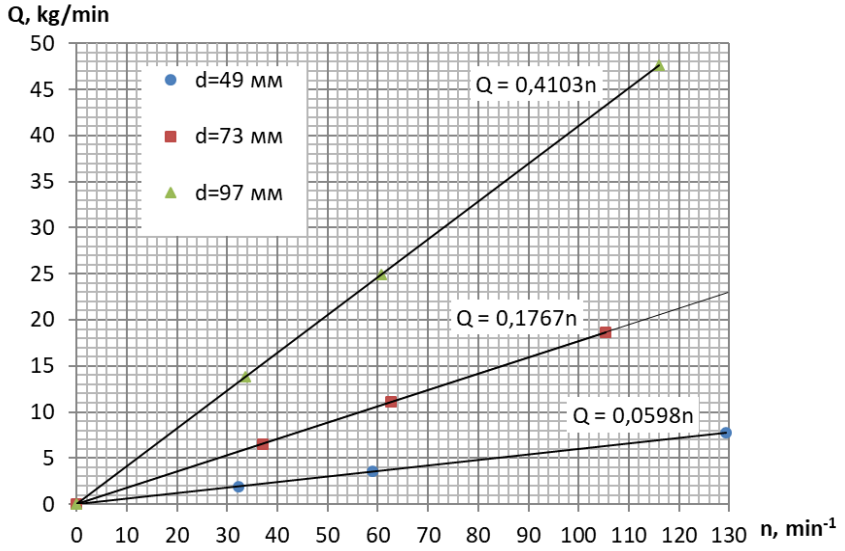


Figure 3. *Dependence diagram of spiral-screwed feeder supply vs. rotation frequency of helix drive shaft*

Experiments on dosing output of free-flowing and granulated mixed fodders with different designed parameters were carried out to study an error of SSF dosing under continuous (at the duration of output) and discrete (at the number of helix revolutions) operating modes. Free-flowing mixed fodder had average weighted diameter of particles equal to 1.09 mm and 336 kg/m^3 of bulk mass, granulated mixed fodder – 5 mm of particle diameter and 658 kg/m^3 of bulk mass. Helix diameter was equal to 49, 73, and 97 mm, helix pitch – 0.75, 1, and 1.25 of helix diameter, gap between helix and shroud ranged from 2.5 to 7.5 mm.

On the basis of research data, equations of regression for feed, supplied power, dosing relative error of free-flowing and granulated mixed fodders are received [6]. It is established that the least error is achieved when the gap is equal to 5 mm.

Response surfaces with different diameters and pitches of helix (Fig. 4) are presented for the visual comparison of dosing quality of granulated and free-flowing material under discrete and continuous operating modes of the SFF.

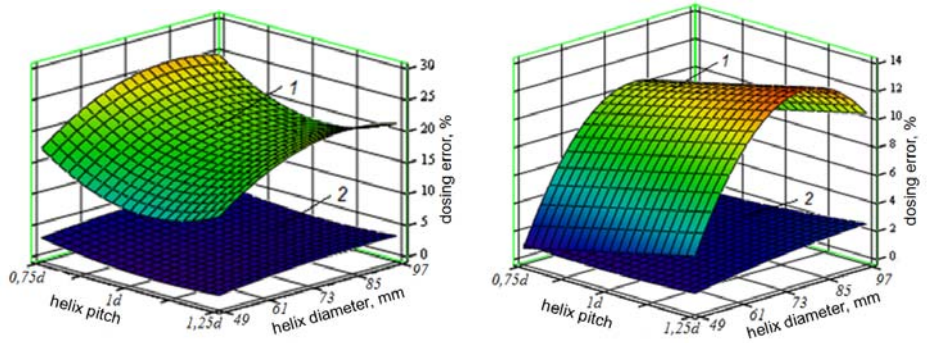


Figure 4. *Relative error of dosing with the SSF when the gap is 5 mm;a – dosing of granulated mixed fodder, b – dosing of free-flowing mixed fodder; 1 – continuous operating mode of the SSF, 2 – discrete operating mode of the SSF*

Figure 4 shows that dosing error under discrete and continuous operating modes of the SFF is 2 – 5 times higher than the value of dosing error under discrete mode of the SFF, when dosing is carried out according to the number of complete revolutions of working body (helix).

The optimal designed parameters under discrete operating mode of the SFF are following: helix diameter – 49 mm, helix pitch – 1d = 49 mm, and gap - 5 mm. With the indicated parameters, a specific feed is 30 g/rev for free-flowing and 60 g/rev for granulated mixed fodder, but a total relative error did not exceed 2%, when the dosing is carried out with the helix equal to specific feed.

5 CONCLUSION

The method of discrete dosing with spiral-screwed feeder is the most effective that increases the accuracy of dry material dosing. The reviewed device and method of dosing with spiral-screwed feeder provides a stringency of material dose formation, increases accuracy and stability of its measuring and can be applied in different industrial branches.

NOMENCLATURE

Q – spiral-screwed feeder supply, kg/min
n – rotation frequency, rpm
d – diameter, mm

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SINGLE-STAGE CYCLOID REDUCER DYNAMIC ANALYSES USING PLM SOFTWARE

Ivan Pantić[1], Miloš Matejić[2], Mirko Blagojević[3]

Abstract: The new possibilities of modern PLM software contribute to a higher quality and more productive development of new products. Thanks to these software, engineers can respond to very complex market demands in an appropriate timeframe. Especially interesting are the modules for creating much various simulations and dynamic analyzes of the most complex machine assemblies in conditions that are very close to the real conditions of exploitation. In this paper, using the Autodesk Inventor and SolidWorks software, a dynamic analysis of single-stage cycloid reducer was performed. The forces calculation that occurs on the elements of this reducer is conducted. Also, these values are compared with the analytically obtained results. The results obtained largely correspond to the analytical calculated values so that the application of PLM software for different types of calculations and analysis in the product development phase is welcome.

Key words: dynamic analyses, simulation, cycloid reducer, normal force, output force

1 INTRODUCTION

The cycloid reducer is a very complex mechanical gearbox. Designing a cycloid reducer is, in every aspect, an extremely demanding process. The loads calculation process is particularly complex. The analytical model for the force calculation on the elements of the cycloid reducer was first defined by *Kudrijavcev*, [1]. The model was further developed by other researchers [2,3]. Today's modern PLM software (*Autodesk Inventor, Solidworks, Catia*, ...) provides dynamic analysis of the most complex machine systems. The kinematic analysis of the cycloid reducer using the PLM software was presented in [4], while the analysis of the stress-deformation state of the elements of the cycloid reducer as well as the modal analysis was described in the papers [5,6,7,8,9]. On the loads distribution in the cycloid reducer, the stiffness of certain elements, the friction, and the clearance size are also greatly influenced by [10,11,12,13,14,15].

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In this paper, the *Autodesk Inventor* and *SolidWorks* software calculates the normal and output forces of the rotary angle for a single one-stage cycloid reducer. Then the obtained results were compared with the analytically obtained values [16], as well as with each other.

2 SINGLE-STAGE CYCLOID REDUCER

Dynamic analysis was performed for a specific single-stage cycloid reducer as shown in Figure 1.

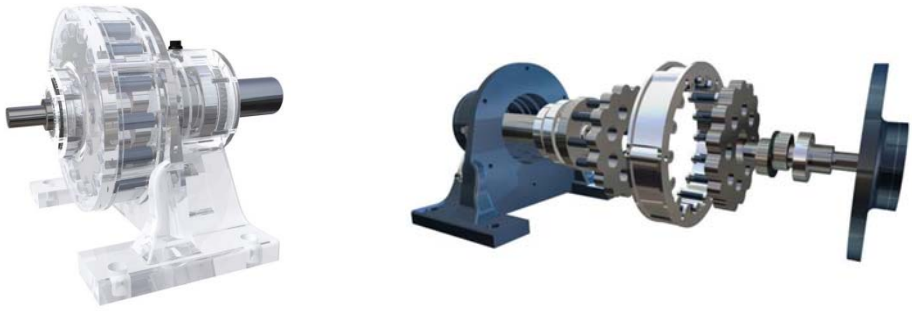


Figure 1. *Single stage cycloid reducer*

The basic parameters of the analyzed cycloid reducer, used in the calculation and generation of the CAD model, are given in Table 1.

Table 1. *Basic parameters of single-stage cycloid reducer*

Parameter	*Value*	*Unit*
Input torque	*51,24*	*Nm*
Output torque	*731,00*	*Nm*
Input rpm	*1450*	*min^{-1}*
Gear transmission ratio	*15*	*/*
Efficiency	*0,95*	*/*
Number of cycloid discs teeth	*15*	*/*
Number of ring gear rollers	*16*	*/*
Eccentricity	*4,5*	*mm*
Ring gear pitch radius	*90*	*mm*
Radius of ring gear rollers	*7,2*	*mm*
Radius of output rollers	*7*	*mm*

In order to simplify the simulation process, the following assumptions have been introduced:

1. The input shaft, the eccentric and the needle bearing are considered as one sub-assembly,
2. A central gear together with the axles, as well as the output shaft with the output axles are considered as one sub-assembly,
3. Only the theoretical case of meshing is analyzed, when all the cycloid gear tooth are meshing with central gear rollers and half of them carries the load.

The numerical designations of the central and output rollers is shown in Figure 2.

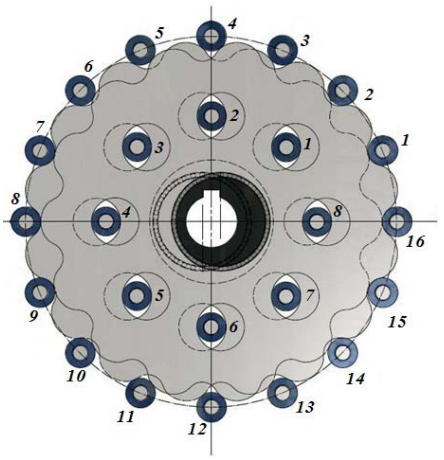


Figure 2. *Central and output rollers designation*

As it shown in Figure 2, a single-stage cycloid reducer is analyzed, with two cycloid gears relatively turned to each other for an angle of 180 ° to balance the dynamic loads and forces.

3 CALCULATION OF NORMAL AND OUTPUT FORCES

The values of the normal forces can be calculated analytically by using the equation:

$$F_{\mathrm{Ni}} = \left(c \cdot \Delta\beta\right) \cdot r_{\mathrm{i}} \cdot \sin\psi_{\mathrm{i}} \tag{1}$$

The values of the output forces are calculated analytically according to the equation:

$$F_{\mathrm{Kj}} = \left(c_{\mathrm{K}} \cdot \Delta\beta\right) \cdot r_{\mathrm{Kj}} \cdot \sin\psi_{\mathrm{Kj}} \tag{2}$$

A more detailed force calculation method is given in the references [1,2]. Calculated analytical values of normal and output forces are given in Tables 2 and 3.

Table 2. *Normal forces calculation – analytical method*

	Roll. No.	Driving angle β, °						
		0	30	60	90	120	150	180
Normal force, N	1	0	0	0	0	0	0	0
	2	0	1177,2	0	0	0	0	0
	3	0	1398,2	802,9	0	0	0	0
	4	0	1321,3	1413,1	0	0	0	0
	5	0	1158,8	1385,7	1376,5	0	0	0
	6	0	942,4	1243,5	1434,5	1177,2	0	0
	7	313,5	686,1	1039,3	1318,5	1398,2	802,9	0
	8	0	401,9	790,3	1129,8	1321,3	1413,2	0
	9	0	101,6	508,8	890,7	1158,9	1385,8	1376,5

Table 2. *Normal forces values – analytical calculation method (continuation)*

	Roll. No.	Driving angle β, °						
		0	30	60	90	120	150	180
	10	0	0	206,7	614,5	942,4	1243,6	1434,5
	11	0	0	0	313,6	686,1	1039,4	1318,6
	12	0	0	0	0	401,9	790,3	1129,8
	13	0	0	0	0	101,6	508,8	890,7
	14	0	0	0	0	0	206,7	614,5
	15	0	0	0	0	0	0	313,6
	16	0	0	0	0	0	0	0

Table 3. *Output forces values – analytical calculation method*

	Roll. No.	Driving angle β, °						
		0	30	60	90	120	150	180
Output forces, N	1	2775,7	883,0	0	0	0	0	0
	2	3925,4	3328,9	1720,8	0	0	0	0
	3	2775,7	3824,8	3711,5	2470,3	478,4	0	0
	4	0	2080,2	3528,1	3903,9	3093,7	1342,6	0
	5	0	0	1278,0	3050,6	3896,1	3557,6	2137,9
	6	0	0	0	410,3	2416,7	3688,7	3839,6
	7	0	0	0	0	0	1658,9	3292,1
	8	0	0	0	0	0	0	816,1

After that, *SolidWorks* and *Autodesk Inventor* software packages (in their specific environments) also are used determine the values of these forces. Tables 4 and 5 show the values of the normal and the output forces defined in the *SolidWorks* software, while tables 6 and 7 show the values of these forces specified in the *Autodesk Inventor* software.

Table 4. *Normal forces values – SolidWorks*

	Roll. No.	Driving angle β, °						
		0	30	60	90	120	150	180
Normal force, N	1	120,7	348,3	0	0	0	0	0
	2	194,4	1364	0	0	0	0	0
	3	94,3	1662,7	1142,7	0	0	0	0
	4	55,0	1596,7	1648,7	790,4	0	0	0
	5	20,6	1300,9	1664,7	1482,1	347,9	0	0
	6	0	971,9	1398,1	1670,7	1355	0	0
	7	0	598,0	1054,2	1559,1	1659,3	1171,1	0
	8	0	248,8	694,8	1208,1	1601,0	1659,9	786,9
	9	0	8,5	370,2	813,3	1286,4	1676,9	1480,7
	10	0	0	94,9	463,2	948,7	1413,6	1654,6
	11	0	0	0	176,5	574,8	1047,3	1523,6
	12	0	0	0	0	244,8	703,0	1213,7
	13	0	0	0	0	17,3	370,7	793,2
	14	0	0	0	0	0	91,3	465,6
	15	0	0	0	0	0	0	185,6
	16	20,2	0	0	0	0	0	0

Table 5. *Output forces values – SolidWorks*

	Roll. No.	Driving angle β, °						
		0	30	60	90	120	150	180
Output force, N	1	1911,7	560,7	0	0	0	0	0
	2	3344,5	2752,1	1192,1	0	0	0	0
	3	2595,1	3354,7	3153,5	1952,6	329,1	0	0
	4	480,0	1697,7	2996,3	3407,1	2560,8	899,4	0
	5	0	0	1006,9	2533,4	3364,0	2999,0	1502,5
	6	0	0	0	464,6	1979,1	3202,7	3302,1
	7	0	0	0	0	0	1323,4	2813,7
	8	0	0	0	0	0	0	697,1

Table 6. *Normal forces values – Autodesk Inventor*

	Roll. No.	Driving angle β, °						
		0	30	60	90	120	150	180
Normal force, N	1	89,7	386,5	0	0	0	0	0
	2	206,9	1326,3	0	0	0	0	0
	3	97,4	1662,7	1149,4	0	0	0	0
	4	78,0	1587,9	1631,7	802,1	0	0	0
	5	34,9	1325,8	1658,2	1496,3	284,4	0	0
	6	0	968,5	1404,5	1682,7	1328,0	0	0
	7	0	602,3	1071,8	1571,2	1643,3	1136,5	0
	8	0	250,8	703,0	1194,3	1612,4	1639,9	737,8
	9	0	11,8	362,2	823,6	1292,4	1678,9	1464,7
	10	0	0	97,8	436,5	923,7	1401,6	1643,1
	11	0	0	0	182,5	601,5	1054,7	1513,5
	12	0	0	0	0	252,8	715,4	1221,2
	13	0	0	0	0	20,6	374,46	806,6
	14	0	0	0	0	0	101,3	472,3
	15	0	0	0	0	0	0	203,4
	16	16,4	0	0	0	0	0	0

Table 7. *Output forces values – Autodesk Inventor*

	Roll. No.	Driving angle β, °						
		0	30	60	90	120	150	180
Output force, N	1	2106,8	589,4	0	0	0	0	0
	2	3379,5	2818,5	1192,4	0	0	0	0
	3	2590,2	3332,8	3127,9	1964,2	318,9	0	0
	4	492,2	1705,2	2990,1	3396,1	2542,8	925,4	0
	5	0	0	1028,8	2499,9	3363,8	3012,1	1514,8
	6	0	0	0	473,3	2010,1	3251,4	3326,7
	7	0	0	0	0	0	1418,2	2837,4
	8	0	0	0	0	0	0	702,4

4 RESULTS ANALYSES

After the analytical calculation of the normal and the output forces, and after the obtained values of the same forces in the *SolidWorks* and *Autodesk Inventor* software, the obtained results were compared. Table 8 shows the percentage deviations of the maximum values of the normal forces. The deviations were determined for both software, and for the analytical values, the obtained gain values were taken. Table 9 shows the percentage deviations of the maximum values of the output forces.

Table 8. *Percentage deviations of maximum values of normal forces related to analytical calculated values*

Roll. No.	Deviation, %	
	Autodesk Inventor	Solidworks
1	22,90	21,49
2	16,10	15,93
3	18,07	17,75
4	19,80	19,31
5	18,81	18,22
6	17,30	16,46
7	16,99	16,05
8	19,43	19,12
9	18,52	18,38
10	11,88	16,26
11	14,78	15,55
12	8,09	7,43
13	9,43	10,94
14	23,14	24,23
15	35,11	40,79
16	/	/
Note: Designation (/) shows that on both calculation analytical and numerical was equal to 0.		

Table 9. *Percentage deviations of maximum values of output forces related to analytical calculated values*

Roll. No.	Deviation, %	
	Autodesk Inventor	Solidworks
1	24,09	31,13
2	13,90	14,70
3	11,69	11,97
4	11,57	11,92
5	12,15	12,63
6	12,95	13,30
7	13,81	14,53
8	13,93	14,59

5 CONCLUSION

This paper is a result of the author's desire to explore the possibilities of dynamic simulations within *SolidWorks* and *Autodesk Inventor*. It has also been shown that using dynamic simulations can significantly contribute to a more quality and faster development of new products. The obtained results lead to the following conclusions:

- Using dynamic simulations, obtained results has a very small deviations related to results obtained by analytical methods.
- The deviation of the maximum values of the normal and output force obtained in the *SolidWorks* and *Autodesk Inventor* software from the analytically obtained values is not negligible. That means the dynamic model of the analyzed cycloid reducer should be further developed. In addition, it is needed to explore the possibilities of dynamic simulations that are not used in these analyses.
- The results obtained in these two software packages differ very little from one another, which is a very valuable conclusion.

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NOMENCLATURE

Variables:

c stifeness of central gear rollers, N/m

c_K stifeness of output rollers, N/m

F_{ni} normal force on gear tooth, N

F_{Kj} output force, N

r_i distance between contact point of i^{th} central gear roller and cycloid gear, and cycloid gear center, mm

r_{Kj} distance between contact point of j^{th} output roller and cycloid gear, and cycloid gear center, mm

Greek symbols

$\Delta\beta$ angular movement of cycloid gear, rad

ψ_i placement angle of normal force, rad

Subscripts and superscripts

N central gear rollers
K output rollers
i number of central gear roller
j number of output roller

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UTICAJ KOLIČINE MASTI NA DINAMIČKO PONAŠANJE KUGLIČNIH LEŽAJA

Mirjana Bojanić Šejat[1], Aleksandar Živković[2], Ivan Knežević[3], Milan Rackov[4], Milan Zeljković[5]

Rezime: Kotrljajni ležaji proizvode vibracije, što može biti posledica geometrijske nesavršenosti tokom proizvodnog procesa ili geometrijskih grešaka koje se pridružuju komponentama ležaja i slično. Nivo vibracija zavisi od mnogo faktora, unutrašnje konstrukcije elemenata ležaja, talasastosti, površinske hrapavosti staza kotrljanja i eksploatacionih uslova. Često ležajevi prerano otkažu zbog kontaminacije, lošeg podmazivanja, visokih temperature, loše ugradnje/montaže, neuravnoteženosti i zakošenja prstenova (npr. zakošenje unutrašnjeg prstena u odnosu na spoljašnji). Svi ovi faktori utiču na porast vibracija ležaja. U ovom radu je prikazan uticaj količine masti na nivo vibracija ležaja. Uticaja navedenog parametara je određen eksperimentalnim putem.

Ključne riječi: Dinamičko ponašanje, Kuglični ležaj, Podmazivanje

INFLUENCE THE AMOUNT OF LUBRICATION ON DYNAMIC BEHAVIOR OF THE BALL BEARING

Abstract: Rolling bearings produced vibration, which can be results from geometrical imperfections during the manufacturing process, or geometrical errors in associated bearing components and etc. The vibration level will depend upon many factors, the inner construction of the bearing elements, waviness, surface roughness of the raceways, and exploitation condition. Many bearings fail prematurely in service because of contamination, poor lubrication, temperature extremes, poor fitting/fits, unbalance and misalignment. All these factors lead to an increase in bearing vibration. In this paper are presents influences the amount of lubrication on the bearing vibration. Determining the influence of the above parameters were determined by experimental testing.

Key words: Dinamic behavior, Ball bearing, Lubrication

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1 UVOD

Kotrljajni ležaji su jedni od najrasprostranjenih mašinskih elemenata. Gotovo da nema mašine, aparata ili uređaja, a da u svojoj konstrukciji ne sadrže veći ili manji broj kotrljajnih ležaja. U velikom broju slučajeva se smatraju kritičnim elementima u sklopu, od čijih radnih sposobnosti u mnogom zavisi funkcionalnost, pouzdanosti i eksplataciona svojstva celokupnog sklopa u koji su ugrađeni. Međutim, kvalitet ležaja sam za sebe nije dovoljan za ostvarenje svih zahteva koji se pred njega postavljaju. Samo pod idealnim uslovima kotrljajni ležaji mogu da ostvare sve svoje projektovane karakteristike. Pored statičkog i toplotnog ponašanja, jedan od važnih pokazatelja kvaliteta ležaja je i njegovo dinamičko ponašanje. Dinamičko ponašanje kotrljajnih ležaja je posledica dejstva spoljašnjih u unutrašnjih sila koje nastaju usled različitih uticaja u toku eksploatacije čime izazivaju oscilatorno kretanje elemenata ležaja, na različitim amplitudama i frekvencijama oscilovanja.

Pri dejstvu spoljašnjih sila, usled obrtanja elemenata ležaja dolazi do periodične promene elastičnih deformacija staza kotrljanja, što dovodi do pojave vibracija elemenata ležaja [1-3]. Eksperimentalna istraživanja se izvode u labaratorijskim uslovima i uslovima eksploatacije. Labaratorijska ispitivanja se obično izvode na specijalnim, za tu svrhu namenjenim probnim uređajima na kojima se simuliraju različiti režimi rada ležaja. Analiza vibracija u ovakvim uslovima se radi na osnovu smernica koje propisuje ISO 1542-1-2004(E). Nivo vibracija se analizira u tri frekventna područja 50-300, 300-1800 i 1800-10000 Hz, za manje ležaje pri broju obrtaja 1800 o/min. Veći ležaji se ispituju pri broju obrtaja 700 o/min, sa odgovarajućim frekventnim područjima: 20-120, 120-700 i 700-4000 Hz [4]. Sveobuhvatan pregled mernih tehnika koje se koriste za analizu vibracija kotrljajnih ležaja prikazuju Marinescu [5], Howard [6], Harris [3], Harnoy [7]. S druge strane, da bi se obezbedio ispravan rad ležaja, neophodno je obezbediti pravilno podmazivanje sa tačno definisanom količinom maziva. Način podmazivanja ima veliki uticaj na temperaturu, vek i dinamičko ponašanje ležaja.

U radu je analiziran uticaj količne masti za podmazivanje na frekvencije elemenata ležaja i amplitude brzine na karakterističnim frekvencijama. Analiza uticaja pomenutog parametra je izvršena na osnovu eksperimentalnih podataka primenom Furijerove transformacije za radijalni kuglični ležaj 6006.

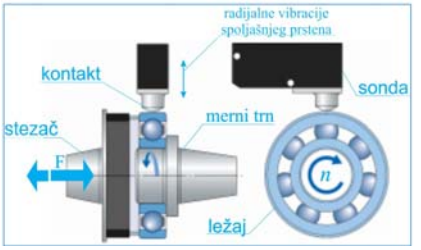
2 EKSPERIMENTALNO ISPITIVANJE

Na slici 1 je prikazan eksprimentalni uređaj za merenje vibracija kotrljajnih ležaja. Ležaj se preko unutrašnjeg prstena postavlja na merni trn koji je posredstvom konusa i navojne veze spojen sa vretenom koje je uležišteno hidrodinamičkim ležajima. Vreteno se tokom merenja obrće konstantnim brojem obrtaja (n=1800 [o/min]). Spoljašnji prsten je stacionaran i opterećen aksijalnom silom preko pneumatskog cilindra. Osnovni elemenat pri merenju vibracija predstavlja elektrodinamički davač brzine (slika 2) koji na svom izlazu generiše napon čija je amplituda i frekvencija proporcionalna brzini vibracija koje generiše posmatrani kotrljajni ležaj. Obzirom da je amplituda signala koji se dobija pomoću korišćene elektrodinamičke sonde mala, za digitalnu obradu i prikaz signal je pojačan primrnom pojačavača. Blok dijagram sistema za ispitivanje vibracija kotrljajnih ležaja je prikazan na slici 3. Elementi za analognu obradu signala su pojačavač i filtar propusnik opsega. Pojačavač ima zadatak da pojača nivo signala sa elektrodinamičkog davača brzine na nivo koji je pogodan za digitalnu obradu i prikaz. Ovde je korišćen pojačavač sa pojačanjem od 1500, čime je obezbeđena dovoljna amplituda signala za digitalnu obradu. Frekvencijski opseg signala koji je od interesa za ispitvanje vibracija

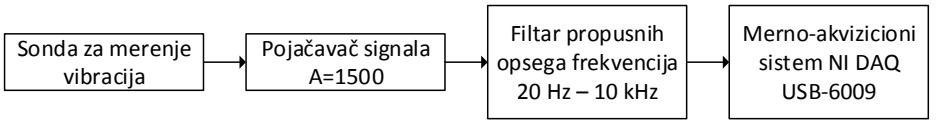
kotrljajućih ležaja je od 20Hz do 10kHz. Filtar ima zadatak da ograniči spektar signala dobijenog sa pojačavača na pomenuti opseg. Projektovani filtar uvodi relativno malo slabljenje oscilacija talasa u jednom i više frekventnih opsega i relativno veliko slabljenje za oscilacije drugih frekvencija (za manje od 20 Hz i veće od 10 kHz) prema standardu SRPS ISO 15242-1 (Kotrljajni ležaji-Metode merenja vibracija Deo 1: Osnove). Propusni opseg filtara je takođe definisan na osnovu pomenutog standarda. Digitalizacija signala se vrši primenom merno-akvizionog sistema NI DAQ USB-6009. Frekvencija semplovanja iznosi 48kHz, dok je rezolucija internog A/D konvertora 13bit-a. Na ovaj način je obezbeđena kvalitetna priprema signala dobijenog primenom elektrodinamičkog davača brzine i njegova digitalizacija za dalju računarsku obradu.



Slika 1. *Merno-kontrolni uređaj za merenje i kontolu vibracija kotrljajnih ležaja*



Slika 2. *Šematski prikaz principa merenja pomoću elektrodinamičkog davača brzine* [8]



Slika 3. Blok dijagram sistema za merenje

Frekvencije ležaja Za određivanje uticaja pomenutih parametara ležaja od velikog značaja je poznavanje frekvencija elemenata ležaja, u odnosu na koje se definiše lokacija i izvor vibracija, odnosno uzrok pravilnog/nepravilnog rada ležaja. Kod kotrljajnih ležaja postoje četiri frekvencije vibracija: frekvencija kaveza (f_c), frekvencija unutrašnjeg prstena (f_i), frekvencija spoljašnjeg prstena (f_o) i frekvencija kotrljajnih tela (f_b).

Frekvencija kaveza ili osnovna frekvencija ležaja je:

$$f_c=\omega_c/2\pi \tag{1}$$

$$\omega_c = \Omega\left[1+\frac{(d_b/d_m+\cos\alpha_o)(\cos\alpha_o\cos\beta+\sin\alpha_o\sin\beta)}{(d_b/d_m-\cos\alpha_i)(\cos\alpha_i\cos\beta+\sin\alpha_i\sin\beta)}\right]^{-1} \tag{2}$$

gde su: ω_c-ugaona brzina kaveza [rad/s]; Ω-ugaona brzina unutrešnjeg prstena sa vretenom [rad/s]; d_b- prečnik kotrljajnih tela [mm]; d_m-srednji prečnik ležaja [mm] (d_m=(D+d)/2); α_o-ugao kontakta sa spoljašnjom stazom kotrljanja [rad]; α_i-ugao kontakta sa unutrašnjom stazom kotrljanja [rad] i ugao nagiba kotrljajnih tela (β). Frekvencije unutrašnjeg (f_i) i spoljašnjeg prstena (f_o) je definisana kao frekvencija prelaska kotrljajnih tela preko tačke na unutrašnjoj odnosno spoljašnjoj stazi kotrljanja.

U slučaju obrtanja spoljašnjeg prstena frekvencije unutrašnjeg/spoljašnjeg prstena su:

$$f_i = \frac{Z}{2\pi}\omega_c\left(1-\frac{d_b}{d_m}\cos\alpha_i\right)$$
$$f_o = \frac{Z}{2\pi}\omega_c\left(1+\frac{d_b}{d_m}\cos\alpha_u\right) \quad (3)$$

Frekvencija kotrljajnih tela se može izraziti u funkciji ugaone brzine kotrljajnih tela, na osnovu srednjeg prečnika, prečnika kotrljajnih tela, ugla kontakta sa stazama kotrljanja i ugaone brzine kaveza:

$$f_b = \frac{\omega_c}{2\pi}\frac{d_k/d_m+\cos\alpha_s}{\cos\alpha_s\cos\beta+\sin\alpha_s\sin\beta} \quad (4)$$

Na osnovu prethodnih relacija određene su frekvencije elemenata ležaja i one iznose: f_c=30 [Hz], f_i=186 [Hz], f_o=138 [Hz], f_b=161 [Hz].

3 REZULTATI ISPITIVANJA

3.1 Uvodne napomene

Oko 90% svih uležištenja se podmazuju mašću. Mast ima prednost u odnosu na ulje što se lako zadržava u ležaju, naročito kod kosih i vertikalnih vratila, a osim toga potpomaže zaptivanje uležištenja. Faktor broja obrtaja (faktor brzohodosti) nd_m je jedan od najvažnijih kriterijuma izbora postupka podmazivanja. Pri velikom broju obrtaja, prevelika količina masti izazva porast temperature, zbog porasta unutrašnjeg trenja. Zato se ležajevi pune sa količinom masti koja iznosi 30-50% od zapremine.

Kod visokobrzinskih ležaja se uvek koristi tzv. minimalno podmazivanje da bi se smanjilo trenje masti i kotrljanih tela. Količina masti zavisi od prečnika ležaja, tipa ležaja i faktora brzohodosti i može se izračunati iz relacije [9]:

$$K = n \cdot d_m, \quad (5)$$

$$Q_{min} = K \cdot Q\ [cm^3] \quad (6)$$

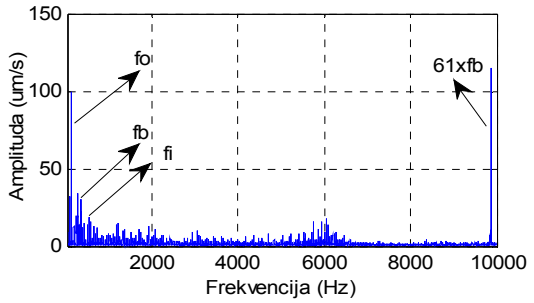
gde je: K-funkcija faktora brzohodnosti, n-broj obrtaja [o/min], i Q_{min}-minimalna količina masti i Q-referentna količina masti koja je u funkciji tipa i prečnika ležaja. S druge strane, kod ležaja koji rade na nižim brojevima obrtaja količina potrebne masti se može približno odrediti iz relacije:

$$Q_m = D*B/k_t \quad (7)$$

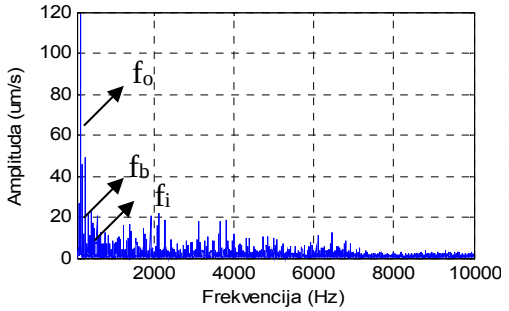
gde su: D-prečnik spoljašnjeg prstena, B – širina ležaja i k_t – koeficijent koji zavisi od perioda zamene i/ili dopune masti u ležaju. Na osnovu prethodnog, za ležaj 6006, za potrebe eksperimentalnih ispitivanja su definisane sledeće količine masti: 0,7; 1,4; 2,1 i 2,8 [g]. Takođe pri eksperimentalnom ispitivanju su posmatrani ležaji sa klasama radijalnog zazora: C2, C0, C3, C4 i C5. Minimalno spoljašnje aksijalno opterećenje ležaja je definisano iz minimalne sile koja je potrebna da bi došlo do kotrljanja kotrljajnih tela, dok je maksimalno aksijalno opterećenje određeno iz statičke nosivsti posmatranog ležaja.

3.2 Analiza rezultata

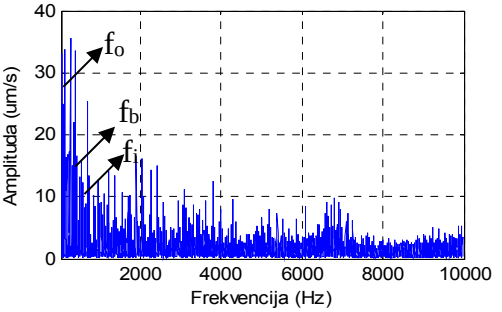
Da bi se analizirao uticaj količine masti razmatrani su ležaji sa istim radijalnim zazorom od 10 [μm]. Uticaj količine masti je razmatran za aksijlano opterećenje od 200 [N], koje je definisano na osnovu standarda SRPS ISO 15242-2. Promena amplitude brzine za različite količine masti je prikazano na slikama 4, 5, 6, 7 i 8.



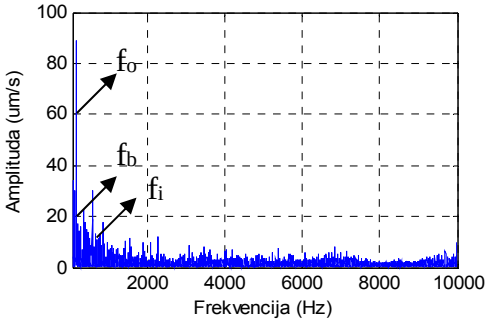
Slika 4. *Spektar vibracija u frekventnom domenu za ležaj bez podmazivanja*



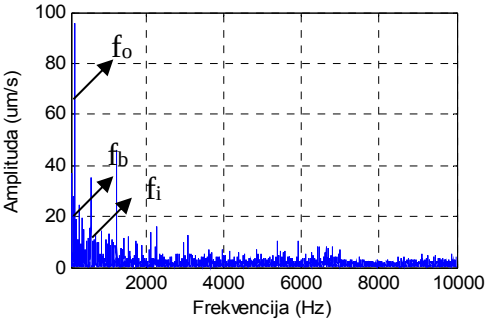
Slika 5. *Spektar vibracija u frekventnom domenu za ležaj podmazan sa 0,7 [g] masti*



Slika 6. *Spektar vibracija u frekventnom domenu* za ležaj podmazan sa 1,4 [g] masti



Slika 7. *Spektar vibracija u frekventnom domenu za ležaj podmazan sa 2,1 [g] masti*



Slika 8. *Spektar vibracija u frekventnom domenu za ležaj* podmazan sa 2,8 [g] masti

Na slici 4 je prikazana promena frekvencije i amplitude brzine elemenata ležaja za slučaj kada nema podmazivanja. Pri delovanju aksijalnog opterećenja, kada nema podmazivanja, maksimalna amplituda brzine je na frekvenciji kotrljajnih tela odnosno na $61xf_b$=9821 [Hz]. Maksimalna amplituda brzine iznosi 136 [μm/s] kao što je prikazano na slici 4. U slučaju kada je ležaj podmazan sa 0,7 [g] masti, dominantna amplituda brzine je na frekevnciji spoljašnjeg prstena f_o=138 [Hz], pri čemu njena vrednost iznosi 118,9 [μm/s]. Kada je količina masti 1,4 [g] maksimalna amplituda iznosi 33,6 [μm/s], takođe na frekvenciji spoljašnjeg prstena i tri puta je manja nego u slučaju kada je ležaj nepodmazan, odnoso 3,5 puta je manja u odnosu na ležaj sa 0,7 [g] masti. Maksimalna amplituda brzine na frekvenciji spoljašnjeg prstena iznosi 95,9 [μm/s], odnosno 88,8 [μm/s] za ležaj podmazan sa 2,1, odnosno 2,8 [g] masti.

Amplitude brzine na frekvencji unutrašnjeg prstena iznose od 40,5 do 42,7 [μm/s] za ležaj bez masti i ležaje sa 0,7; 2,1 i 2,8 [g] masti, dok amplituda brzine na frekvenciji kotrljajnih tela iznosi od 30,1 do 33,4 [μm/s] za iste slučajeve podmazivanja. Za ležaj podmazan sa 1,4 [g] masti amplituda brzine na frekvenciji unutrašnjeg prstena iznosi 23,4 [μm/s], pri čemu je amplituda brzine na frekvenciji kotrljajnih tela 16,8 [μm/s]. Na osnovu prethodnog se može zaključiti da se najmanje ampitude vibracija na svim frekvencijama elemenata ležaja javljaju kada je ležaj podmazan sa 1,4 [g] masti, što odgovara količini masti kojom se ovaj tip ležaja podmazuje u proizvodnji.

4 ZAKLJUČCI

Maksimalne amplitude brzine, kod posmatranog radijalnog ležaja, se javljaju na frekvenciji spoljašnjeg prstena. Pri delovanju konstantnog aksijalnog opterećenja i za posmatrani radijalni zazor amplitude brzine se ne menjaju značajno za količine masti od 0,7; 2,1 i 2,8 [g]. Promena amplitude brzine u ovim slučajevima je oko 2 %. Kod ležaja koji je podmazan sa 1,4 [g] masti ampitude brzine su oko tri puta manje na frekvenciji spoljašeg prstena, odnos dva puta manje na frekvenciji unutrašeg prstena i kotrljajnih tela u odnosu na ležaje podmazane sa ostalim razmatranim količinama masti. Ovde treba napomenuti, da su u radu prikazana preliminarna istraživanja koja nisu razmatrala promenu aksijlanog opterećenja i promenu radijalnog zazora sa količinom masti u ležaju. Da bi se upotpunila slika uticaja količine masti na dinamičko ponašanje ležaja, u skorijoj budućnosti, se planiraju istraživanja koja su vezana za analizu uticaja spoljašnjeg opterećenja, radijalnog zazora i količine podmazivanja na dinamičko ponašanje radijalnih ležaja.

Napomena: *Rad predstavlja deo istraživanja na projektu "Savremeni prilazi u razvoju specijalnih rešenja uležištenja u mašinstvu i medicinskoj protetici", ev. broj TR 35025, podržanom od strane Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije*

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COMPARATIVE MODAL ANALYSIS OF THE SPATIAL BEAM FRAMES OF A TYPE "H" AND "X"

Rade Vasiljević[1]

Abstract: In this paper a comparative modal analysis with FEM approach of two spatial beam frames of type "H" and "X" is description. The both types of spatial frame have the same main geometric dimensions. They differ only in the horizontal plane. The first type of spatial frame on the horizontal plane has a type "H" frame, while the second type of spatial frame on the horizontal plane has a type "X" frame. The paper compares the corresponding modal parameters of two types of spatial frames ("H" and "X") obtained during their comparative modal analysis.

Key words: spatial frame, type "H", type "X", FEM, comparative modal analysis

1 INTRODUCTION

In constructive engineering, it is relatively frequent case that implemented constructing solutions are not optimal. The dynamic analysis of the structures is very important for improving the performances. In the dynamic analysis of construction, the modal analysis represents the first phase in the evaluation of the dynamic stability.

In this paper, modal analysis of the two types of spatial beam frames was conducted numerically by using the method with consistent masses. The finite element models of the typical spatial frames are formed and solved. The theoretical results of numerical analyses are verified by using the simulation software (SAP2000®).

The concretely, in this paper a comparative modal analysis of two spatial frames of type ″H″ and ″X″ was given.

1.1 Spatial frame description - type ″H″

The spatial frame of type "H" is shown in Fig. 1. This spatial frame has four legs with height *H*, which are connected with "H" type frame in the horizontal plane. Rest on four fixed supports. The main overall dimensions of the spatial frame of type "H" are equal:

- columns height, H=6 [m], and
- spread between the columns of the frame, A=B=6 [m].

The dimensions of the cross-section of the spatial frame of type "H" are equal:

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- profile height, h=400 [mm],
- profile width, b=400 [mm], and
- profile thickness, t=10 [mm].

The main mechanical characteristics of the spatial frame of type "H" are equal:

- elastic modulus, $E=2.1\times10^{11}$ [N/m^2],
- shear modulus, $G=0.8\times 10^{11}$ [N/m^2], and
- mass density of beam, ρ=7850 [kg/m^3].

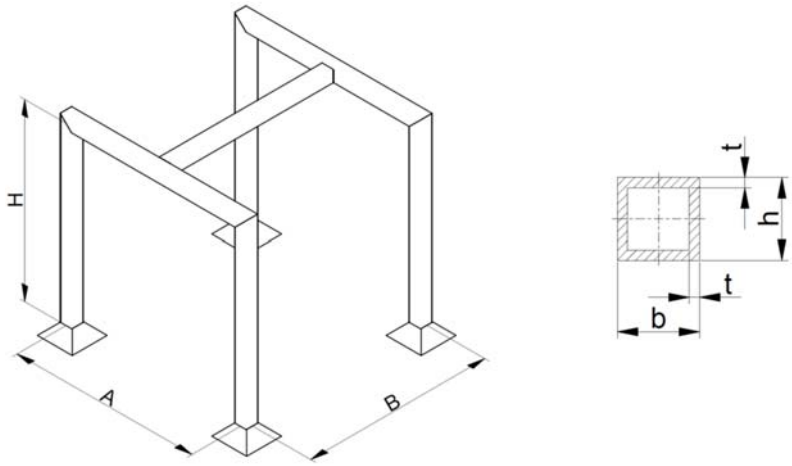


Figure 1. *Spatial frame - type "H"*

1.2 Spatial frame description - type "X"

The spatial frame of type "X" is shown in Fig. 2. This spatial frame has four legs with height H, which are connected with "X" type frame in the horizontal plane. Rest on four fixed supports. The main overall dimensions, dimensions of the cross-section and the main mechanical characteristics of the "X" type spatial frame (Figure 2), are the same as in the spatial frame of type "H" (Figure 1).

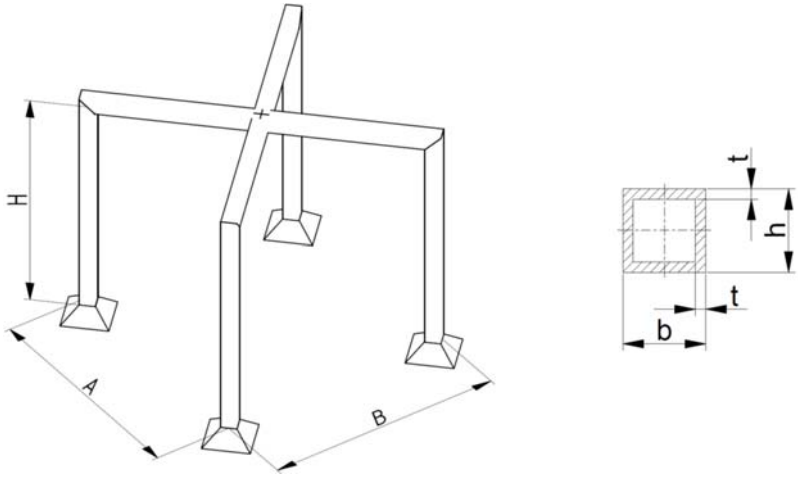


Figure 2. *Spatial frame - type "X"*

2 MODAL ANALYSIS

Analysis of 3D beam finite element using the method of consistent masses is given in paper [1]. Also, mathematical formulation of the modal analysis of the spatial beam frames is given in the paper [1]. Equation of the free undamped oscillation of the system read [1]:

$$\mathbf{M}_{uu}\ddot{\mathbf{U}}_{uu} + \mathbf{K}_{uu}\mathbf{U}_{uu} = \mathbf{0} \tag{1}$$

Circular frequencies of the spatial frames are obtained by solving algebraic equation:

$$\det\left(\mathbf{K}_{uu} - \omega^2\mathbf{M}_{uu}\right) = 0 \tag{2}$$

Based on the circular frequencies obtained by the oscillation periods via expression:

$$T_i = \frac{2\pi}{\omega_i} \qquad \text{....(3)}$$

Frequencies of the spatial frames are obtained based on expression:

$$f_i = \frac{\omega_i}{2\pi} = \frac{1}{T_i} \qquad \text{....(4)}$$

2.1 Modal analysis - type ″H″

The FE model of the spatial frame of a type “H” is shown in Figure 3.

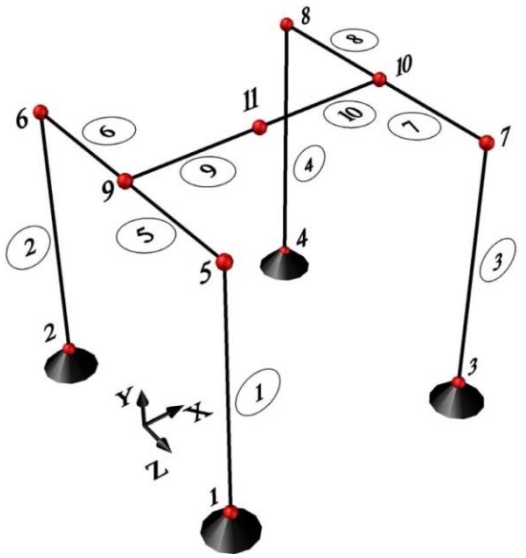


Figure 3. *FE model of spatial frame - type "H"*

The stiffness matrix of the FE model of spatial frame of a type ″H″ in the direction of unknown displacements read:

$$\mathbf{K}_{uu} = \left[\mathbf{K}\right]_{54\times 54} \tag{5}$$

The mass matrix of the FE model of spatial frame of a type ″H″ in the direction of unknown displacements read:

$$\mathbf{M}_{uu} = \left[\mathbf{M}\right]_{54\times 54} \tag{6}$$

Based on equations (1)-(6) and defined starting data by using Mathematica® [2-3], was written computer code "RV.ModAn-H" for calculating the oscillation period, circular frequencies and the frequency. Obtained are their value for all degrees of freedom (i= 54).

From the frequency response functions of the spatial frame of a type "H", the corresponding calculation frequencies of the individual modes are separated and shown in the Table 1.

Table 1. *Frequencies for adopted FE model - type "H"*

Mode No	*Mode shapes*	*Frequency f [Hz]*		*Disparity [%]*
		Method of consistent masses	*Simulation by SAP2000 software*	
1	*Hor. - long.*	*2.69*	*2.67*	*0.74*
2	*Hor. - lat.*	*4.72*	*4.67*	*1.06*
3	*Tor.*	*4.90*	*4.84*	*1.22*
4	*Tor.*	*9.97*	*9.85*	*1.20*
5	*Tor.*	*17.43*	*16.88*	*3.15*
6	*Hor. – long.*	*23.38*	*22.31*	*4.58*

By comparing the values of frequencies obtained by using the mathematical model with the finite element approach (method of consistent masses) and the purely numerical method (FEA software SAP2000®), excellent coinciding of the first frequency with relative difference 0.74 [%] is noticed. Other frequencies good coincide. Thus, for example, for the next five frequencies the relative difference amount to 4.58 [%], which is very good for the 3D model.

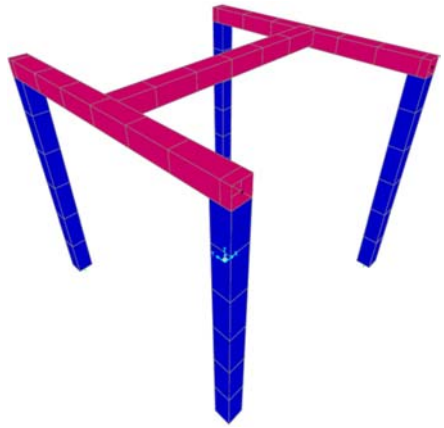


Figure 4. *SAP2000® FE model of spatial frame - type "H"*

On Figure 5 there are presented two main calculated mode shapes of oscillation of the frame of type “H”, which are obtained from software SAP2000®.

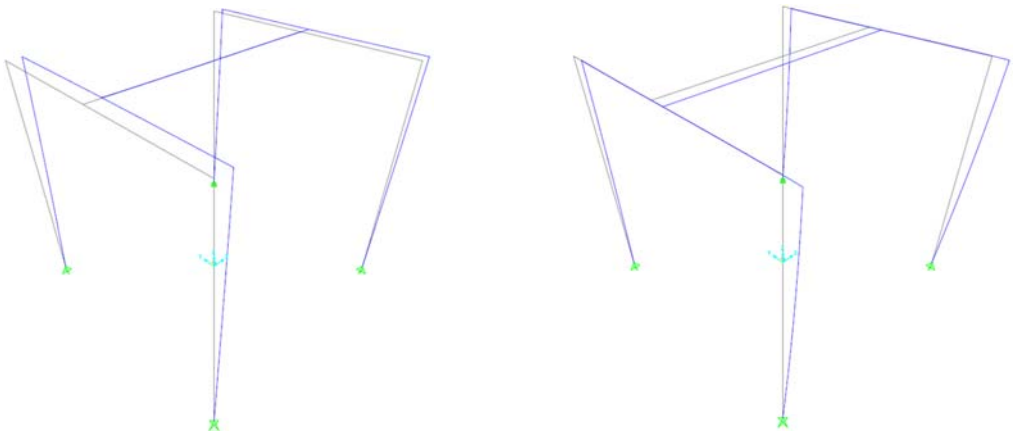


Figure 5. *First 2 mode shapes of spatial frame - type "H"*

2.2 Modal analysis - type "X"

The FE model frame of type “X” is shown in Figure 6.

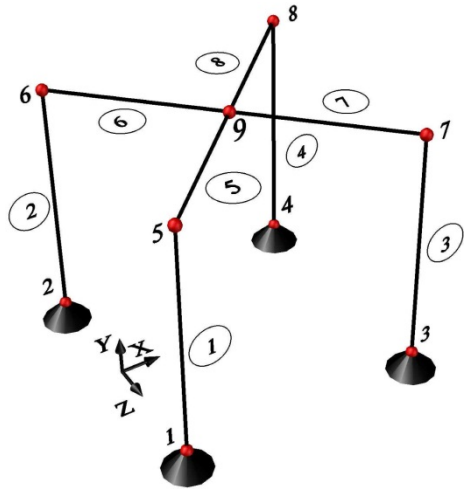


Figure 6. *FE model of spatial frame - type "X"*

The stiffness matrix of the FE model of spatial frame of a type ″X″ in the direction of unknown displacements read:

$$\mathbf{K}_{uu} = \left[\mathbf{K}\right]_{42\times 42} \tag{7}$$

The mass matrix of the FE model of spatial frame of a type ″X″ in the direction of unknown displacements read:

$$\mathbf{M}_{uu} = \left[\mathbf{M}\right]_{42\times 42} \tag{8}$$

Based on equations (1)-(4), (7), (8) and defined starting data in Mathematica® [2-3], was written computer code "RV.ModAn-X" for calculating the oscillation period, circular frequencies and the frequency. Obtained are their value for all degrees of freedom (i= 42).

From the frequency response functions of the spatial frame of a type "X", the corresponding calculation frequencies of the individual modes are separated and shown in the Table 2.

Table 2. *Frequencies for adopted FE model - "X"*

Mode No	*Mode shapes*	*Frequency f [Hz]*		*Disparity [%]*
		Method of consistent masses	*Simulation by SAP2000 software*	
1	*Tor.*	*3.74*	*3.71*	*0.80*
2	*Hor. – diag.*	*3.92*	*3.89*	*0.76*
3	*Hor. – diag.*	*3.92*	*3.89*	*0.76*
4	*Tor.*	*14.64*	*14.17*	*3.21*
5	*Tor.*	*17.64*	*17.08*	*3.17*
6	*Tor.*	*17.64*	*17.08*	*3.17*

By comparing the values of frequencies obtained by using the method of consistent masses and the FEA software SAP2000® excellent coinciding of the first frequency with relative difference 0.80 [%] is noticed. Other frequencies good coincide. Thus, for example, for the next five frequencies the relative difference amount to 3.17 [%], which is very good for the 3D model.



Figure 7. *SAP2000® FE model of spatial frame - type "X"*

On Figure 8 there are presented two main calculated mode shapes of oscillation of the frame of type "X", which are obtained from software SAP2000®.

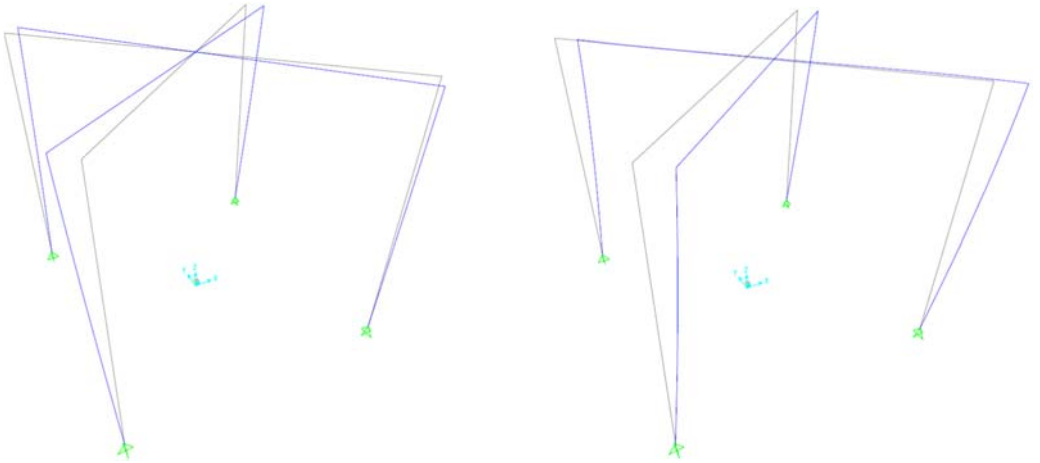


Figure 8. *First 2 mode shapes of spatial frame - type "X"*

3 CONCLUSION

During the modal analysis of two types of spatial frames calculating, i.e. method with consistent masses, its modal parameters (frequencies and oscillation modes) are determined and compared with corresponding values obtained by FE software SAP2000®. Parameters obtained by method of consistent masses and using software SAP2000® are compared to verify calculated models and quality of producing.

Analysis of calculating and SAP2000® parameters confirmed a relatively high accordance for frames of type “H” and “X”, whereby verified calculating models and their producing.

The main aim of this paper is the comparison of modal parameters (frequencies and oscillation modes) between two types of spatial frames (“H” and “X”). Albeit both frames have the same spread and height, there are differences in modal parameters. These differences come from the difference in their frames at the horizontal plane.

It is possible to understand the behaviour of two types of frame during its own undamped oscillation. The portal type “H” is slightly more elastic than portal type “X” which means it has a slightly unfavourable dynamic stability, as it has a lower first frequency of 28.07 [%].

This paper provides a basis for modal analysis of the carrying structure of a type ″H″ and ″X″ portal cranes.

NOMENCLATURE

$\mathbf{M}_{uu}$ mass matrix of the system in the direction of unknown displacement, kg
$\mathbf{K}_{uu}$ stiffness matrix of the system in the direction of unknown displacement, N/m
$\ddot{\mathbf{U}}_{uu}$ vector of unknown acceleration, m/s^2
$\mathbf{U}_{uu}$ vector of unknown displacement, m
ω circular frequency, rad/s
f frequency, Hz
T period, s

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MODELING AND STRUCTURAL ANALYSIS OF CYLINDRICAL COIL SPRING

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Abstract: This paper analyzes the stress-deformation condition of cylindrical coil spring of the handgun CZ 999 using Autodesk Inventor software. The obtained results show that, because of the round spring shape, the distribution of the stress at the cross section of the coil is uneven and that the maximum stress occur approximately to the axis of the spring.The paper also analyzes the influence of wave thickness on the stress value and spring strain and draws appropriate conclusions.

Key words: cylindrical coil spring, stress, deformation, Autodesk Inventor

1 INTRODUCTION

Elastic elements are used to make machine assemblies that allow large mutual connection displacements under load. This function is realized on the principle of transforming mechanical work into potential energy and vice versa. In practice, the term elastic elements often used term spring.

The springs are mechanically functional elements capable of elastically deforming under the influence of external loads and that the absorbed energy is converted again into mechanical work. Work in the spring accumulates in the form of potential energy used for various purposes (achieving constant compressive or tensile force, strike absorption, achieving force or coupling in shorter or longer intervals, etc.).

Due to the variety of applications, springs have found their place in armaments as very important elements. The construction of weapons, and gun as a subject of spring application presented in this paper, has been changing over time, adapting to market demands, but also to new achievements material development.

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This issue is interesting to many researchers so there is a large number of papers dealing with the analysis of different types of springs. In the paper [1] a methodology for design and analysis of springs that are not circular cross-sections has been presented, using analytical and numerical methods. The focus was on obtaining closed forms of analytical expressions, while numerical analysis would only be used when the expressions were too complicated or for confirmation of analytical results.

Numerical and experimental methods for determining the fiber orientation angles of carbon/epoxy resin composite spring wire diameters are shown in the paper [2] to provide a spring of similar characteristics to a spring made of steel, with spring mass reduced by 55%.

In the paper [3] there are shown springs that apply to cranks of the robots. The springs are rectangular cross-section and can carry heavy loads. This paper presents a new spring winding method. By hardening the spring material, the load capacity is improved, which is of key importance for the cranks of the robot.

2 RECOIL SPRING OF HANDGUN CZ 999

The handgun Zastava CZ 999 is a semi-automatic weapon that functions on the principle of short-cut barrel. Burned gunpowder gasses, when throwing a bullet, move to the bottom of the bullet by pushing it along the barrel to the muzzle of the barrel on the one side. On the other side, gasses moved across the bottom of the bullet capsule on the barrel bushing, causing the movement of tubular and movable parts in the opposite direction of the movement of the projectil. In this movement, the movable parts of the handgun compress the recoil spring.

By compressing the recoil spring of the gun, the potential energy accumulates therein, the release of which, at the end of the compression process, the movable parts return to the original position. When designing springs, the spring parameters must be chosen such that the energy of the movable parts is sufficient to compress the spring to the length required for the normal operation of the gun by the construction model. The stroke of recoil spring is dependent on the energy of the moving parts. If the stiffness of the spring and its length is large, the energy of the movable parts will not be enough to compress the spring to the required length. The low value of the accumulated energy in the spring produces a slow return to the original position and hence the handgun function is compromised.

In the maximum compressed working condition the spring force must be in the range of 60 to 80 N.

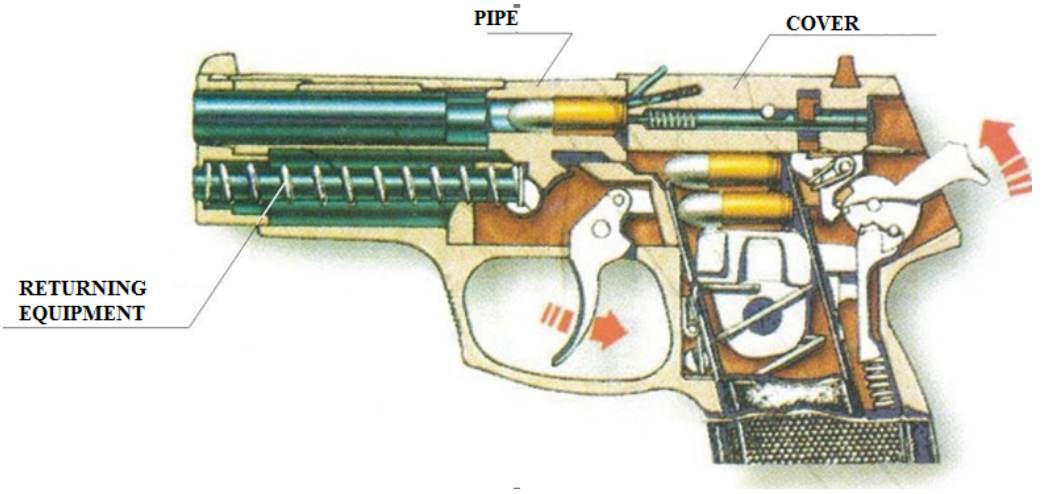


Fig 1. *Handgun CZ 999*

3 ANALYSIS OF THE STRESS-DEFORMATION STATE OF THE RECOIL SPRING OF HANDGUN CZ 999

Recoil spring of handgun Zastava CZ 999 is 113 mm long, 10,5 mm diameter and 1,6 mm thick. The spring material is steel $67S_iC_r5$. The number of active coils of the spring is 22. The spring is exposed to a force of 69 N [4].

The value of the spring deformation is:

$$f = \frac{8 \cdot z_a \cdot (D/d)^3 \cdot F}{G \cdot d} = \frac{8 \cdot 22 \cdot 6,5^3 \cdot 69}{83000 \cdot 1,6} = 25,11 \ mm \tag{1}$$

While the working stress value is:

$$\tau = k \cdot \frac{T_t}{W_p} = 1,26 \cdot \frac{358,8}{0,803} = 563 \ MPa \tag{2}$$

$$k = \frac{4K-1}{4K-4} + \frac{0,615}{K} = \frac{4 \cdot 6,5 - 1}{4 \cdot 6,5 - 4} + \frac{0,615}{6,5} = 1,23$$

$$K = \frac{D}{d} = \frac{10,5}{1,6} = 6,5$$

$$W_p = \frac{\pi \cdot d^3}{16} = 0,803 \ mm^3$$

The permitted stress has a value [4]:

$$\tau_{doz} = \frac{\tau_{TM}}{S_{\min}} = 622,8 \ MPa \tag{3}$$

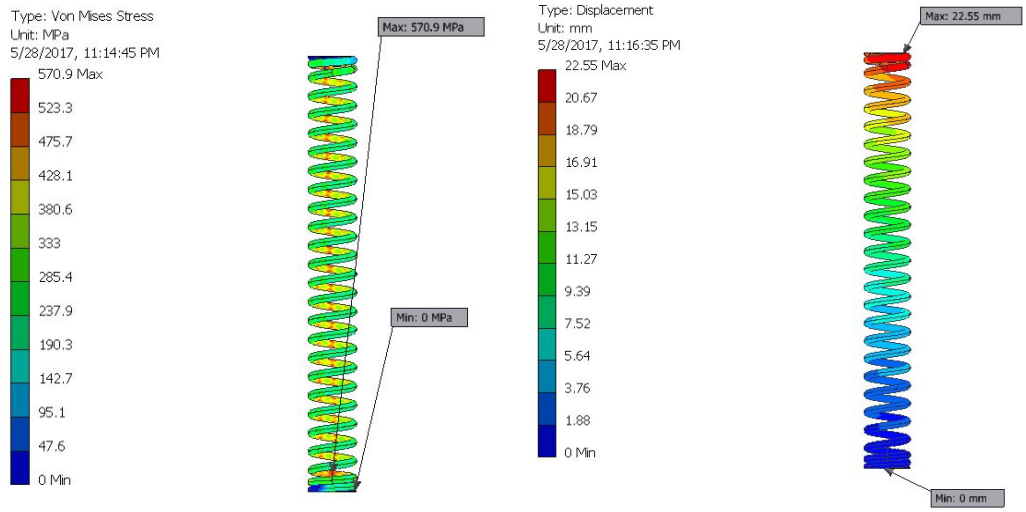
Autodesk Inventor software fully supports the design of complex structures in the machine industry. Apart from the modeling of parts, it also enables the generation of technical documentation, different calculations and simulations as well as stress-deformation analysis using the finite element method (FEM).

The model of the analyzed spring with the generated finite element network can be seen in Figure 2.



Figure 2. *Spring model with a network of finite elements*

After the boundary limits and load assignment, a stress analysis and spring deformation was performed, and the results of the analysis are shown in the figure 3 (a) and (b).



(a) *(b)*

Figure 3. *Results of stress-deformation analysis*

(a) Distribution of Von Mises stresses, (b) Deformation values

In accordance with the expectations, the highest value of stress are in the internal side of the coil's curve. Numerical results of a certain stress and deformation value are compared with the values obtained by the analytical calculation, as can be seen in Table 1.

Table 1. *Analitycal and numerical values of stress and deformation*

	Numerical values	*Analytical values*	*Difference in %*
Stress, N/mm²	*570,9*	*563*	*1,38*
Deformation, mm	*22,5*	*25,11*	*9,4*

The possibility of changing wire thickness was further analyzed. The stress values for wire diameters of 2 mm, 1,6 mm, 1,5 mm and 1 mm are shown in Figure 4.

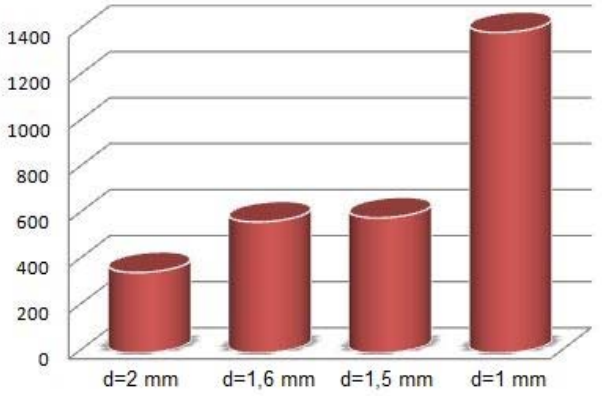


Figure 4. *Stress values (MPa) of springs of different thicknesses of wire*

The values of the strain deformation of different wire thicknesses are shown in Figure 5.

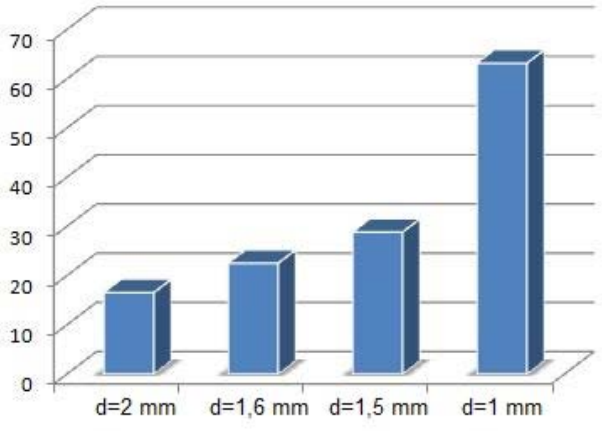


Figure 5. *Deformations (mm) of springs of different thicknesses of wire*

It can be concluded that decreasing the thickness of the wire results in increased stress and deformation, and vice versa. It is also concluded that the chosen thickness value of the wire (1,6 mm) is made on the basis that in case of smaller thickness wire the stresses and deformations were above the prescribed values.

4 CONCLUSION

When designing the springs, the specific requirements of the construction in which the springs are to be installed are met. In this paper, the circular cross - section of the CZ 999 handgun has been analyzed. The analysis shows that the major stress occurrences on the inner side of the curvature coils and this spring have the best utilization of the material compared to the produced work in the spring.

Also, different thicknesses of wire of springs compared. It was concluded that by applying a spring of less wire thickness than the prescribed value (1,6 mm) in the case of handgun CZ 999, the stresses and deformations were above the permissible values and eliminated the possibility of correcting the thickness of the wire.

ACKNOWLEDGMENT

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CALIBRATION CERTIFICATION OF ATTRIBUTE CHECK FIXTURES FOR TUBE MANUFACTURING USING STRUCTURED LIGHT 3D SCANNERS

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Saša Jovanović[4], Đorđe Marković[5]

Abstract: To make production of correct parts without rework and prevention the scrapping of good parts, manufacturers of tubes for automotive industry rely on attribute check fixtures. Fixtures are intended to answer the question does the product conform to the dimensional specifications and tolerances. In this paper the methodology for calibration certification of attribute check fixtures for tube manufacturing using structured light 3D scanners is presented. Sample preparation, 3D scanning, processing of point cloud and generation of measurement reports are described. GOM Inspect software was used to process meassuring data ang measured results generation. A large amount of recorded measuring points with high accuracy of measurement ensures that certification pass only fixtures that meet the requirements defined by the documentation. Based on measuring results, accredited laboratories may issue calibration certificates. The presented methodology is a valuable tool for calibration certification of attribute check fixtures for tube manufacturing. The methodology presented in this paper can be applied for calibration certification to all other types of gages, fixtures and jigs.

Key words: Calibration, Attribute check fixtures, Polygonal model, 3D digitizing, Measurement, ATOS

1 INTRODUCTION

Three dimensional coordinate metrology is one of the foundations of modern product quality concepts [1]. Universal applicability and the possibility of high degree of automation has ensured that this measurement technology has a primacy for more than 30 years. The CAD data is the absolute authority for advanced manufacturing compliance. Modern metrology software provides interface between CAD models and

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measuring devices in real-time. Conventional coordinate measuring machines (CMM) are performing measurements based on set of points obtained by touching the measuring object [3]. The measurement result depends on the selection and number of measuring points.

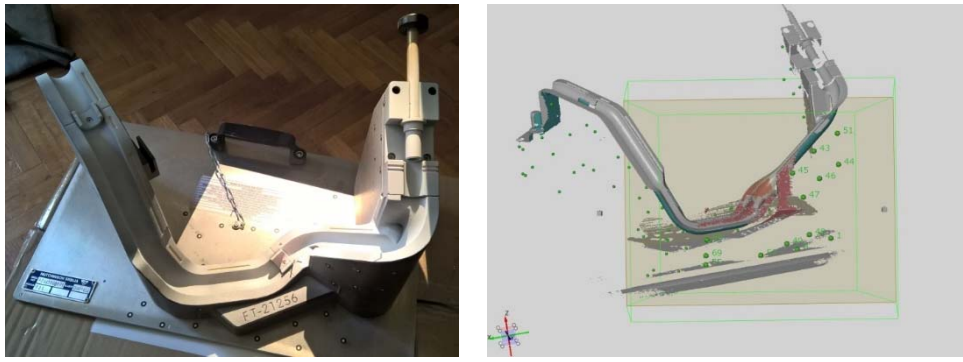
Many applications require fast and efficient in-proces control and the use of expensive sophisticated devices is inadequate. The most obvious examples come from the automotive industry, where entire product series are controlled by simple fixed devices – gages and fixtures [4]. Precision tubes for the automotive industry must meet the highest performance requirements, especially in terms of geometric accuracy [4]. In-Vehicle attribute check fixtures forms a template that precisely coordinates the locations of components throughout the entire product, as well as their respective assembly points, so that every part goes exactly where it's supposed to go [5]. If the tube fits into the cavity, the part is correct; if it does not fit, it is not correct. A well-designed and -constructed fixture makes the process run smoothly [6-11].

Modern 3D scanning technologies provide the possibility of 3D digitization of the entire surface of an object with a very high accuracy of the position of each recorded point [12]. The 3D scan consists of millions of measurement points and represents a faithful digital copy of a real physical object [13]. Since application of 3D scanning allows for full insight into the current state of configuration of these tools, in this paper the methodology for calibration certification of attribute check fixtures for tube manufacturing using structured light 3D scanners is presented.

2 ACQUISITION PROCEDURE

A full-contour fixture makes contact with the tube along its entire run, end-to-end (Figure 1a). The body of the fixture checks most of the contours and features. Additional hardware, such as the items located at each end and in the middle of the tube, are used for verifying the locations of specific tube features.

Sample preparation, 3D scanning, processing of point cloud and generation of measurement reports are described in the folowing sections.



(a) (b)

Figure 1. *Attribute check fixture: (a) physical model, and (b) actual data obtained by 3D digitzing*

2.1 3D digitizing

Opposite to CMM, 3D scanner captures dense set of points, called Point Cloud,

on visible surfaces of objects that are subject to 3D scanning [10]. In other words, the point cloud is a set of points whose positions in the space are determined by measurement.

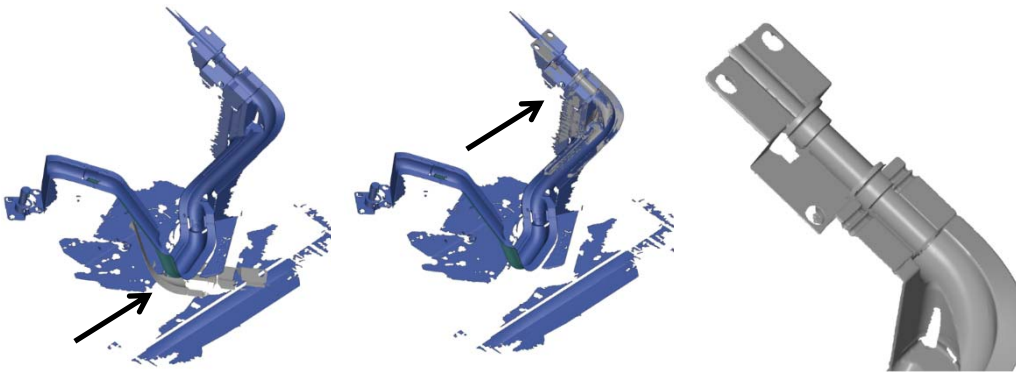
In order to full-fill its task to verify the geometry of attribute check fixtures on the basis of the point cloud and polygonal model, measured results must be an order of magnitude more accurate than the machine used to manufacture the part. The measurements shown in this paper were performed using an optical measuring system ATOS (Advanced TOpometric Sensor) [13].

2.2 Model Preparation

GOM Inspect software was used to process meassuring data ang measured results generation. GOM Inspect is advanced state-of-the-art dimensional metrology software [2]. It enables fast accurate work comparing the digital world to the physical world while meeting today's strict demands of quality control.

3D scanning allows adding areas that have been missed to scan or have been modified/upgraded (Figure 2). A new scan needs to be aligned to the old one, since it is in the arbitrary position (Figure 2a). Alignment is carried out through areas that are common to both scans (Figure 2b). In this way, one project can contain different positions of moveable elements (Figure 2c).

The software GOM Inspect has many features to process a polygonal mesh. However, it is very important that the polygonal mesh is unprocessed, as the filling of holes, decimations, and similar interventions on the mesh make changes onto original mesh and introduce unmetered assumptions. The only changes are permissible in terms of removing unnecessary data (Figure 2c).



(a) (b) (c)

Figure 2. *Model preparation*

2.3 Model Transformation

The model obtained in the previous step is in an arbitrary position in the space. In order to be usable for measurement, it is necessary to transform it to the coordinate system CAD model through the procedure called alignment. There is the initial alignment or prealignment and the main alignment.

Using the function Prealignment, software prealign the actual data to the nominal data (CAD) regardless of the start position. The more structured a component is, the

faster the software finds a solution for the alignment. For flat or rotationally symmetric components, the software needs a longer search time. Prealignment is required before any further alignment or inspection.

The function Local Best-Fit With Tolerances aligns actual data to nominal data via a best fitting with defined tolerance limits. Figure 3a shows on top the CAD data and below the measured actual part. The actual data is not prealigned yet. The question is whether the built-in part fits into the CAD data. The CAD and the actual elements are interwoven (Figure 2). Figure 3b shows the result of prealignment. The local best-function function requires defining the area of the model by which the match will be performed (Figure 3c). The result of the alignment with the tolerance definitions (Upper limit +0.2 mm and Lower limit -0.2 mm) is shown in Figure 3d.

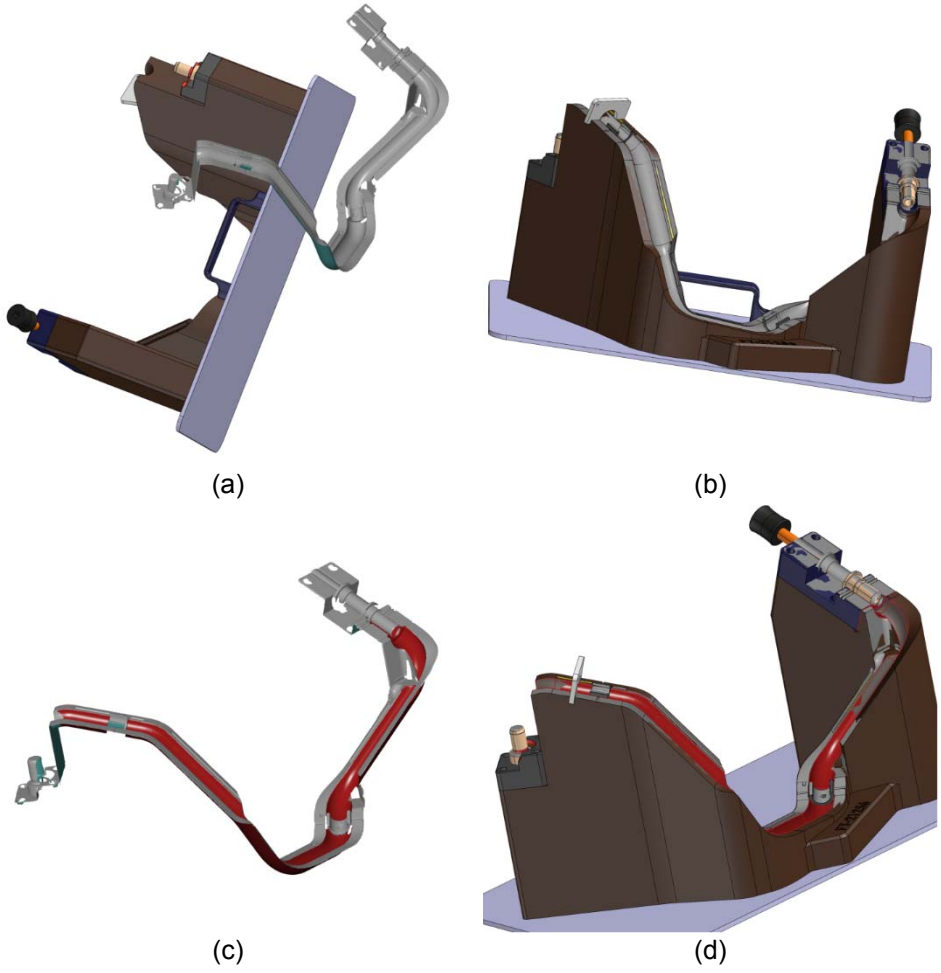


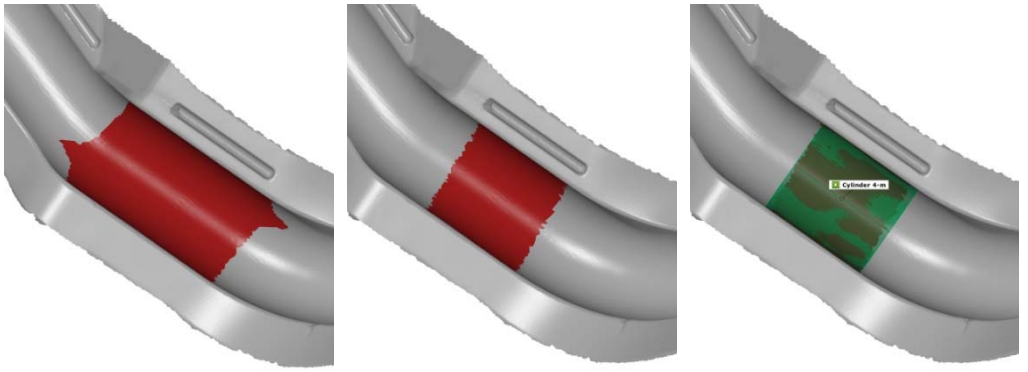
Figure 3. *Alignment of nominal (CAD) and actual (digitized) data:*
(a) relative position of nominal and actual data before prealignment,
(b) relative position of nominal and actual data after prealignment,
(c) zones of actual data used for main alignment,
(d) relative position of nominal and actual data after best-fit alignemnt

2.4 Feature Extraction

A measuring principle is a simple way to create actual elements. The software creates the actual elements based on the nominal elements (CAD data). During this procedure, the software links the actual element to the nominal element. In addition, the measuring principle contains the information, in which way the software creates and links an actual element.

While creating any feature using Gausian Best-Fit, the software squares the deviations of the selected points or polygons to the possible fitting element, adds up the quadratic deviations, and changes the possible fitting element until the sum is the smallest. Then, the software creates the fitting element. Parameter of the Gaussian method is measuring point outliers – measuring points which will eliminated during calculation. Because we use digitized data, software operates on large number of points, and, to the Gaussian distribution, the values are: (a) 1 sigma = approx. 68.3 % of all points, (b) 2 sigma = approx. 95.4 % of all points, (c) 3sigma = approx. 99.7 % of all points, ... If All points are selected, the software considers all selected points and does not eliminate the measuring point outliers.

By measuring the principle, the software automatically determines the area on the model to fit the cylinder. However, the selected area may be greater than that which is actually cylindrical (Figure 4a). For this reason, the tool indicates the length at which the cylindrical area should be selected (Figure 4b). The cylinder fitted in this way is shown in Figure 4c.



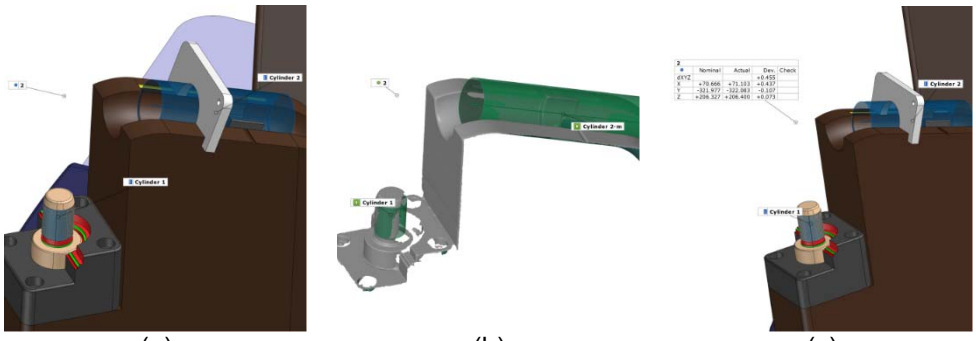
(a) (b) (c)

Figure 4. *Cylinder extraction based on measurement data:*
(a) area of actual data selected by measuring principle,
(b) user corrected area of actual data, and
(c) „actual cylinder" fitted based on user corrected area of actual data

2.5 Control Point Construction

The control points are constructed as intersections of the tube straight line segments or features of the device (Figure 5). For example, point 2 is obtained as a intersection of the cylinders 1 and 2. Cylinder 1 is a feature at which the end of the tube is placed, and the cylinder 2 is a straight line segment of tube. Using the function Referenced Construction, software creates actual elements in the same way as the

nominal elements are created. In other words, the software reproduces the way of construction on the actual data.



(a) (b) (c)

Figure 5. *Procedure for control point construction: (a) construction of features on nominal data, (b) features constructed on actual data using measuring principle (fitting element), and (c) construction of intersection point on nominal data and on actual data using measuring principle (referenced construction)*

3 RESULTS

The control of the geometry of the attribute check fixtures starts from the assumption that with the position of the control points check we can precisely check the compliance of the fixtures with the requirements expressed by the technical documentation. By the procedure described, we obtain a total deviation of the control point constructed on the basis of actual data with respect to the corresponding point on the nominal data, as well as deviations in the direction of the coordinate axes (Figure 6). A large number of measuring points allows to determine the field of deviation of real pieces in relation to engineering ideas – CAD model (Figure 7).

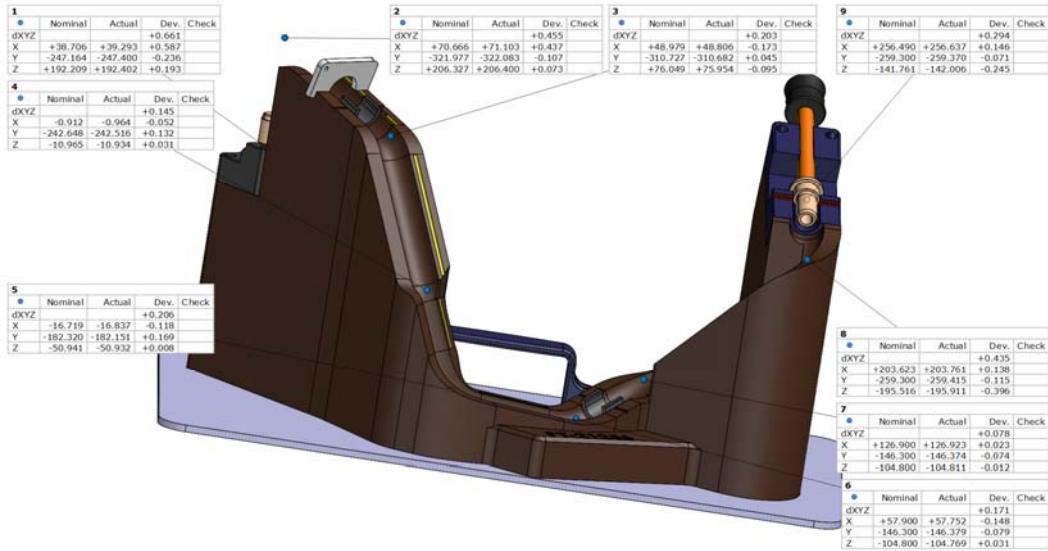


Figure 6. *Measurement results for control points*



Figure 7. *Deviation field of digitized surface in reference to CAD model of attribute check fixture*

Based on these measurements, accredited laboratories may issue appropriate calibration certificates [16]. Calibration certificates issued by Lotric Metrology DOO are available for their users online via the portal MEOL – Measurement On Line (logging with user name and password) [17].

4 CONCLUSION

A part is only as good as its inspection. Fixtures allow the evaluation of many data points in a quick and rational manner. A check fixture is a quick-to-use and easy-to understood tool that ensures the part is built to the customer's requirements.

The paper presents a new approach for calibration certification of attribute check fixtures on the basis of the point cloud and polygonal model captured by structured light 3d scanners. Sample preparation, 3D scanning, processing of point cloud and generation of measurement reports are described. A large amount of recorded measuring points with high accuracy of measurement ensures that certification pass only fixtures that meet the requirements defined by the documentation. Based on presented results, the methodology presented is a valuable tool for calibration certification of attribute check fixtures for tube manufacturing.

In addition to the primary task, to enable validation and certification of attribute check fixtures for tube manufacturing, this procedure also provides the documentation of the device. Thanks to the dense point data, it is possible to monitor the wear and damage of the fixtures over time. The methodology presented in this paper can be applied for calibration certification to all other types of gages, fixtues and jigs (component, assembly, acceptance, variable data, SPC, hot stamp, go/no-go, automated, process, and hand-held gages, assembly, robotic weld, spot weld, mig weld, riveting, hemming, bonding, CMM inspection, drill, and laser fixtures (hot stamp), drill jigs, ...) [6-9, 14].

ACKNOWLEDGMENT

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RAZVOJ KONSTRUKCIJA SA ČVRSTIM PRINCIPOM, PRAKTIČAN PRIMJER

Biljana Marković[1], Marijana Karijšnik[2], Aleksija Đurić[3]

Rezime: Konstruisanje kao stavaralački proces, predstavlja intelektualni rad, koji počinje od inovativne ideje, a čiji je krajnji proizvod tehnička dokumentacija, odnosno proces koji leži između stvaralačke zamisli i proizvodnje. Na putu od ideje do krajnjeg cilja, izrade proizvoda, proces konstruisanja se odvija kroz nekoliko međusobno povezanih i uslovljenih faza. Podela konstrukcija je zasnovana na tome koliko je faza koncipiranja zastupljena u procesu konstruisanja, odnosno kako se do konstrukcijskog rešenja se može doći i skraćenim postupkom. U ovom radu je prikazan razvoj konstrukcjie sa čvrstim principom, na primeru četverostranog College suncobrana.

Klučne reči: konstruisanje, razvoj proizvoda, konstrukcija sa čvrstim principom

DEVELOPMENT OF A RIGID CONSTRUCTION PRINCIPLE, PRACTICE EXAMPLE

Abstract: Constructing (design) as an creative process is an intellectual work that begins with an innovative idea and the final product of it is technical documentation, that is, a process which lies between creative ideas and production. On the way from an idea to an ultimate goal, product manufacturing, the design process takes place through several interconnected and conditioned phases. The division of constructions is based on how much the design phase is represented in the design process, or how the design solution can be achieved by a shortened procedure. This paper presents the development of a rigid construction principle, in the case of four-sided College umbrellas.

Key words: construction (design), product development, rigid construction principles

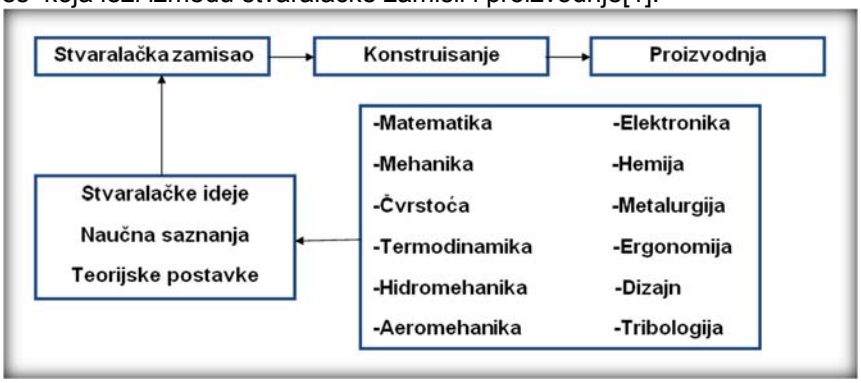
1. UVOD

Konstruisanje predstavlja stvaralački, prvenstveno, intelektualni rad čiji je krajnji proizvod tehnička dokumentacija, koju čine sklopni i radionički crteži, analize stanja

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[3] Aleksija Đurić, Istočno Sarajevo, Mašinski fakultet Istočno Sarajevo, aleksijadjuric@gmail.com

radne sposobnosti, proračuni pojedinih dijelova i uputstva za izradu i eksploataciju.

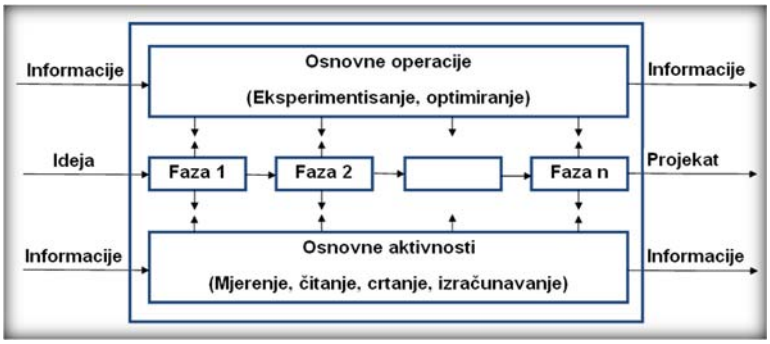
Proces konstruisanja (Slika 1) započinje idejom (stvaralačkom zamišlju) o mašini, određenih karakteristika, za obavljanje određene funkcije. Na kraju procesa konstruisanja dobija se konstrukciona i eksploataciona dokumentacija. Konstruisanje je, dakle, proces koja leži između stvaralačke zamisli i proizvodnje[1].



Slika*1. Proces konstruisanja [1,2]*

Cilj konstruisanja je da za tehničke probleme nalazi optimalna rešenja, odnosno da ispuni sve zahteve vezane za proizvodnju, eksploataciju i reciklažu.

Opšta šema procesa konstruisanja prikazana je na slici 2, u kojoj je osim navedenih faza prikazan i informacioni proces koji se odvija paralelno i u vezi sa ovim procesom. Ulazne informacije su znanja i podaci koji se prikupljaju i koriste u procesu konstruisanja. U okviru procesa one se prerađuju, oplemenjuju, podižu na viši nivo i koriste za odvijanje svake od faza. Ostaju kao novostečeno iskustvo, znanje ili skup novih podataka i predstavljaju još jedan rezultat procesa konstruisanja pogodan za korišćenje u daljem radu [1,2].



Slika 2. *Opšta struktura procesa konstruisanja[1 2]*

2. FAZE U PROCESU KONSTRUISANJA

Proces konstruisanja objašnjen je procedurom definisanom u VDI 2222 koja prikazuje algoritam koji opisuje ovaj proces kroz pet faza [2]. Tokom odvijanja svake od faza može se ostvariti povratna sprega. Time je omogućeno da ako se uoči greška ili

nedostatak učinjen u realizacije neke od prethodnih faza, te se konstruktor može vratiti u nazad i korigovati sve prethodno uočeno. Proces konstruisanja je proces transformacije informacija iz stanja na nižem nivou u viši, s ciljem da se kroz postupno uobličavanje i zadovoljavanje zadatih ograničenja dođe do rješenja koji je podloga za realizaciju materijaliziranog znanja proizvoda.

Prva faza obuhvata razradu ideje i prikupljanje podataka kako bi se definisali uslovi koje mašinski sistem treba da zadovolji. Ovi uslovi (zahtjevi i želje) rezultat su trenutnih potreba tržišta, korisnika i proizvodnih mogućnosti. Unose se u listu zahtjeva koja je rezultat prve faze procesa konstruisanja i koja definiše proizvod (mašinski sistem) na opisnom nivou. To je definicija projektnog zadatka koja obuhvata odgovore na pitanje ŠTA sistem treba da radi. Lista zahtjeva po potrebi može da bude i širi elaborat i mora da obuhvati faktore koji predstavljaju ograničenja i uslove koje treba zadovoljiti.

Druga faza obezbjeđuje odgovor na pitanje kako, odnosno na kom principu će mašinski sistem da radi. To je koncipiranje principa rada i strukture dijelova iz kojih će se sistem sastojati. Rezultat ove faze je koncepcija, odnosno principijelna šema mašinskog sistema. U ovoj fazi mašinski sistem je definisan na nivou principa rada.

Treća je faza razvoja dimenzija i oblika mašinskih dijelova. Za svaki mašinski dio bira se materijal, oblik i način izrade. Iza toga slijedi proračun, odnosno izbor ključnih dimenzija. Simultano, sa izborom dimenzija formira se i oblik koji se usklađuje sa funkcijom, načinom izrade, optimalnim iskorišćenjem mase i dr. Mašinski dijelovi se povezuju u sklopove, jer je oblik u značajnoj mjeri uslovljen odnosom dijelova u sklopu. Rezultat svih aktivnosti u ovoj fazi je preliminarni sklopni crtež. Na ovom nivou mašinski sistem je globalno definisan. Nisu razrađeni manji konstrukcijski detalji i nisu provjerena stanja i ponašanje sistema pri izvršavanju funkcije.

U četvrtoj fazi provjeravaju se naponska stanja, sigurnost i pouzdanost u radu, osjetljivost na pobudu vibracija i sl. Utvrđeni nedostaci se otklanjaju korekcijama dimenzija, oblika, materijala, termičke obrade itd. U nekim slučajevima može biti izrađen prototip čijim se ispitivanjem u uslovima eksploatacije otklanjaju uočeni nedostaci.

Peta faza procesa konstruisanja obuhvata konstrukcijsku razradu. Izrađuju se crteži detalja, propisuju tolerancije, termičke obrade i sl. Konstrukcijska dokumentacija zajedno sa uputstvom za rukovanje, održavanje, reciklažu čini projekat koji je rezultat posljednje faze i procesa u cjelini [2].

3. VRSTE KONSTRUKCIJA

U praksi se do konstrukcijskih rješenja može doći i po skraćenom postupku. Neke od faza u procesu konstruisanja mogu da budu izostavljene. To se odražava na stepen inoviranosti konstrukcijskog rješenja, a rezultati procesa konstruisanja mogu se svrstati u nekoliko grupa. Podjela je zasnovana na stepenu zastupljenosti faze koncipiranja, odnosno na načinu dolaženja do principa rada mašinskog sistema. Po ovom osnovu konstrukcijska rješenja se dijele na ponovljene konstrukcije, konstrukcije sa čvrstim principom, prilagođene konstrukcije, varijantne konstrukcije i nove konstrukcije. Na slici 3 ova podjela je ilustrovana matricom u kojoj je za navedenih pet vrsta konstrukcija pokazan stepen zastupljenosti faza u procesu konstruisanja [1, 2].

Ponovljene konstrukcije se izrađuju u novoj seriji bez ikakvih izmjena. Isključuju se sve faze procesa konstruisanja osim manjih izmjena na tehničkoj dokumentaciji [1].

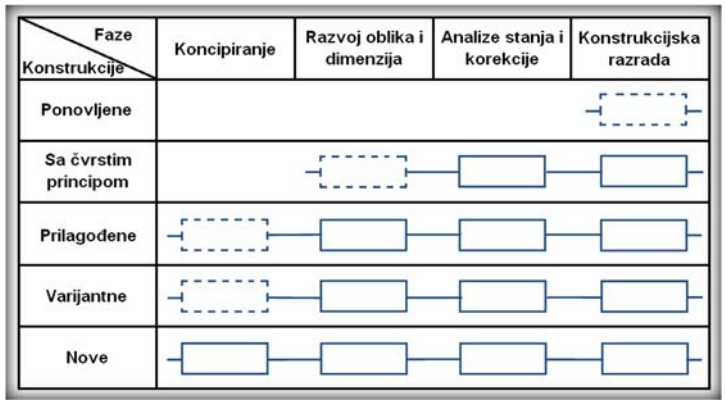
Navedene konstrukcije se bez većih promjena ponovo uvode u proizvodnju i na tržište. Radi se o konstrukcijskim rješenjima za koja je procjenjeno da ih tržište još može prihvatiti bez izmjena. Isto tako, to mogu biti konstrukcije kojih se jedan proizvođač

oslobađa i prepušta ih drugom u obliku dozvole (licence) da ih bez izmjene ili uz neznatne promjene izrađuje pod određenim tržišnim uslovima. U projektu za ove konstrukcije eventualno se mogu mijenjati manji detalji u konstrukcijskoj dokumentaciji ili otklanjati eventualni nedostaci tj. usavršavati. Može biti djelimično zastupljena faza konstrukcijske razrade [1, 2].

Konstrukcije sa čvrstim principom rada su ona konstrukcijska rješenja kod kojih se princip rada iz generacije u generaciju, od proizvođača do proizvođača ne mijenja. Djelimično se mijenjaju oblici, dimenzije, materijal ili termička obrada. Faza koncipiranja kod ovih konstrukcija ne postoji, a faza razvoja oblika i dimenzija mašinskih dijelova zastupljena je samo djelimično. Projekat se izrađuje kroz dvije posljednje faze. Ovakav pristup je svojstven kopiranju postojećih rješenja. Više je zastupljen u prošlost,i kada se do novog principa moglo doći samo u obliku pronalaska izuzetno nadarenih ljudi [1, 2].

Prilagođene konstrukcije (rekonstrukcije) dobijaju se prilagođavanjem poznatih konstrukcionih rješenja novom zadatku (funkciji) koji treba izvršiti. Podrazumijevaju se nova konstrukciona rješenja za pojedine dijelove [1]. Postojeći princip sa postojećih mašina za drugu svrhu, kopira se i prilagođava novim uslovima rada. U ovom slučaju faza koncipiranja idejnog rješenja nije izostavljena, već je skraćena. Postojeći princip sa jednog ili više mašinskih sistema se prilagođava i uklapa u nove uslove [2].

Varijantne konstrukcije imaju isti princip, a varira veličina i raspored pojedinih komponenti unutar sistema [1]. Kod zupčastih prenosnika, napr.ozubljenii par je nosilac principa transformacije obrtnog momenta. Različitim kombinovanjem tog principa dobijaju se različiti višestepeni i drugi prenosnici. Kod motora, napr. klipni mehanizam se kombinuje u različitim varijantama višecilindričnih motora. Faza koncipiranja je zastupljena djelimično, a ostale u potpunosti [2].



Slika 3. *Podela konstrukcija prema zastupljenosti faza [1, 2]*

Nove konstrukcije zasnivaju se na novom principu rada ili predstavljaju novo tehničko rješenje (različito od postojećih). Ovdje se sprovode sve faze procesa konstruisanja [1]. Nastaju kao rezultat u potpunosti sprovedenog procesa konstruisanja, za nove potrebe korisnika ili pri realizaciji novih tehnoloških iskoraka - pronalazaka [2].

Obzirom na prethodno opisanu podjelu, gdje je objašnjeno da konstrukcije sa čvrstim principom nemaju jasno izraženu fazu koncipiranja, zbog postojećeg konstruktorskog rješenja, a faza razvoja oblika i dimenzija može biti djelimično

zastupljena, ovdje je na konkretnom primjeru pokazano na koji način je moguće izvesti izmjenu ovakve konstrukcije, u cilju njenog poboljšanja u traženju rješenja problema koji su uočeni u eksploataciji, a da se ne naruši prvobitna ideja konstruktora (originalno rješenje proizvođača).

4. ANALIZA COLLAGE SUNCOBRAN

Predmet istraživanja koji je opisan u ovom radu odnosi se na četvorostrani Collage suncobran, proizvođača koji je poznat po kvalitetu i dizajnu izrade različitih tipova suncobrana, prilagođenih specifičnim karakteristikama različitih geografskih područja, od osnovnog materijala za izradu noseće konstrukcije - čelik, slika 3.

Navedeni suncobran integriše četiri pojedinačna suncobrana, veličine do 5x5m, u jedan ogromni suncobran na centralnom nosećem stubu, ukupne veličine do 10x10m. S obzirom da se radi o suncobranu koji dolazi iz realnog sektora proizvodnje, cilj je na praktičnom primjeru pokazati način razvoja konstrukcije sa čvrstim principom. Suncobrani se koriste na različitim mjestima i u različitim vremenskim uslovima, od visokih planinskih predjela sa velikim količinama sniježnih padavina, do morskih plaža gdje bura i nevrijeme često znaju napraviti štetu, ukoliko se suncobrani ne zatvore i ukoliko se ne poštuju pravila Priručnika za upotrebu (propisao prizvođač).

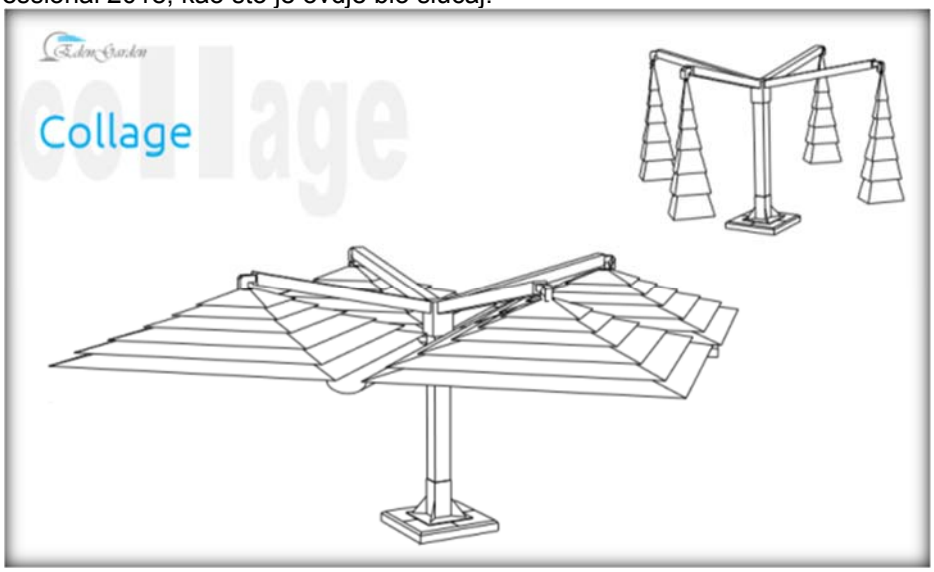
Deformacije na spoju gredice i krsta, koje su se pojavile u određenim geografskim područjima posebno izloženim vjetru i klimatskim promjenama, pokazale su da je neophodno izvesti istraživanje mogućnosti izmjena na konstrukciji suncobrana, kako bi se povećao kvalitet, odnosno spriječila ili minimizirala pojava deformacija, čime bi se produžio rok upotrebe, ali i obezbjedila sigurnost korisnika.

Kao mjerodavno opterećenje analiziran je uticaj vjetra na nosivost konstrukcije. Sila vjetra prvenstveno zavisi od stvarnih karakteristika te prirodne pojave, od brzine i smijera kretanja vazduha, načina djelovanja (konstantno, promjenjivo ili oboje). Djelovanje vjetra na određenu konstrukciju zavisi od dimenzija konstrukcije i njenog položaja u prostoru. Iako je djelovanje vjetra dinamičke prirode, u većini slučajeva se može zamijeniti ekvivalentnim statičkim opterećenjem [3].

Vjetar nastaje usljed nejednake raspodjele toplotne energije u atmosferi i razlike pritiska vazduha, pri čemu nastaju vazdušna strujanja koja se kreću iz područja višeg pritiska prema području nižeg pritiska vazduha. Na formiranje vjetrova, osim neravnoteže atmosfere, utiče još i trenje struje vazduha sa tlom, trenje između čestica vazduha, Coriolisova sila te centrifugalna sila kad se čestice kreću po zakrivljenoj trajektoriji [4].U ovom radu je prikazan proračun opterećenja gredice suncobrana na vjetar prema evropskoj normi EN 1991-1-4. U dodatku EN norme za djelovanje vjetra opisani su pojmovi vrtložnog odvajanja i aerodinamičke stabilnosti poprečnih presjeka mostova. Definisani su kritična brzina vrtložnog odvajanja, sila koja djeluje na presjek pri vrtložnom odvajanju, koeficijent aerodinamičke sile i prikazan je proračun najveće amplitude oscilacija[5].Kao što je već naglašeno Collage suncobran se sastoji iz četiri gredice koje predstavljaju nosače kupola suncobrana, slika 4. U ovom radu, u cilju skraćenja vremena i pojednostavljene analize, izvršeno je ispitivanje samo jedne gredice, i to analogijom sa građevinskikim objektima (podjela kupole suncobrana na površine), koje opisuju način određivanja vanjskog opterećanja na tzv. četverovodne krovove.

Prvi korak pri proračunu gredice je određivanje opterećenja kojima je ona izložena, radnog opterećenja. Radno opterećenje je poznato ukoliko su poznati intenzitet, pravac i smijer opterećenja, njegova promjena u toku vremena i raspodjela

opterećenja u poprečnom presjeku. U opštem slučaju, opterećenje gredice prestavlja prostorne sisteme sila i spregova koji nastaju kao kao poslejidica otpora koji gredica savladava vršeći koristan rad. Nakon definisanja vanjskog opterećenja, potrebno je numeričkom analizom doći do podataka koji omogućavaju korekcije na postojećem dijelu konstrukcije i na taj način uklaniti potencijalne uzroke pojave deformacije, (Ansys Workbench), a prethodno izvesti modeliranje, napr. u programu Autodesk Inventor Professional 2018, kao što je ovdje bio slučaj.



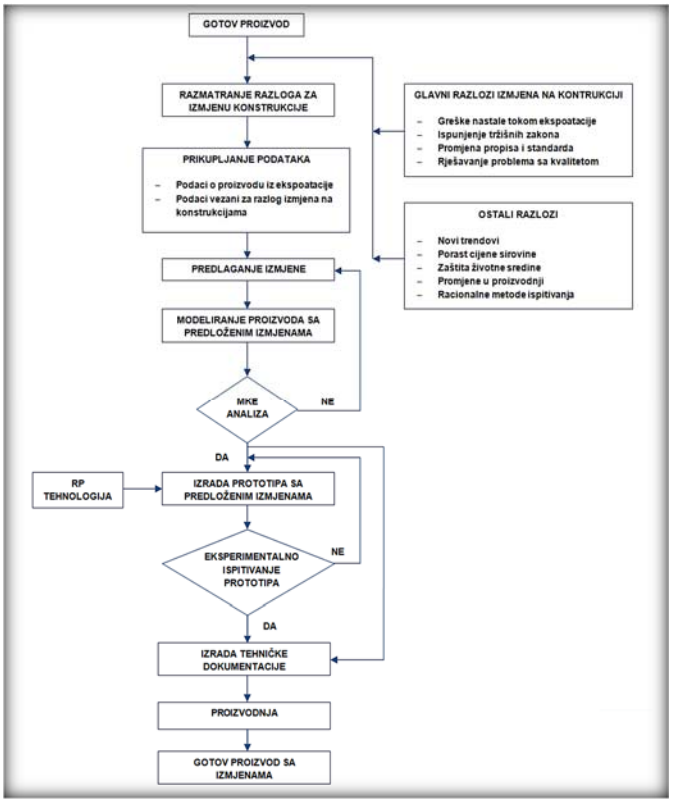
Slika 4.*Četvorostrani Collage suncobran*

5. ALGORITAM ZA ANALIZU I KOREKCIJU KONSTRUKCIJE SA ČVRSTIM PRINCIPOM

Postupak analize i korekcije na konstrukciji sa čvrstim principom predstavljen je algoritmom na slici 5. Iako su danas, u svijetu, kroz dostupnu literaturu, dobro opisane i vrlo poznate metode razvoja novih ili inoviranih proizvoda, ipak je mali broj praktičnih primjera koji detaljno opisuju razvoj različitih vrsta konstrukcija, posebno konstrukcija sa čvrstim principom.

Od ranije je poznato da je često nemoguće povući jasnu granicu između pojedinih vrsta konstrukcija (Slika 3), jer se na različit način tretiraju uticajni faktori koji su uzrok za promjenu konstrukcije, u različitim fazama razvoja.Naglašeno je da se na konstrukcijama sa čvrstim principom ne smije izmijeniti koncepcija, odnosno funkcija dijela na kome se vrši izmjena, u cilju poboljšanja. Naravno, svi konstrukcijski problemi imaju višestruka zadovoljavajuća rješenja, a nemaju jasnog najboljeg rješenja.

Zato je prikazani algoritam (Slika 5) značajan doprinos analizi konstrukcija sa čvrstim principom, u cilju pojednostavljenja razvoja, analize uzroka za izmjenu konstrukcija, kao i praćenja svih uticajnih faktora, koji mogu predstavljati uzrok izmjene.



Slika 5. *Algoritam za analizu i korekciju konstrukcija sa čvrstim principom*

6. ZAKLJUČAK

U ovom radu je prikazan način razvoja konstrukcije sa čvrstim principom, na konkretnom primjeru razvoja, odnosno izmjene (korekcije) na konstrukciji Collage suncobrana. Korišćene su poznate metode razvoja, ali i sve dostupne metode analize konstrukcija, bazirane na MKE, putem dostupnih softvera, koji omogućavaju detaljan prikaz napona i deformacija na postojećoj i izmjenjenoj konstrukciji.Prema tome, primjenom metode konačnih elemenata može se vršiti analiza korekcija na konstrukcijama sa čvrstim principom i na osnovu toga donijeti odluka da li se tom korekcijom nastavlja dalje ili je potrebno raditi dodatne izmjene.

Dodatno, opisan je način istraživanja uticaja vjetra na mašinske konstrukcije. Pomenut je primjer raspoređivanja pritisaka vjetra na konstrukcije koje nisu upravne na djelovanje vjetra, što je prikazano u drugim radovima. Ovaj način istraživanja baziran je na primjeru istraživanja uticaja vjetra na građevinskim konstrukcijama, metodom analogije. Na osnovu prethodno pomenutih analiza, dokazano je da se uticaj vjetra na mašinsku konstrukciju može predstaviti kroz statičku analizu u softveru AnsysWorkbech.

Specifičan doprinos ovog rada ogleda se u definisanju algoritma za analizu i korekciju konstrukcija sa čvrstim principom, kojim su obuhvaćeni uticajni faktori, koji mogu predstavljati uzrok za izmjenu, odnosno korekciju konstrukcija. Dakle, na konstrukcijama sa čvrstim principom je moguće realizovati poboljšanja, u cilju

eliminisanja uzroka pojave deformacija, u eksploatacionim uslovima, korištenje, poznatih metoda razvoja proizvoda, kao i dostupnih softvera za modeliranje, simulaciju i analizu napona i deformacija. Validacija je moguća izradom protoipa, kao i izmjenama na konstrukcionoj dokumentaciji, nakon prihvatanja od strane originalnog proizvođača.

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ANALYSIS OF HOUSING MODELS OF MODERN TWO-STAGE UNIVERSAL GEAR REDUCERS

Milan Rackov[1], Ivan Knežević[2], Siniša Kuzmanović[3], Maja Čavić[4], Marko Penčić[5]

Abstract: Universal two-stage gear reducers are pretty simple products, so today there are many manufacturers around the world that produce this kind of reducers. However, their connecting dimensions and shape are not defined by the standard, so there is a variety of different solution. The connecting dimensions and axis height of gear reducers of most manufacturers are made the same as the gear units of biggest manufacturers (mainly company SEW). In this case they can provide interchangeability of their gear reducers. It is interesting to note that most manufacturers are trying to adopt such a form and shape of reducer that will look different from other solutions. Therefore, they can avoid an accusation of coping competing solution, although manufacturers have almost identical shape like competing (copied) solutions. Due to the volume of matter, the paper presents only the analysis of the forms of the housing of modern two-stage universal gear reducers manufactured in special housing for two-stage gear unit, in order to point out the expected directions of their further development.

Key words: Form, Housing, Universal two-stage gear reducer

1 INTRODUCTION

The basic dividing of universal gear reducers is performed according to the size of gear backlash, i.e. gaps between teeth, on so-called industrial gear units, which are most commonly used in practice and low backlash gears, with rotational backlash less than 10 angular minutes, so they are only used in precision mechanics [1]. Further division of industrial gear units is carried out according to the position of the gears on helical gear and planetary gear units. In this paper, only industrial gear units will be considered, although planetary reducers are increasingly used today in places where large gear ratios with small dimensions should be obtained. The helical gear units can be divided into gear units with parallel shafts and units with coaxial, or almost coaxial shafts. Universal gear units can be further divided according to the mounting method

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into radial, axial and radiaxial mounting [1,2]. According to the number of transmissions, universal gearing gear units can be divided into single, two, three, and multi stage gear units. According to the way of connection between the gearbox and the electric motor, there are gearboxes with classic input shaft without connected electric motor, gearboxes with IEC adapter, when an electric motor should be installed on IEC adapter, and motor geared reducer with mounted special or IEC electric motor. Depending on the size of gear unit, there are small gear units (axis heights $h < 100$ mm), medium gear unit ($100 < h < 500$ mm) and large gear units ($h > 500$ mm) [2]. The size of gear reducer can also have a certain effect on the final shape of gear unit housing. However, producers try to make all housings to be identical to each other. Within this paper, only medium-sized reducers are considered.

2 PROBLEM DESCRIPTION

Universal medium-sized reducers can be manufactured separately in a special housing for single, two, three and multi-stage reducer, which is the best solution, but also the most expensive, justified in large series and such an approach is less common in practice. Single-stage reducers are only manufactured in single-stage housings, although there are manufacturers who do not produce single-stage units at all in order to reduce production costs since they are not relatively demanded. However, if they are required, two-stage reducers with lower transmission ratio are offered instead. [3] Two-stage gear drives are often produced in a special housing for two-stage units, and three-stage reducers are designed by connecting the single-stage reducer housing to the two-stage gear unit. In this case, two-stage reducers are cheaper, while the three-stage reducers are a bit expensive. Four-stage gear drives are manufactured by connecting two-stage reducer with a smaller two-stage gear drive. There are manufacturers who produce universal housing for two and three-stage reducers, so their two-stage reducers are more expensive than two-stage units built in a special case for two-stage reducers. However, their three-stage gear drives are cheaper than three-stage reducers made in a combination of two-stage and single-stage reducer. Four-stage and multi-stage reducers are built by connecting two two-stage, three-stage and two-stage or two three-stage reducers. [3,4] What concept will be adopted depends on which particular segment of the gear ratios (revolution number) is interested for the company. The most demanded are two-stage reducers with high gear ratios, or three-stage reducers with lower gear ratios. Therefore, some companies produce only this type of reducers. Smaller manufacturers tend to the opposite area than the major competitors, but there are manufacturers who have both types of reducers in their product line. In this paper, only two-stage gear reducers are considered, which are produced in a special housing for two-stage unit, which is the basic approach of smaller gearbox manufacturers, since large manufacturers use universal housing for two and three-stage gear units.

3 TWO-STAGE GEAR REDUCERS

The shape of the two-stage gearbox housing with coaxial, or almost coaxial shafts, very much depends on the way of the installation. The most commonly ways of installation are foot-mounted (Fig.1-a), flange-mounted (Fig.1-b,c), foot and flange-mounted (Fig.1-d), flange-mounted type with the extended bearing hub (Fig.1-e) and with hollow shaft-mounted (Fig.1-f). The shape of each case is adapted to certain installation requirements. [3,5]

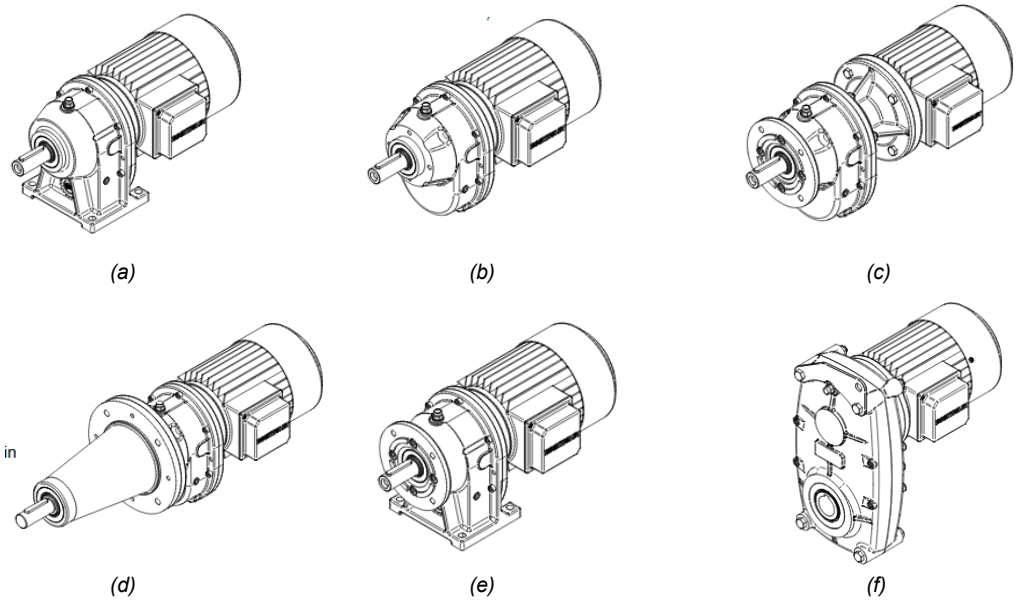


Figure 1. *Characteristic way of installation of universal gear reducer: (a) foot-mounted, (b,c) flange-mounted, (d) foot and flange-mounted, (e) flange-mounted type with the extended bearing hub, (f) with hollow shaft-mounted [5]*

Universal gear reducers are provided for different ways of mounting, so their design is more complicated than special gear reducers which are designed for particular purpose. Since the manufacturers of gear reducers do not know the exact purpose of their units, they try to adapt them to practically all, or almost all, purposes, i.e. the ways and positions of mounting. This is the reason why there are so different forms of gear reducer housing. [3] Within different developed solutions of universal two stage gear reducer, there are two main concept forms: when the output gear is overhanged (Fig. 2-a) and when the output gear is positioned between bearings (Fig. 2-b). The solution with the output gears between the bearings provides more compact construction and greater stiffness of the output shaft, and consequently a more correct fitting between teeth of the gears, but the installation of these gear units is somewhat more complicated. [2,3,4]

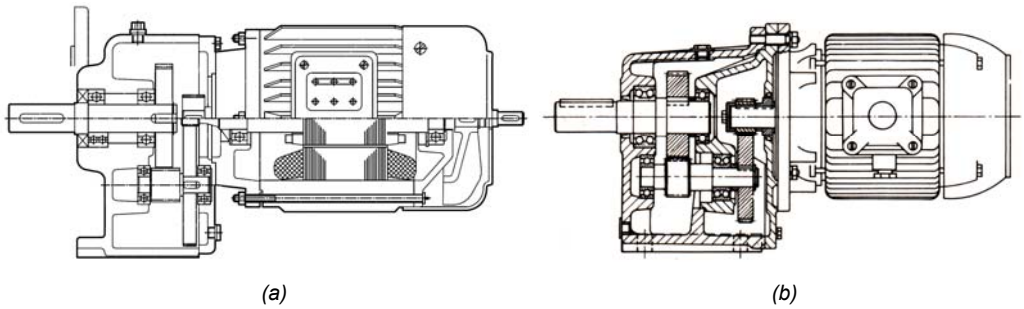


Figure 2. *Characteristic solutions of universal two-stage gear reducer: gear unit with overhanged output gear, solution of company NORD (a) [6], gear unit with output gear between bearings, solution of company ROSSI (b) [7]*

4 ANALYSES OF DIFFERENT SOLUTIONS

The solution with the output gear between the bearings provides more compact construction and greater stiffness of the shaft, and thus more correct fitting of the gears.

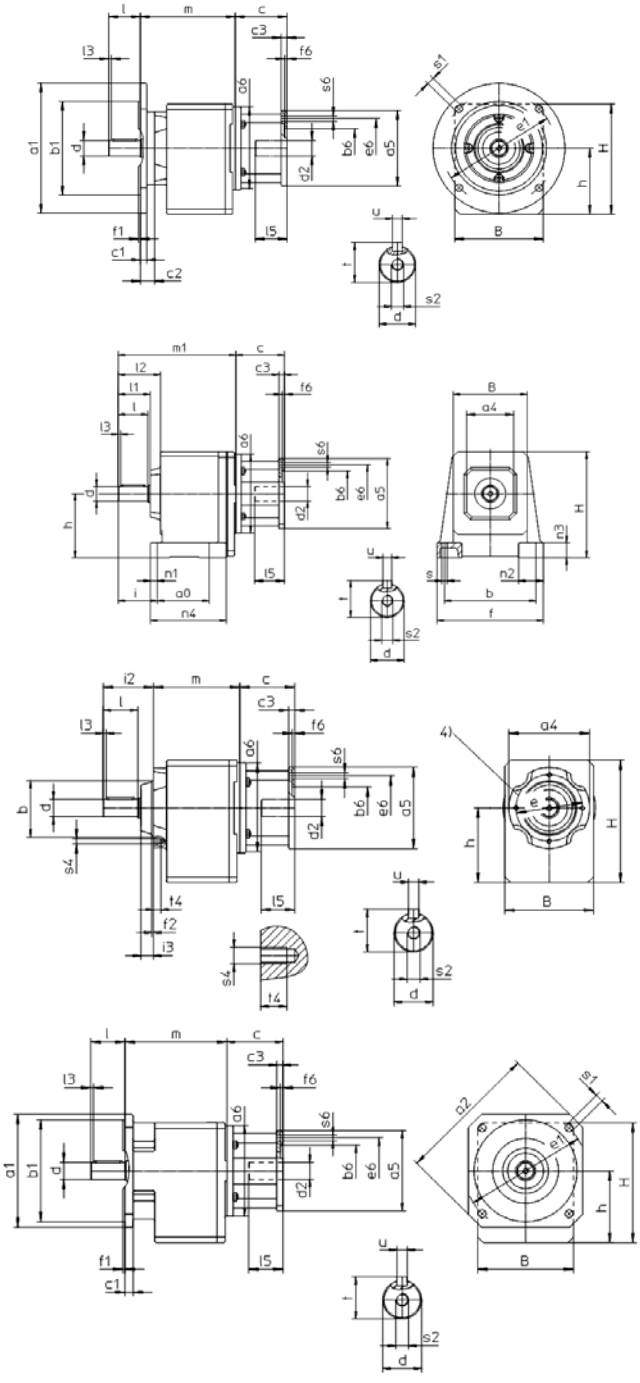


Figure 3. *Characteristic ways of installation of two-stage gear reducer of company STÖBER [8]*

However, the installation of these gearboxes is somewhat more complex. Smaller manufacturer of gearboxes company STÖBER offers the most complete program of two-stage gear units (Fig.3). This manufacturer produces two-stage gear units for foot-mounting and flange-mounting, and all that with three different flange sizes, which is rarely required. Also, this manufacturer produces all these gear units with classical input shaft, with an adapter for IEC motor (flanges dimensions B5 and B14). The form of the housing is very simple. The manufacturer did not take into account material savings as well as additional reinforcement of the housing. The shape of the housing provides better heat removal and easier maintenance (cleaning), which also improves heat dissipation and thus ensures regular operation of the gearbox.

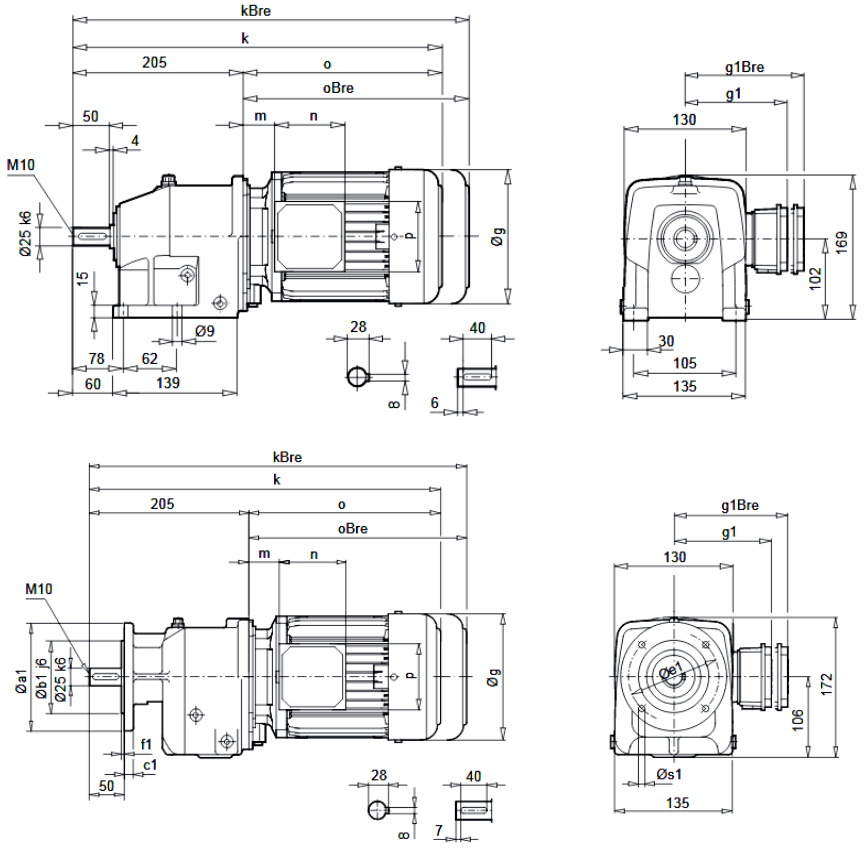


Figure 4. *Characteristic ways of installation of two-stage gear reducer of company NORD [6]*

Similar gear reducers are produced by company NORD (Fig.4) and BOCKWOLDT (Fig.5). However, they produce two-stage gear units for foot-mounting and flange-mounting, but only with one dimension of flange size connected with housing. Company BOCKWOLDT also produce flange-mounted gear reducers with the extended bearing hub. Both companies produce gear units with classic input shaft and with adapter for IEC electric motors. The shape of the case is somewhat more complicated but still very simple and elegant. [5,6]

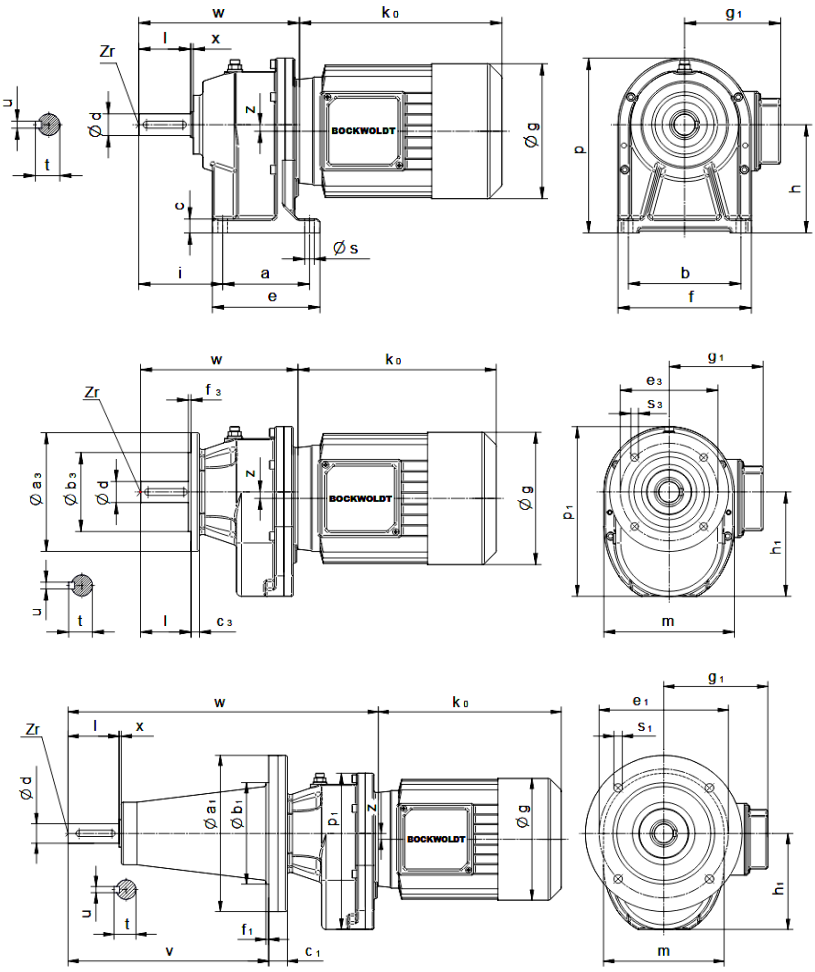


Figure 5. *Characteristic ways of installation of two-stage gear reducer of company BOCKWOLDT [5]*

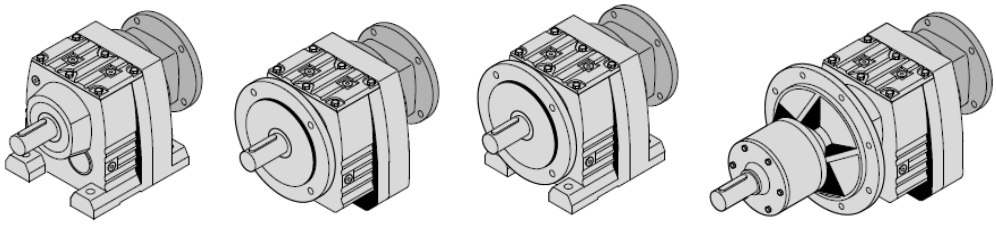


Figure 6. *Characteristic ways of installation of two-stage gear reducer of company SEW [9]*

Company SEW (Fig.6) also produces two-stage gear units for foot-mounting and flange-mounting. It also produces, but in smaller amounts, foot and flange-mounting and flange-mounted gear reducers with the extended bearing hub. Their housings have also simple construction, but with the sideward waviness of ribbed

housing, due to better cooling of the surface and due to the increased stiffness and strengthness of the housing body. [9]

Company NORD produces only gear units for foot-mounting and flange-mounting, as they are most required within two-stage gear units, since it is not justified (according to them) to have a wider production program [6].

5 EXPECTED DIRECTIONS FOR FURTHER DEVELOPMENT

According to the solutions of the world's leading manufacturers of two-stage gear units, it can be expected that the further development of two-stage gear units is done in only the two basic types of installation - with the foot-mounting and with flange-mounting (Fig.7). Other forms of installation are less demanded and it is expected that smaller gear reducer manufacturers are based on that segment of market demands which is not covered by leading manufacturers.

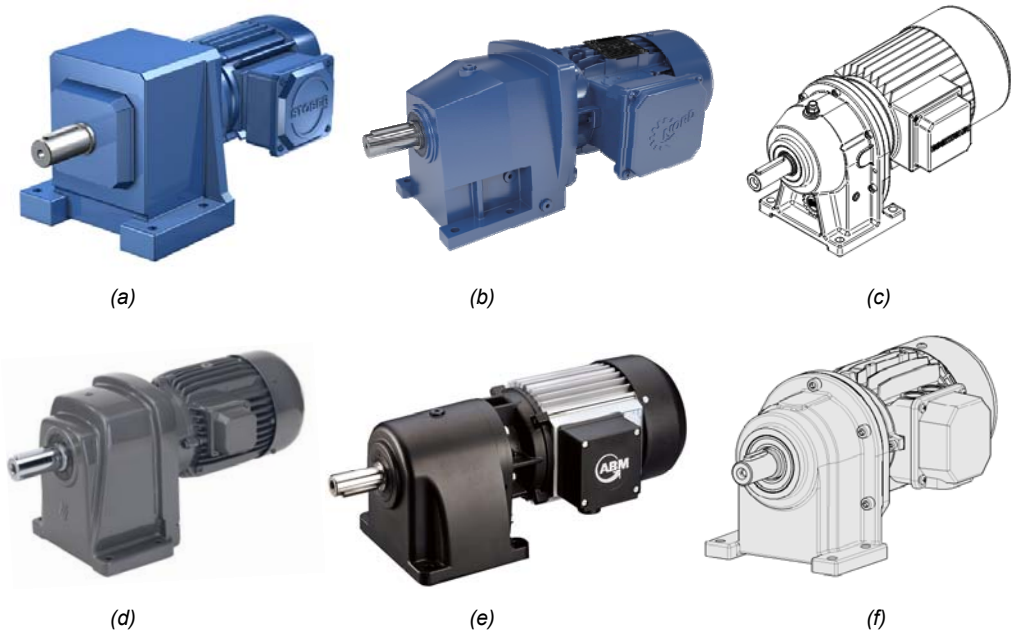


Figure 7. *Characteristic design solution of two-stage gear reducer of companies STÖBER (a) [8], NORD (b) [6], BOCKWOLDT (c) [5], BEGE/STROTER (d) [10], ABM (e) [11], REHFUSS (f) [12]*

6 CONCLUSION

It is evident that modern solutions of two-stage gear reducer housing, beside its functional requirements, put aesthetic requirements in the first place, regardless of material consumption and manufacturing complexity. This means the design of the gearbox increasingly plays a fundamental role in the selection of the gear unit, although the gears units are installed in the machine and are often not directly visible to the observer. Since the modern gear reducers are in terms of quality, technical characteristics and prices fairly uniform, the design of the gearbox must be given special attention, since the nice gear reducer attracts the attention of the customer and

makes a purchase decision based on its design. This conclusion can be achieved by observing the solutions implemented by the world's leading gear units manufacturers.

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DESIGN OF THE TRANSITION ZONE OF TURBINE SHAFT TO FLANGE BY BIOMIMETICS PRINCIPLES

Dejan Momčilović[1], Ivana Atanasovska[2], Radivoje Mitrović[3],

Abstract: The consideration of the optimal design of the transition zone of turbine shaft to flange has a high impact within the turbines design. The main principles of biomimetics give a new and prosperous point of view on the machine design, and could recommend new options in the design solutions for the zones with high stress concentrations. In this paper, a particular turbine shaft with flange is used for research of the possible biomimetics solutions in the zone of the transition radius. The traditional design of this transition zone is compare with the new design option inspired with transition zones in nature. The presented turbine shaft to flange design by biomimetics principles are based on the design of transition zones on trees. The Finite Element Analysis is performed for the traditional designed transition zone, as well as for the transition zone with design based on the biomimetics. The comparative analysis of the obtained results leads to the conclusions about the advantages of the biomimetics approach in this area of machine design.

Key words: Biomimetics, Finite Element Analysis, Fatigue, Fracture, Turbine shaft

1 INTRODUCTION

Machines are in many respects similar to living creatures. Their birth is laborious thing. They get afflicted with childhood illnesses (the period of initial trials) and undergo a sort of adolescence (the break-in period); then they work for a long time, get old, and eventually pass away. Machines ache from rough handling; their bodies collect scratches and dents which deteriorate. It is no wonder that such terms from the world of the living as “aging,” “fatigue,” “inheritance,” “survivability,” [1] exist in theory of machine design.

Last decade, the present and the future requirements in machine element design are shifted toward energy efficiency, as a common term that describe longer life of machines and more reliable operation with diminishing overhaul periods. Optimization of machine elements geometry is also one of key pathways toward that goal of the energy efficiency. Using biomimetic principles as inspiration, fine optimization of present

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geometries of machine elements can be done, which will lead to longer and safer life of machines. The good example of solutions offered by nature, with emphasize on design of geometry can be found in the references of few authors dedicated to research in this area [2-3].

2 THE BASIC BIOMIMETICS PRINCIPLES

Biomimetics is a word that emerged as a combination of words: bios - life and mimetic – imitation. Biomimetics is a discipline that finds sustainable technological solutions using patterns and strategies of nature that have passed the most difficult tests of evolution and time. Biomimetics is different from other bio-approaches based on the targeted observation and study of organisms and ecosystems, and the application of the so-called basic design principles in innovation. Although Otto Schmitt defined this discipline in 1957, now is the right moment for biomimetics, as the processes of developing of the human awareness about the need for returning to the nature and to establishing harmony with the environment (expressed through the requirements for Sustainable Development, Ecology and Energy Efficiency) and high technological development in all spheres (Measuring Instruments, Mathematical Methods, Production Technologies) achieve their peak, [4]. In that sense, it is not surprising that this discipline tends to be the top interest of scientists, first of all those who deal with a multidisciplinary approach.

2.1 Transition radius on trees

In this paper, the biomimetics principles are used in the research of the innovative design for the transition zones of the high loaded shafts. The inspiration is found in the geometry solutions of the nature in the case of trees, [2]. In figure 1 two examples of the transition zone on trees are shown.



(a) (b)

Figure 1. *Transition zone on trees:*
(a) Platanus in Topcider park, in Belgrade, Serbia, photo: D. Momčilović;
(b) The tree in the forest with the geometrically reconstruction of transition zone, [2]

The figure 1(a) shows the Platan in Topcider park (lat. Platanus acerifolia), which is a monument of the nature of the botanical character which is located in Topcider in front of Milosev konak, in Belgrade, Serbia and which is believed to have planted around 1830. The red line in this photo shows the geometrical solution for transition zone in the join of the branch of this tree and the support that people set to hold the branch. This transition zone is the excellent example how the nature make solutions. Figure 1(b) shows the geometrically reconstruction of the transition zone of a tree in the forest, [2]. The transition zone is explain as a series of Isosceles triangles, in which each subsequent triangle has a leg equal to a half of the hypotenuse of the preceding one. This geometrically biomimetics principle is used for the new design of the transition zone of the particular turbine shaft.

3 THE DESIGN OF THE TRANSITION ZONE OF TURBINE SHAFT TO FLANGE

For the research presented in this paper, a particular shaft with flange is used. The selected shaft is a real horizontal hydro turbine shaft with significant radius change at transition zone from shaft to runner flange, which was the cause of failure, [5]. Figure 2 shows the 3D model of the shaft with the detail of the traditional design of the shaft to flange transition zone. Before the end of the guarantied working period, a failure of the shaft appeared. It was caused by cracks on shaft to flange radius, [5]. This failure initiated a comprehensive research of the deformation and stress state of the traditional design of the particular shaft in the real loading conditions.

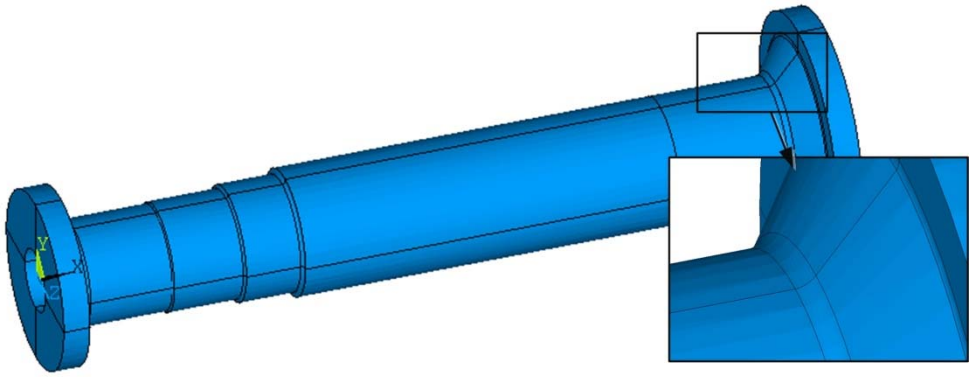


Figure 2. *3D model of a hydro turbine shaft with the detail of the traditional design of shaft to flange transition zone*

3.1 Traditional design solution

The traditional design of shaft to flange transition zone is characterized with single radius arc, as the zoomed detail shows in figure 2. The finite element model is developed for this design solution. The Finite Element Analysis is performed in previous phases of the research for all load variation, as well as arc radius variation, [6]. The conclusions about the disadvantages of the traditional design option of the shaft to flange transition zone is discussed and the conclusions defined the requirement for new innovative design which will solve the existing problems about critical stress distribution.

3.2 The new design inspired by biomimetics

On the base of the geometrically reconstruction of nature inspired design of the

trees presented in figure 1(b), the new innovative design of the transition zone of the investigated hydro turbine shaft is developed. The basic schema of this design solution is shown in figure 3. A new 3D model of the shaft with this modification is developed and shown in figure 4. The Finite Element Analysis (FEA) is performed for the load regime corresponds to the static load during start of operation and change of the operating runner's blades position, which is selected as critical one, [6]. The loads were taken from the original shaft manufacturer's documentation and for this load regime is defined by: the maximum axial hydraulic force simulated by the forces in axial direction (the *x* axis direction) at points of connecting the shaft flange to the runner, pressure in servomotor simulated by surface pressure inside of flange and axial force, own shaft's weight simulated by gravitational acceleration, runner's weight reduced to the points of connecting the flange with runner and the torque on the runner simulated by the forces in radial direction in all the nodes at the shaft flange perimeter, so that the total torsion moment from these forces represents the torque, while the bending moments of these forces as well as the forces themselves are mutually cancelled.

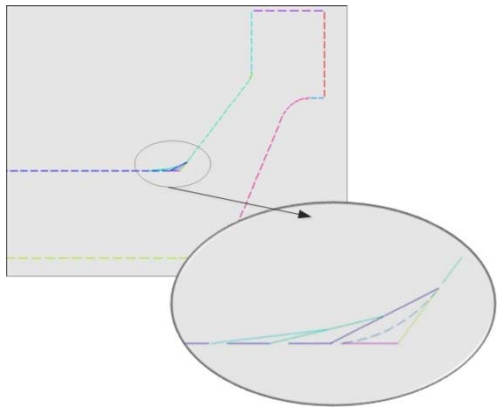


Figure 3. *The schema of the new design of the transition shaft to flange zone inspired by biomimetics*

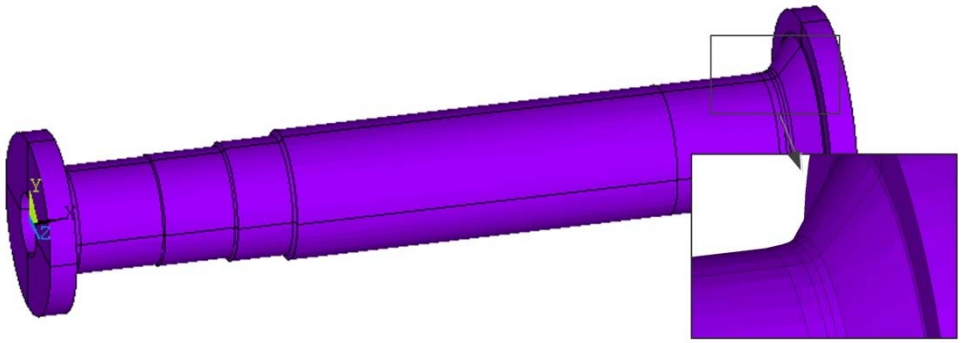


Figure 4. *3D model of a hydro turbine shaft with the detail of the new design of shaft to flange transition zone inspired by biomimetics*

3.3 Results comparison

The FEA results for both of the design variants are shown in figure 5 and 6. The normal stress component in the direction of shaft axis defines the fatigue load that is

critical in the case of the considered zone, therefore this component of the stress state results is selected for comparison and discussion of the traditional and biomimetics design. Figure 5 shows the 3D contour plots for this stress component in the investigated transition zone for both of the modeled cases, while figure 6 shows the cross section plots for the same FEA results.

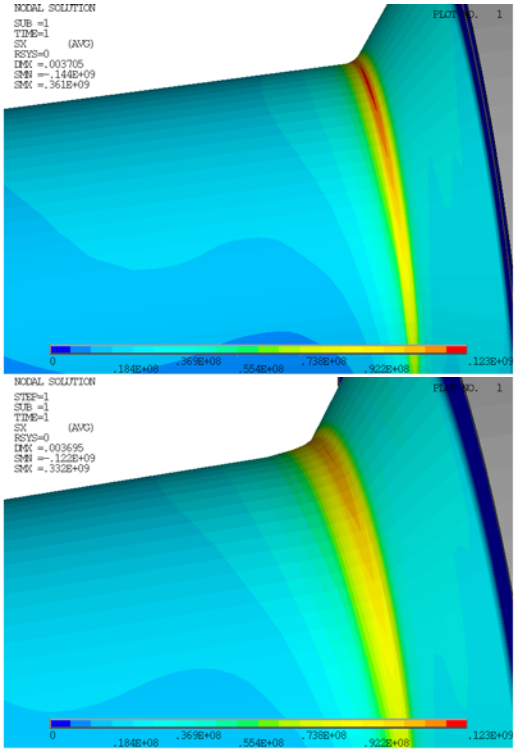


Figure 5. *FEA results for normal stress in the axis direction – 3D contour plot (a) traditional design; (b) design inspired by biomimetics*

4 DISCUSION AND CONCLUSIONS

The basic principles of the machine elements design inspired by biomimetics is presented in this paper. The particular turbine shaft is used for application of the new and innovative design of the transition zone which traditionally has a single radius arc form. New design is developed on the basis of the nature designed transition zones on trees. The Finite Element Analysis is performed for both of the investigated design for the same load conditions which simulated real operation. The results are shown by appropriate contour plots. It is obvious that the maximum value of the normal stress component obtained for the new design solution is lower than the maximum value of the normal stress component obtained for the traditional design for about 10%, which is very important decreasing level. Also, the cross section plots show the significant improvement of the stress distribution in the case of the new design solution. Therefore, the future research in this area is recommended.

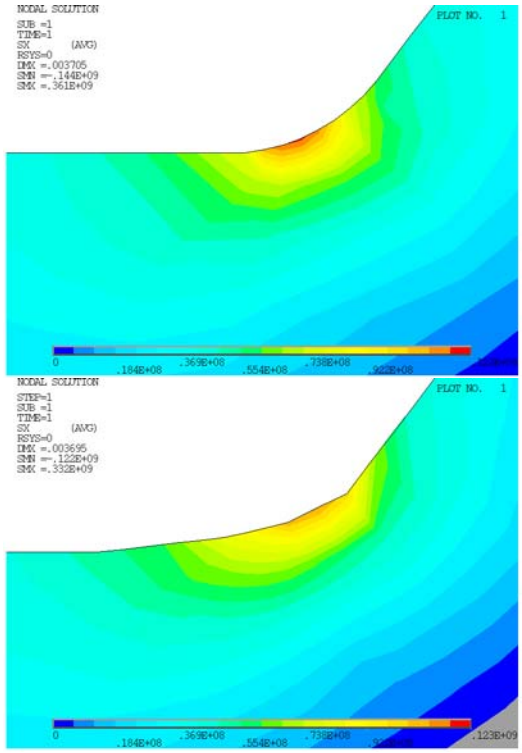


Figure 6. *FEA results for normal stress in the axis direction – cross section plot (a) traditional design; (b) design inspired by biomimetics*

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A COMPARISON OF TRUSS STRUCTURAL OPTIMIZATION TYPES WITH AND WITHOUT BUCKLING DYNAMIC CONSTRAINTS

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Abstract: Most research to date which covers the topic of truss structural optimization either doesn't consider, or uses fixed constraints for buckling. This paper presents a comparison of truss structural optimization types with and without the use of Euler buckling dynamic constraints. The difference is presented on a standard test model with 17 bars using continuous variables for cross section and node positions. The optimization method used is genetic algorithm for optimizing sizing, shape, topology, and their combinations. The implementation of dynamic constraints significantly increases the complexity of the calculations, however the results of using such an approach leads to practically applicable results.

Key words: Dynamic constraints, Euler buckling, Genetic algorithm, Structural optimization, Truss

1 INTRODUCTION

Truss structural optimization is a complex engineering problem which considers many variables and constraints. Minimal weight optimization can be approached through optimizing aspects of sizing, shape, and topology or their combinations. Truss sizing optimization observes each cross-section geometry as a variable, shape optimization varies the geometrical configuration's set node positions, and topology optimization creates new geometrical configurations by removing elements. The goal of this process is to achieve a truss design conceptwith a minimal weight, and consequently decrease costs.

In order to achieve practically applicable results the resulting truss construction must be able to withstand applied stress and avoid buckling, while keeping displacement within limits. Researchers have only recently started to include buckling constraints in optimization. This is largely due to the fact that buckling constraints change with every iteration of the optimization process according to the current truss setup. As a result

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using this constraint increases the problem complexity, and thereby calculation times drastically. The optimization of just one, or a combination of two or all three, of these types has been the subject of a lot of research using a broad range of heuristic optimization methods.

Researchers in [1] have used natural frequency bounds for truss optimization using an improved method in order to minimize truss weight. Khatibinia and Yazdani have in [2] used a multi-gravitational search algorithm for truss sizing optimization on 10, 18, 72, and 200 bar truss problems without considering buckling constraints on all examples. Tejani et al. [3] conducted simultaneous sizing, shape and topology optimization of planar and space trusses without considering buckling, but accounting for possible unacceptable topologies using Grubler's criterion. Assimi et al [4] considered a static critical buckling load constraint for sizing and topology optimization, using genetic programing.

Dynamic buckling constraints have only recently become part of structural optimization calculations when it comes to testing new methods. Ozbasaran [5] even added frequency analyses to further validate optimization results, and tested them on basic planar and space truss models. Degertekin et al [6] used Jaya algorithm for sizing shape and topology design optimization in order to minimize weight and tested it on common benchmark problems. Authors in [7-9] included dynamic constraints for buckling in their research using various optimization methods. Comparison of optimization results with and without buckling was done in [10], using continuous variables on a 10 bar truss example, and a sizing optimization comparison was done by researchers in [11], showing the drastic increases in weight when these constraints are implemented. Further research done in [12] shows the influence of using discrete variables as opposed to continuous for cross-section dimensions on all combinations of truss optimization types on a 10 bar truss problem.

This research is focused on showing the difference in using buckling constraints for solving complex truss structural optimization problems and gives a comparison of results on a typical 17 bar truss problem. The example is optimized for sizing, topology, shape and all their combinations in order to illustrate the importance of using dynamic buckling constraints on all types of structural optimization problems.

2 PROBLEM FORMULATION

The general problem of structural truss optimization implies the simultaneous optimization of sizing, topological, and shape aspects of the initial model. Nevertheless, practice shows that the combination of two, or all three of these aspects is not always possible or desired. The goal of this research is to analyse and show difference in results of optimizing any single, or any combination of these aspects on one of the most frequently used examples for truss optimization with and without using buckling constraints.

The objective functions of all optimization configurations used aim to find the combination of variables that minimize weight. For truss optimization found in literature the minimum weight design problem, limited by a range of cross-section areas and displacement, can be defined as:

$$\begin{cases} minW(A,\ n,\ l) = \sum_{i=1}^{i=n} \rho_i A_i l_i \text{ with } A = (A_1, \ldots, A_n) \\ \text{subjected to} \begin{cases} A_{min} \le A_i \le A_{max} & \text{for } i = 1, \ldots, n \\ u_{min} \le u_j \le u_{max} & \text{for } j = 1, \ldots, k \end{cases} \end{cases} \quad (1)$$

In (1) ,*n* is the number of used truss elements, *k* is the number of nodes, l_i is the length of the i^{th} element, A_i is the area of the i^{th} element cross section, u_j is displacement of the j^{th} node. This objective function criteria, depending on which combination or single optimization is conducted, changes accordingly, while the constraints remain the same for all problems.

2.1 Euler Buckling Constraint

Truss elements are subjected to either compression or tension forces. In order to ensure a stable construction, compressed elements must be checked for buckling. F_{Ai} is the axial compression force, F_{Ki} is Euler's critical load, E_i is the modulus of elasticity, and I_i is the minimum area moment of inertia of the cross section of the of the i^{th} element.

Since the same areas figure as denominators in the Euler buckling expression, the critical force load (2) can be used as the buckling constraint to minimize calculation. Therefore the constraint used in this research is given as (3).

$$F_{Ki} = \frac{\pi^2 \cdot E_i \cdot I_i}{l_i^2} \quad (2)$$

$$\left|F_{Ai}\right| \le F_{Ki} \text{ for } i = 1, ..., n \quad (3)$$

As force distribution changes in shape and/or topology optimizations and their combinations and the minimal area moment of inertia changes with every iteration of sizing optimization this constraint is considered to be dynamic. Dynamic constraints are very complex as the constraint value changes with each iteration making the search space much more difficult for the algorithm to navigate without getting a local optimum. This is why, especially with the combination of all three simultaneous optimizations, it is necessary to repeat the optimization multiple times to ensure a global optimum. This type of optimization problem requires the use of non-linear optimization and in this paper genetic algorithm (GA) was used due to availability and its favorable characteristics.

2.2 The Design Problem

In order to show the difference between optimal models which do not consider buckling and ones that do, this research uses the 17 bar truss problem. The initial truss model bar and node layout is given in figure 1. This is one of the more commonly used examples from literature for truss optimization. For this example the material characteristics are: Young modulus 206842.719MPa, and density of 7.4g/cm^3. A single point load of 444.82kN is applied in node 9, as shown in figure 2. Each bar cross section is an independent variable minimal area of all members is limited to 0.643cm^2 for full circular cross-section profiles. The only other fixed constraint is a displacement limitation for all nodes of ±0.0508m of all nodes in both x and y directions.

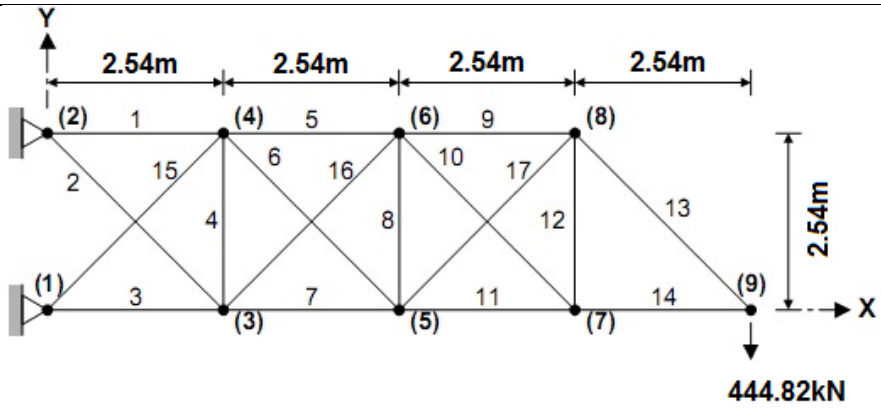


Figure 1. *Initial 17 bar truss model configuration*

The initial cross-section area for all calculations is 8659.01mm^2 (105mm diameter). This model has a weight of 3181.777kg and is calculated by optimizing the initial model which would have the same diameter of all bars and a minimal weight in such a configuration for the example with buckling. For examples which do not consider sizing the areas are 6361.73mm2 (90mm diameter) without buckling, and 8659.01mm^2 (105mm diameter) with buckling. Topology optimization is limited to the removal of at most 6 bars. A 1mm precision for node location is set when using shape optimization. Shape optimization observes the *x* and *y* positions of nodes 3-8 as variables, as well as the *y* position of node 9.

3 RESULTS

The originally software used for all calculations was verified in [10] and used in this paper for examples both with and without buckling. Sizing results with and without buckling are the same as in [11]. All three individual types of optimization, their three combinations of two, and a complete structural optimization using all three simultaneously were conducted according to the aforementioned setup without buckling, and repeated with buckling included. Table 1 gives the optimal cross-section areas, weight and displacement for the 17 bar truss example without using the buckling constraint. Cross-section areas marked in bold do not meet buckling criteria, while the ones in italic are also subjected to compression but are loaded below the buckling threshold.

Table 2 shows the optimal coordinates of nodes with variable positions for the results which take into account shape optimization without buckling constraints. Since node 9 only has a variable for its y coordinate, the x coordinate is the same for all four cases.

Optimal results for all three optimization types and their combinations is given in table 3. Coordinates for the results which take into account shape optimization with the buckling constraints are given in table 4.

Table 1. *Optimal solutions of the 17 bar truss problem without buckling constraints*

Area of bar [cm^2]	Sizing	Topo.	Shape	Sizing and topology	Sizing and shape	Topology and shape	Sizing, topology and shape
1	90.883	63.317	63.317	83.046	74.199	63.317	71.742
2	13.98	63.317	63.317	39.549	41.279	63.317	44.602
3	88.314	**63.317**	**63.317**	*110.916*	*92.793*	**63.317**	*94.952*
4	0.645	63.317	*63.317*	**31.164**	**8.793**	63.317	**9.194**
5	64.084	63.317	63.317	57.694	65.659	63.317	64.746
6	22.763	63.317	63.317	40.997	2.749	63.317	2.817
7	64.636	**63.317**	**63.317**	**90.019**	**43.572**	**63.317**	**43.433**
8	0.645	*63.317*	*63.317*	*31.18*	1.726	*63.317*	3.996
9	41.186	63.317	63.317	31.107	34.842	63.317	32.218
10	23.089	63.317	63.317	42.817	15.138	63.317	14.809
11	39.158	*63.317*	*63.317*	*61.154*	*38.27*	*63.317*	36.241
12	9.805	*63.317*	*63.317*	**31.809**	**0.662**	*63.317*	**0.646**
13	36.981	63.317	63.317	41.192	29.868	63.317	29.579
14	30.296	*63.317*	**63.317**	**31.54**	**30.24**	**63.317**	**29.984**
15	25.136	-	*63.317*	-	**6.08**	-	-
16	14.517	-	*63.317*	-	**25.527**	-	**31.59**
17	11.113	-	*63.317*	-	**7.52**	-	**6.419**
Weight [kg]	**1183.071**	**1839.241**	**2133.025**	**1463.045**	**1070.09**	**1656.366**	**1068.898**
Displ. [m]	**0.508**	**0.508**	**0.508**	**0.508**	**0.508**	**0.508**	**0.508**

Table 2. *Optimal coordinates without buckling constraints where shape is optimized*

Opt. type / Node	Shape	Sizing and shape	Topology and shape	Sizing, topology and shape
3 (x; y) [m]	(2.88; 0.059)	(2.253; -0.172)	(2.063; 0.003)	(2.225; -0.138)
4 (x; y) [m]	(2.887; 2.548)	(3.507; 2.873)	(3.777; 2.476)	(3.882; 2.2848)
5 (x; y) [m]	(5.302; 0.295)	(6.229; 0.041)	(5.132; 0.219)	(6.317; -0.076)
6 (x; y) [m]	(5.331; 2.271)	(5.271; 2.789)	(6.051; 2.335)	(5.215; 2.818)
7 (x; y) [m]	(6.753; 0.291)	(7.6; 0.095)	(6.917; 0.486)	(7.753; 0.012)
8 (x; y) [m]	(7.09; 2.086)	(8.449; 2.076)	(7.518; 2.3)	(8.464; 2.018)
9 (x; y) [m]	(10.16; 1.042)	(10.16; 1.26)	(10.16; 1.245)	(10.16; 1.193)

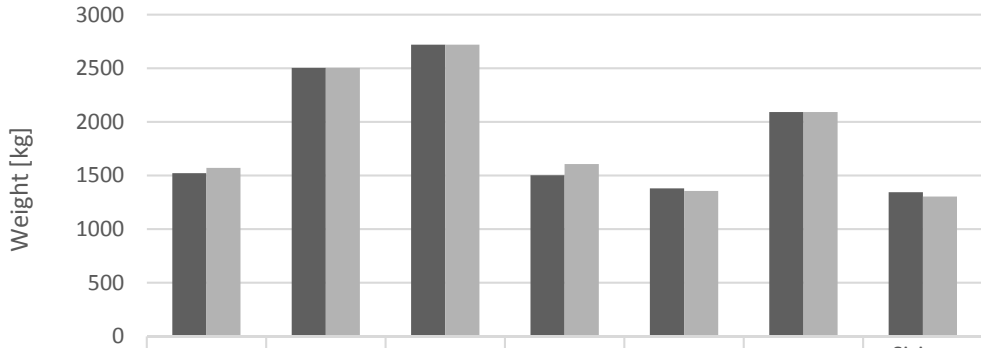
Table 3. *Optimal solutions of the 17 bar truss problem without buckling constraints*

Area of bar [cm^2]	Sizing	Topo.	Shape	Sizing and topology	Sizing and shape	Topology and shape	Sizing, topology and shape
1	79.794	86.59	86.59	80.269	78.254	86.59	62.467
2	6.962	86.59	86.59	32.662	13.465	86.59	26.469
3	93.299	86.59	86.59	107.101	94.455	86.59	93.592
4	15.636	86.59	86.59	42.494	1.825	86.59	0.669
5	56.137	86.59	86.59	56.941	59.775	86.59	64.587
6	0.774	86.59	86.59	41.937	12.859	86.59	34.21
7	59.62	86.59	86.59	88.991	71.12	86.59	71.2
8	4.695	86.59	86.59	42.382	0.655	86.59	32.394
9	31.191	86.59	86.59	29.254	52.748	86.59	35.391
10	35.44	86.59	86.59	38.146	12.844	86.59	29.162
11	55.431	86.59	86.59	64.149	64.51	86.59	42.798
12	35.57	86.59	86.59	42.211	0.6959	86.59	27.721
13	30.352	86.59	86.59	41.01	57.076	86.59	35.775
14	41.459	86.59	86.59	42.125	67.148	86.59	42.63
15	61.006	-	86.59	-	50.437	-	39.921
16	68.013	-	86.59	-	31.262	-	-
17	38.345	-	86.59	-	25.147	-	-
Weight [kg]	**1522.064**	**2503.411**	**2720.756**	**1501.902**	**1380.235**	**2091.971**	**1345.12**
Displ. [m]	**0.0508**	**0.0375**	**0.0508**	**0.0508**	**0.0508**	**0.0508**	**0.0508**

Table 4. *Optimal coordinates with buckling constraints where shape is optimized*

Opt. type / Node	Shape	Sizing and shape	Topology and shape	Sizing, topology and shape
3 (x; y) [m]	(2.679; 0.104)	(2.491; 0.359)	(2.886; 0.052)	(2.765;- 0.096)
4 (x; y) [m]	(3.003; 2.211)	(3.933; 2.495)	(2.764; 2.404)	(2.751; 2.375)
5 (x; y) [m]	(5.37; 0.315)	(5.171; 0.741)	(5.384; 0.23)	(5.1; 0.188)
6 (x; y) [m]	(5.467; 1.799)	(6.176; 2.272)	(5.006; 2.249)	(2.254; 242)
7 (x; y) [m]	(6.873; 0.274)	(7.013; 1.039)	(7.310; 0.409)	(7.379; 0.5)
8 (x; y) [m]	(6.642; 1.712)	(7.390; 2.308)	(6.660; 2.158)	(8.174; 2.22)
9 (x; y) [m]	(10.16; 0.968)	(10.16; 1.547)	(10.160; 1.305)	(10.16;1.334)

Figure 2 shows a graphic comparison of optimal weights between continuous and discrete cross-section models.



	Sizing	Topology	Shape	Sizing and topology	Sizing and shape	Topology and shape	Sizing, topology and shape
continuous	1522.064	2503.411	2720.756	1501.902	1380.235	2091.971	1345.12
discrete	1571.875	2503.411	2720.756	1607.739	1355.876	2091.971	1303.889

Figure 2. *Comparison of discrete and continuous optimization results according to type*

4 CONCLUSION

In real-world applications it is impossible to produce trusses which are the result of optimization with continuous cross-sectional variables, simply because of the costs linked to the production of specific, non-standard, dimensions of cross-sections in high enough tolerances. It was noted that even the slightest variations in cross-section diameter of optimal solutions with continuous variables leads to the construction not meeting constraint criteria. This paper showed the influence of using discrete cross-section variables, and compared results of all types, and combinations of truss structural optimization on a 17 bar truss example. In addition to the use of discrete variables, in order to ensure practically useable designs, the optimization process was constrained using dynamic buckling constraints. As a result the resulting structures which use achieved using this method weigh more than their counterparts from literature which do not consider buckling constraints.

The use of discrete variables gives models with similar weights. The difference between continuous and discrete variable models is around 3% for sizing optimization, around 7% for sizing and topology, around -2% for shape, and around -3% for sizing, shape and topology optimization. Since the Euler buckling constraint is added, it is very difficult for the method to achieve an absolute optimum, hence the continuous models have, an unexpectedly greater weight than their discrete counterparts, however this difference is negligible and is most likely caused by method parameters. The more complex the optimization, with more aspects being optimized and the addition of constraints which further divide the search space, the more difficult it is to achieve global optima. It can also be noted, that the topology optimization and shape optimization for both examples give the same results. This is because in order to define a cross-section to use for these two cases the initial model was optimized for sizing first, with using the same cross-section for all elements. The resulting value for both continuous and discrete models were close to 86.59cm^2, which is a discrete diameter of 90mm, so the results were considered to be the same.

The intent of this research was to prove that there are insignificant differences in optimal weight between continuous and dynamic constraints. It can be concluded from

the results that using discrete variables in optimization gives useable results when combined with buckling constraints. Further research in this field will include the influence of cross-section standard tolerances on optimal models in terms of satisfying set constraints.

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MERENJE UTICAJA PRITISKA VAZDUHA NA KARTING VOZILA PRIMENOM CAE TEHNOLOGIJE

Saša Vasiljević[1], Dragan Rajković[2], Sonja Kostić[3], Jasna Glišović[4]

Rezime: Konstrukcija vozila i zahtevi koji se postavljaju pred konstruktorima postaju sve složeniji. Razvojem inženjerskih metoda, usavršavaju se i savremene inženjerske tehnologije koje omogućavaju ispitivanje novog proizvoda bez proizvodnje prototipova. Takve tehnologije omogućavaju ispitivanje modela u virtuelnom okruženju na virtuelnom modelu tzv. CAE tehnologije. U ovom radu je izvršena analiza uticaja pritiska vazduha na modelu karting vozila pri različitim brzinama kretanja. Ovakvo ispitivanje omogućava da se izvrši aerodinamička analiza vozila i da se uoče elementi na karting vozilu koji narušavaju aerodinamiku. Primenom CAE tehnologija mogu se dobiti verodostojni podaci o uticaju vazduha na različitim delovima vozila prilikom kretanja vozila. Samim tim dolazi se do zaključaka koji delovi vozila mogu narušiti ili negativno uticati na aerodinamiku vozila.

Ključne riječi: CAE, karoserija, karting, merenje, pritisak.

MEASUREMENT THE INFLUENCE OF AIR PRESSURE ON THE EXAMPLE OF KARTING VEHICLES USING CAE TECHNOLOGY

Abstract: The construction of the vehicle and the requirements that are placed before the constructors become more and more complex. By developing engineering methods, modern engineering technologies are being improved, which enable the testing of new products without prototype production. Such technologies allow testing the model in a virtual environment on a virtual model of the so-called. CAE technologies. In this paper an analysis of the influence of air pressure on the model of karting of vehicles at different speeds of movement was carried out. Such an examination allows aerodynamic vehicle analysis to be carried out and to detect elements on karting a vehicle that disturbs aerodynamics. Using CAE technology, reliable data on air impact on different parts of the vehicle can be obtained while moving the vehicle. Consequently, it comes to the conclusions that parts of the vehicle can impair or negatively affect the aerodynamics of the vehicle.

Key words: CAE, bodywork, carting, measuring, pressure.

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1 UVOD

Otpor vazduha može imati uticaja na kretanje vozila, a samim tim i na performanse istog. Pre svega taj uticaj se ogleda u specifičnoj potrošnji goriva, ali i na vučnim karakteristikama vozila. Uticaj je još izraženiji kod sportskih vozila koja imaju pogonske agregate koji mogu dostići jako velike brojeve obrtaja i obrtne momente, kao i velike brzine. Ukoliko je aerodinamičnost vozila jako mala,prilikom njegovog kretanja sena površini karoserije vozila stvara otpor, koji u osnovi predstavlja pritisak vazduha koji deluje na površinu karoserije vozila. Povećanjem brzine vozila povećava se i pritisak, a samim tim i otpor kretanju vozila.

Razvojem današnje tehnologije omogućeno je da sena virtuelnom modelu vrše ispitivanja koja su vezana za merenje i analizu pritiska vazduha na karoseriji vozila, i to u različitim uslovima eksploatacije. U ovom radu primenom softverskog paketa SOLIDWORKS 2017 je izvršeno ispitivanje uticaja vazduha na sopstveni, novo projektovani model karting vozila. Cilj rada jeste da se primenom savremenih CAE tehnologija (kompjuterski podržano inženjerstvo, eng. Computer Aided Engineering) prikaže način testiranja modela vozila na pritisak od struje vazduha i to, u kojoj meri i kojim intenzitetom se stvara pritisak pri određenim uslovima ispitivanja. Ovakav način ispitivanja ima niz prednosti, pre svega manji troškovi ispitivanja (nema potrebe za izradom fizičkog modela, kao i laboratorija za ispitivanje), laka i brza izrada ili izmena na modelu koji se ispituje, mogućnost vršenja simulacije više puta pod različitim uslovima.

2 CAE TEHNOLOGIJA U RAZVOJU PROIZVODA

Razvoj proizvoda danas zahteva puno novca i vremena. Razlog tome jeste to što je potrebno svaki novo-razvijeni proizvod ili element proizvoda ispitati primenom maketa ili prototipa. CAE tehnologija omogućava proveru modela u pogledu aerodinamičnosti, opterećenja nekog proizvoda u različitim uslovima eksploatacije. Ako se uzme u obzir da je nekada jako teško izvršiti simulaciju na prototipu, onda do potpunog izražaja dolazi pozitivna strana primene CAE tehnologija, koje upravo omogućavaju simulaciju realnih uslova. Takođe je moguće uočiti sve nedostatke nekog modela proizvoda i to pre samog početka proizvodnje.

Ovakva tehnologija omogućava da se model ispituje kako prilikom strujanja fluida preko spoljašnjih površina, tako i unutar nekog elementa. Kada je reč o ispitivanju modela prilikom strujanja unutar nekog proizvoda misli se recimo na ispitivanje centrifugalnih turbina. Centrifugalne turbine imaju jako složene zahteve u smislu aerodinamike i geometrije, pa je veoma teško postići njihovu kompatibilnost [1]. CAE tehnologija omogućava ispitivanje i optimizaciju modela u pogledu materijala, geometrijskih mera i oblika koji se primenjuju na datom modelu. Ispitivanja se mogu vršiti na različitim temperaturama koje se mogu javiti u realnim uslovima i na taj način dobiti precizni podaci o karakteristikama modela i potrebama za njegovom eventualnom optimizacijom [2,3].

Primena ovih tehnologija je od posebnog značaja prilikom razvoja novih vozila jer omogućava ispitivanje sistema na vozilu, dinamike vozila, aerodinamičnosti vozila, itd. Osvrćući se na temu ovog rada bitno je napomenuti da ovakva tehnologija ispitivanja precizno simulira uslove kretanja vozila, a samim tim i dejstvo različitih sila na motornom vozilu. Ispitivanja ovim tehnologijama omogućavaju i precizno određivanje performansi vozila i njegovih komponenti, u smislu da li zadovoljavaju postavljene zahteve i da li se mogu dostići odgovarajuće vučno brzinske karakteristike [4,5].

2.1 CAE tehnologije u razvoju motornih vozila

Motorna vozila imaju jako specifične zahteve koji se postavljaju pred konstruktorom. Ti zahtevi se ogledaju u ekonomičnosti vozila (mala potrošnja goriva), a da pri tom imaju zadovoljavajuću maksimalnu brzinu, dovoljnu snagu da savladaju maksimalne uspone itd. Da bi se ispunili prethodno navedeni zahtevi, vozilo pre svega mora imati odgovarajuću aerodinamičnost, pogotovo vozila koja dostižu velike brzine kretanja. Prilikom kretanja vozilo mora savladati otpore koji se suprotstavljaju kretanju vozila, a samim tim vučna sila na točkovima vozila mora biti veća od otpora da bi se vozilo moglo kretati. Najveći udeo u svim silama otpora pri većim brzinama kretanja vozila pripada otporu vazduha koji je direktno vezan za aerodinamičnost vozila. Primenom CAE tehnologija moguće je izmeriti silu koje se javlja kao otpor vazduha na karoseriji vozila, pa na osnovu tog merenja odrediti da li vozilo zadovoljava odgovarajućom vučnom silom, odnosno da li se mogu dostići željene brzine ili odgovarajuće performanse vozila. Ovim tehnologijama se lako mogu odrediti najopterećeniji delovi vozila i u kom delu vozila je najniža vrednost pokazatelja aerodinamike ili pak dolazi do vrtloženja [6,7,8].

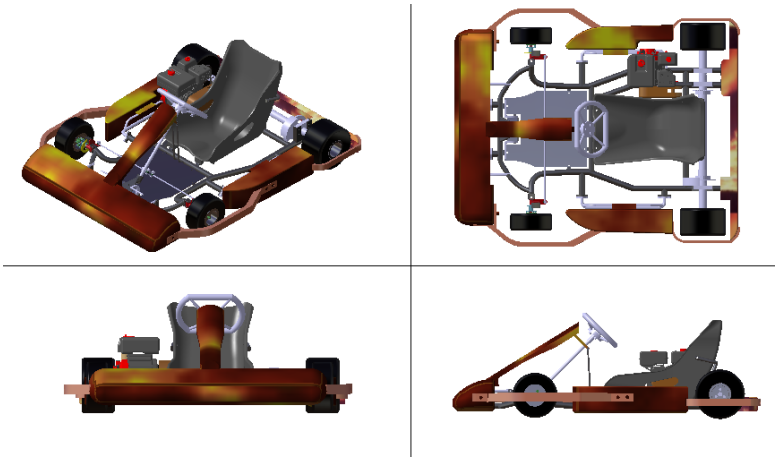
3 METODOLOGIJA I MODEL ISPITIVANJA

Ispitivanje se vrši na sopstvenom virtuelnom modelu karting vozila koji je dizajniran primenom softverskog paketa CATIA V5, dok se ispitivanje pritiska vazduha na karting vozilo i merenje vrši primenom softverskog paketa SolidWorks2017, tj. primenom softverskog dodatka FlowSimulator u okviru SolidWorks2017.

U ovom radu,ispitivanje modela karting vozila na uticaj pritiska vazduha, kao i merenje vrednosti pritiska vazduha je izvršeno prilikom kretanja vozila brzinama od 10 km/h, 30 km/h, 50 km/h, 70 km/h i 90 km/h Zadati spoljašnji uslovi u virtuelnom prostoru su takvi da je temperatura 293,2K odnosno 20,5^{o}C i da je normalni pritisak 101325 Pa (odnosno 1,013bar). Ovakvom analizom i merenjem pritiska vazduha na karoseriju karting vozila prilikom njegovog kretanja, mogu se tačno definisati najjopterećeniji delovi vozila, kao i videti potreba za optimizacijom konstrukcije na delovima kod kojih je eventualno došlo do stvaranja velikih otpora vazduha, kao i velikih vrtloženja vazduha. Pored prethodno rečenog, posmatranjem vrednosti stvorenog pritiska vazduha na karoseriju vozila može se zaključiti da li su izmereni pritisci na karoseriji prihvatljivi za karting vozila i da li su u granicama zadatih vrednosti. Naravno da je pored izmerene vrednosti pritiska vazduha na karoseriju i elemente vozila, jako važno proveriti da li dolazi i u kojoj meri do vrtloženja vazduha kako ne bi došlo do stvaranja potpritiska vazduha. Stvaranje potpritiska vazduha je negativna pojava koja takođe stvara otpor prilikom kretanja što se loše odražava na vučne karakteristike vozila. Primenjeni softverski program omogućava grafički prikaz vrednosti pritiska vazduha po zonama. U ovom radu granice prikaza su date na skali od 101275 Pa do 101376 Pa, i to u cilju da bi se što tačnije prikazale najopterećenije i najrasterećenije zone na karting vozilu.

3.1 Model karting vozila koji se ispituje

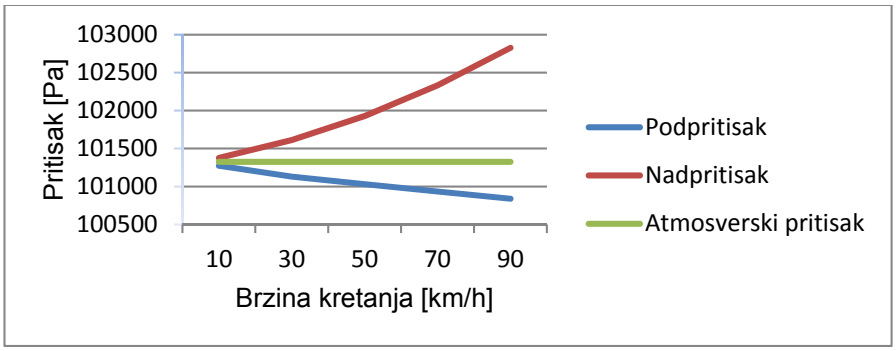
Model karting vozila na kome se u virtuelnom okruženju vrši merenje pritiska vazduha je prikazan na slici 1. Karting vozilo je modelirano u softverskom paketu Catia V5. Namena ovog modela vozila je rekreacija i zabava. Model vozila je projektovan tako da svojim dimenzijama odgovara tehničkim propisima koji su postavljeni od strane Internacionalne komisije za karting vozila (eng. Skraćenica CIK-FIA).



Slika 1.*Model karting vozila za koji se vrši merenje pritiska vazduha*

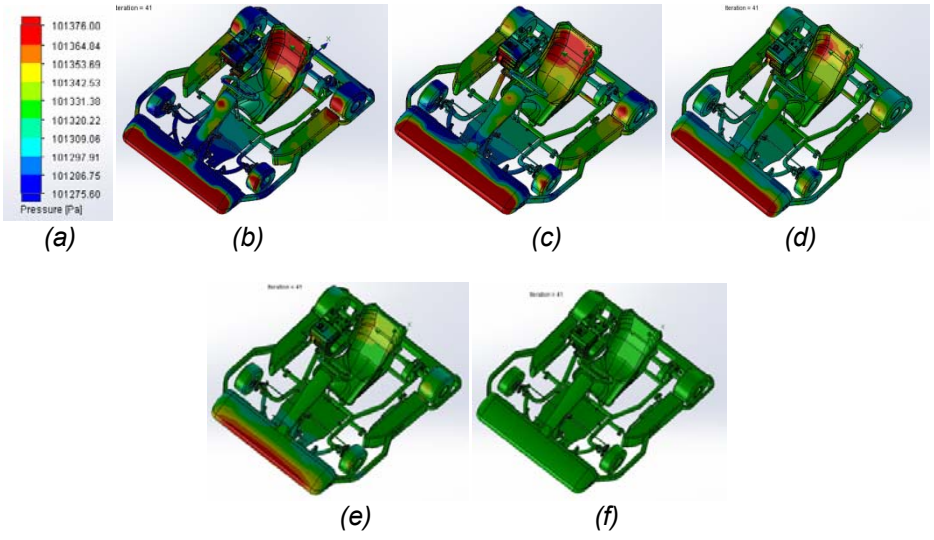
4 REZULTATI

Primenom pomenute metodologije dobijeni rezultati su takvi da je utvrđeno da prilikom kretanja vozila najvećom brzinom od 90 km/h dolazi do porasta pritiska vazduha, ali i do porasta potpritiska. Merenjem pritiska vazduha prilikom promena brzina kretanja vozila od 10 km/h do 90 km/h, utvrđeno je da je najveći izmereni pritisak 102827,03 Pa (pri brzini od 90 km/h) dok je najmanji izmereni pritisak 101376,93 Pa (pri brzini kretanja vozila od 10 km/h). Kada je reč o nastalom potpritisku najveća vrednost je 100839,59 Pa (pri kretanju brzinom od 90 km/h), dok najmanja vrednost iznosi 101275,28 Pa (pri brzini od 10 km/h). Potpritisak koji se javlja pri brzini od 90 km/h ima negativno dejstvo na performanse i ekonomičnost vozila, imajući u vidu da se javlja vrtloženje vazduha i povećanje sila otpora vazduha. Na slici 2 je dat prikaz promene pritiska i potpritiska koji se javlja prilikom kretanja karting vozila u zavisnosti od promene brzine (od 10 km/h do 90 km/h).Na istoj slici je dat prikaz normalnog atmosferskog pritiska u virtuelnom prostoru u kome se vrši merenje pritiska vazduha. Sa dijagrama je uočljivo da pritisak, kao i potpritisak vazduha ima eksponencijalni rast u odnosu na promenu brzine kretanja vozila. Potpritisak ima negativan porast pritiska, što nekada može zbuniti, međutim što je veća vrednost razlike između potpritiska vazduha i normalnog atmosferskog pritiska,to se povećava otpor kretanju vozila koje se manifestuje negativnim uticajem na performanse vozila. Analizom dobijenih vrednosti može se zaključiti da dobijene i izmerene vrednosti pritiska vazduha na karting vozilo ne odstupaju mnogo u odnosu na normalni atmosferski pritisak, što je prihvatljivo. Pregledom literature drugih autora koji su se bavili sličnom problematikom [8], dobijeni rezultati u ovom radu se mogu smatrati validnim i reprezentativnim.



Slika 2. *Promena maksimalnog pritiska vazduha na karting vozilo u zavisnosti od brzine kretanja*

Pored podataka o maksimalnim pritiscima koja su dobijena pomenutim softverom u ovom radu, mogu se prikazati sve zone vozila koje su najopterećenije, odnosno gde se javlja maksimalno dejstvo sile vazduha, ali isto tako i u kojim zonama postoji najmanje opterećenje. Na slici 3 su dati prikazi dejstva vazduha na karoseriju vozila u različitim zonama. Crvenom bojom označene su najopterećenije zone vozila nadpritisakom vazduha, dok je plavom bojom dat prikaz najrasterećenijih zona ili pak zona gde se javljaju potpritisci. Na slici 3a je prikazana skala zoniranja od najopterećenijih do najrasterećenijih delova, dok su na slikama od 3b do 3ddati prikazi vozila sa opterećenjima po zonama u zavisnosti od brzine kretanja vozila. Analizom grafičkih prikaza opterećenja karting vozila može se takođe zaključiti da su najveća opterećenja nastala pri kretanju vozila brzinom od 90 km/h (slika 3b),kao i da najveća opterećenja nastaju na najisturenijim delovima vozila kao što su sedište, prednji branik vozača, pogonski agregat i delovi točkova iznad branika. Takođe se može zaključiti da se sa smanjenjem brzine smanjuje i vrednost pritiska vazduha, ali da je najveći pritisak uvek na prednjem braniku.



Slika 3. *Grafički prikaz uticaja pritiska vazduha na određenim delovima karting vozila, gde su: a) Skala opterećenja vozila pritiskom vazduha pri brzinama od 10 do 90 km/h b) 10 km/h c) 30 km/h d) 50 km/h e) 70 km/h f) 90 km/h*

5 ZAKLJUČCI

Primena savremenih inženjerskih tehnologija je omogućila napredovanje u razvoju svih proizvoda i to na mnogo jednostavniji način uz smanjenje troškova ispitivanja novih proizvoda. Primena CAE tehnologija može imati široku primenu u projektovanju novih konstrukcija, sklopova ili pak sastavnih elemenata nekog sklopa. Ovakve tehnologije omogućavaju ispitivanje elemenata ili sklopova bez ikakvih fizičkih prototipova, postavljanjem realnih uslova ispitivanom virtuelnom modelu, čime se direktno omogućava i izmena na virtuelnom modelu i ponovno ispitivanje i tako ubrzava proces provere performansi..

U ovom radu je izvršeno ispitivanje dejstva vazduha na model karting vozila kao i merenje maksimalnog i minimalnog nastalog pritiska pri različitim brzinama kretanja. U poređenju sa dostupnom literaturom, došlo se do zaključaka da su vrednosti pritiska za ovakav model vozila prihvatljivi i u granicama očekivanih. Grafičkom metodom analize pritiska vazduha na delove karting vozila, može se zaključiti na kojim delovima karting vozila dolazi do najvećih opterećenja pritiskom vazduha, pa samim tim i koji su to delovi koje je potrebno ponovno analizirati i optimizovati da bi vozilo imalo što bolju aerodiamičnost i da bi došlo do rasterećenja. Ponovnim modeliranjem bi se moglo odrediti i koje je elemente potrebno tako projektovati da bi došlo do preusmeravanja vazduha. Na taj način je moguće doći do zaključka kako rasteretiti zone i delove vozila gde je veće opterećenje pritiskom vazduha a koje nije moguće zameniti (gotovi delovi, kao što su motor ili sedište) optimizacijom delova koji bi mogli preusmeriti vazduh van tih kritičnih elemenata.

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PARAMETARSKO MODELIRANJE CILINDRIČNOG ZUPČANIKA S EVOLVENTNIM OZUBLJENJEM

Marko Rastija[1], Krešimir Vučković[2], Stjepan Risović[3]

Sažetak: U ovom radu izrađena je programska procedura za parametarsko modeliranje dvodimenzijskog modela zupčanika s evolventnim ozubljenjem u čeonoj ravnini. Za izradu programske procedure korišten je VBA modul u sklopu programskog paketa AutoCAD 2014. Opisan je proces izrade programske procedure uz teorijski opis nekih pojmova evolventnog ozubljenja i objašnjenje pojedinih pojmova vezanih uz teoriju i primjenu zupčanika. Programskom procedurom je omogućeno dvodimenzijsko parametarsko modeliranje cilindričnog zupčanika s ravnim i kosim, simetričnim i asimetričnim zubima. Parametri obuhvaćeni programskom procedurom su normalni modul, broj zubi, faktor pomaka profila, kut nagiba boka zuba i profil ozubljenja.

Ključne riječi: dvodimenzijski model, evolventno ozubljenje, parametarsko modeliranje, zupčanik

PARAMETRIC MODELLING OF SPUR GEAR WITH INVOLUTE TEETH

Abstract: In this paper a procedure for parametric modelling of two-dimensional model of gear with involute teeth in transverse plane was programmed. The procedure was programmed in VBA module of AutoCAD 2014 software. Description of programmingprocess is given, as well as explanation of involute gearing and certain terms and concepts of gear theory and application. Procedure is programmed for two-dimensional parametric modeling of spur and helical gears with symmetric or asymmetric teeth. Parameters used by procedure are normal module, number of teeth, coefficient of profile shift, helix angle and basic rack parameters.

Key words: gear, involute gearing, parametric modelling, two-dimensional model

1 UVOD

Težnja za prijenosom što veće snage uz istovremeno smanjenje dimenzija i mase samih zupčanika i zupčanih prijenosnika uzrokuje znatno povećanje naprezanja boka i korijena zuba. Bok zuba opterećen je dodirnim pritiskom, a korijen zuba

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savijanjem. Budući da zubi tijekom rada periodično ulaze u zahvata i iz njega izlaze, naprezanja koja se javljaju ciklički osciliraju. Analitički se proračun zupčanika provodi prema određenoj normi (DIN, ISO...), a osim na principima mehanike i čvrstoće, temelji se i na nizu eksperimentalno određenih faktora koji uzimaju u obzir specifičan oblik, način i raspodjelu opterećenja zuba zupčanika.

Provedba eksperimenta je skupa, složena, a često i dugotrajna. Svaka značajnija promjena u konstrukciji zupčanika iziskuje novi eksperiment kojim se utvrđuje utjecaj takve promjene na naprezanje zuba zupčanika. Razvoj računalne tehnologije, kako fizičkih komponenti računala (procesor, memorija, grafičke komponente) tako i programskih paketa, omogućava provedbu sve složenijih numeričkih proračuna i analiza. Provedba numeričke analize na računalu jeftinija je od eksperimenta, omogućava jednostavnu promjenu parametara ili konstrukcije zupčanika i ponovnu provedbu analize bez potrebe za ponovnim postavljanjem ispitnog postava i opreme što rezultira dobivanjem većeg broja podataka i rezultata u kraćem vremenu.

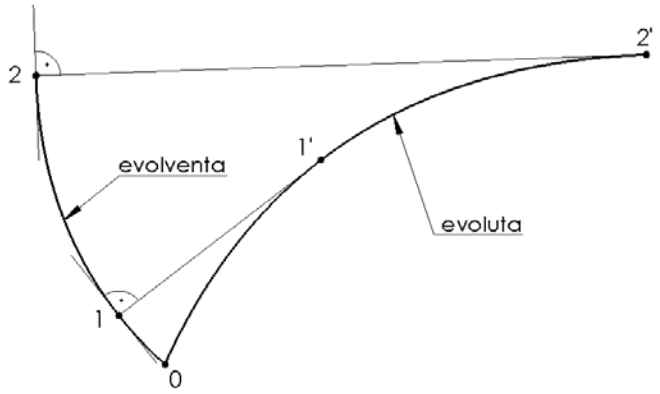
Za provedbu numeričke analize, najčešće pomoću metode konačnih elemenata (MKE), potrebno je izraditi trodimenzijski geometrijski model zupčanika. Temelj svakog takvog trodimenzijskog modela je dvodimenzijskimodel samog zupčanika u čeonoj ravnini. Kako bi se dobili što točniji rezultati same analize, nužno je da geometrijski model zupčanika bude što sličniji stvarnom zupčaniku. Budući da je profil zuba zupčanika definiran točno određenim krivuljama koje je moguće matematički opisati, za izradu što točnijeg dvodimenzijskog modela zupčanika u čeonoj ravnini potrebno je te krivulje što točnije modelirati. Postojanje programske procedure koja bi automatski crtala tražene krivulje, odnosno sam profil zuba i u konačnici cijeli zupčanik, na osnovi matematičkih formula i zadanih parametara zupčanika (modul, broj zubi, kut nagiba boka, pomak profila itd.) uvelike bi olakšala sam proces modeliranja i ubrzala cijeli proces numeričke analize, uz postizanje tražene preciznosti i točnosti. Izrada takve programske procedure za parametarsko modeliranje dvodimenzijskog modela zupčanika u čeonoj ravnini tema je ovog rada.

2 EVOLVENTNO OZUBLJENJE

U ovom radu razmatrana je geometrija profila zuba zupčanika s evolventnim ozubljenjem jer je to najzastupljenija vrsta ozubljenja. Prema [1] razlog za to je što evolventno ozubljenje posjeduje određene prednosti u odnosu na druge vrste ozubljenja, a to su:

- alati za izradu evolventnog ozubljenja mogu se proizvesti s velikom preciznošću
- moguće je mijenjati debljinu zuba i ostvariti nestandardni osni razmak promjenom položaja alata prilikom izrade zupčanika
- nestandardni (s pomakom profila) zupčanici mogu se proizvesti standardiziranim alatima koji se koriste i za proizvodnju standardnih zupčanika
- mala promjena osnog razmaka ne uzrokuje greške u prijenosu

Općenito, evolventa je ravninska krivulja koja je nerazdvojivo povezana sa svojom evolutom, ravninskom krivuljom koja predstavlja geometrijsko mjesto svih središta polumjera zakrivljenja evolvente (Slika 1). Normala na tangentu u bilo kojoj točki evolvente tangira evolutu [1].

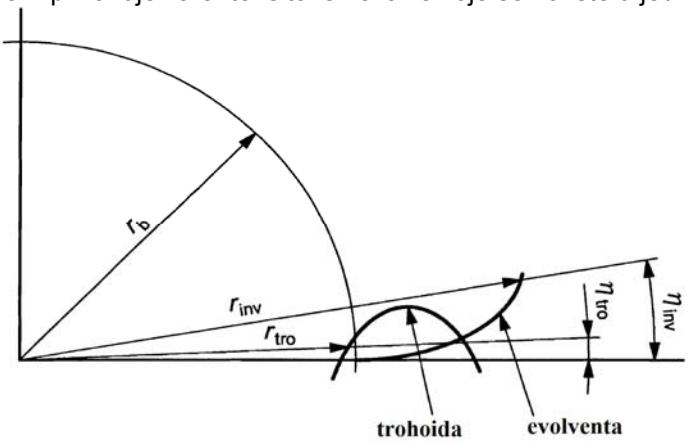


Slika 1. *Evolventa i evoluta*

Evolventa čija je evoluta kružnica opisuje profil zuba zupčanika s evolventnim ozubljenjem. Dakle, svaka točka na valjnom pravcu (generatrisi) koji se bez klizanja valja po obodu temeljne kružnice r_b opisuje evolventu koja predstavlja bok zuba zupčanika [2]. Kao što je ranije rečeno, temeljna kružnica kao evoluta predstavlja geometrijsko mjesto svih središta polumjera zakrivljenja evolvente.

2.1 Matematički opis evolvente i prijelazne krivulje

U ovom radu razmatrana je geometrija zuba zupčanika izrađenog pomoću alata s ravnim bokovima. Pri izradi programske procedure korištene su jednadžbe dane u [3]. Slika 2 prikazuje karakterisitčne veličine koje se koriste u jednadžbama.



Slika 2. *Evolventa i trohoida u polarnom koordinatnom sustavu* [3]

Jednadžbe su dane u polarnim koordinatama pa tako evolventu opisuju sljedeće jednadžbe u parametarskom obliku:

$$r_{\mathrm{inv}} = \frac{d_{\mathrm{b}}}{2} \cdot \sqrt{1+\xi^2}, \tag{1}$$

$$\eta_{\mathrm{inv}} = \xi - \arctan \xi \tag{2}$$

pri čemu je ξ parametar evolvente, a odgovara kutu rotacije generatrise (valjnog pravca).

Prema [3] prijelazna krivulja koja spaja evolventni dio zuba i podnožnu kružnicu zuba jest trohoida koju opisuju sljedeće jednadžbe u parametarskom obliku

$$r_{\text{tro}} = \sqrt{\left(\frac{d}{2} - B\right)^2 + \left(\frac{B \cdot \cos\beta}{\tan\varphi}\right)^2}, \tag{3}$$

$$\eta_{\text{tro}} = \theta + \varepsilon - \alpha_{\text{t}}, \tag{4}$$

pri čemu su *B*, *θ*, *ε* i *A* pomoćni faktori određeni izrazima:

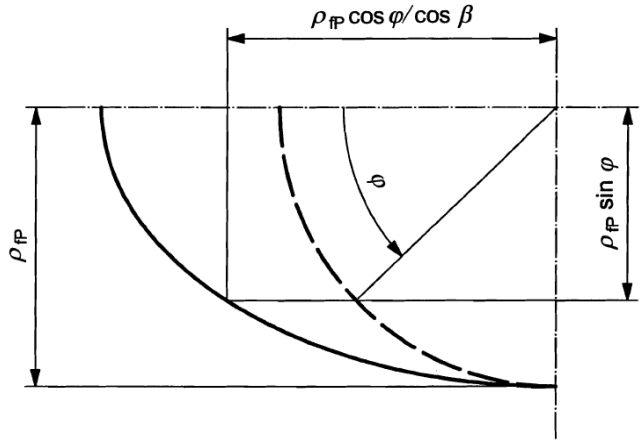
$$B = h_{\text{fP}} - x \cdot m_{\text{n}} - \rho_{\text{fP}} + \rho_{\text{fP}} \cdot \sin\varphi, \tag{5}$$

$$\theta = \tan\alpha_{\text{t}} + \frac{2}{d} \cdot \left(\rho_{\text{fP}} \cdot \frac{\cos\varphi}{\cos\beta} - A - B \cdot \frac{\cos\beta}{\tan\varphi}\right), \tag{6}$$

$$A = \frac{\rho_{\text{fP}}}{\cos\alpha_{\text{n}} \cdot \cos\beta} + \left(h_{\text{fP}} - x \cdot m_{\text{n}} - \rho_{\text{fP}}\right) \cdot \tan\alpha_{\text{t}}, \tag{7}$$

$$\varepsilon = \arctan\frac{B \cdot \cos\beta}{\left(\frac{d}{2} - B\right) \cdot \tan\varphi}, \tag{8}$$

dok je *φ* parametar trohoide definiran prema Slici 3.

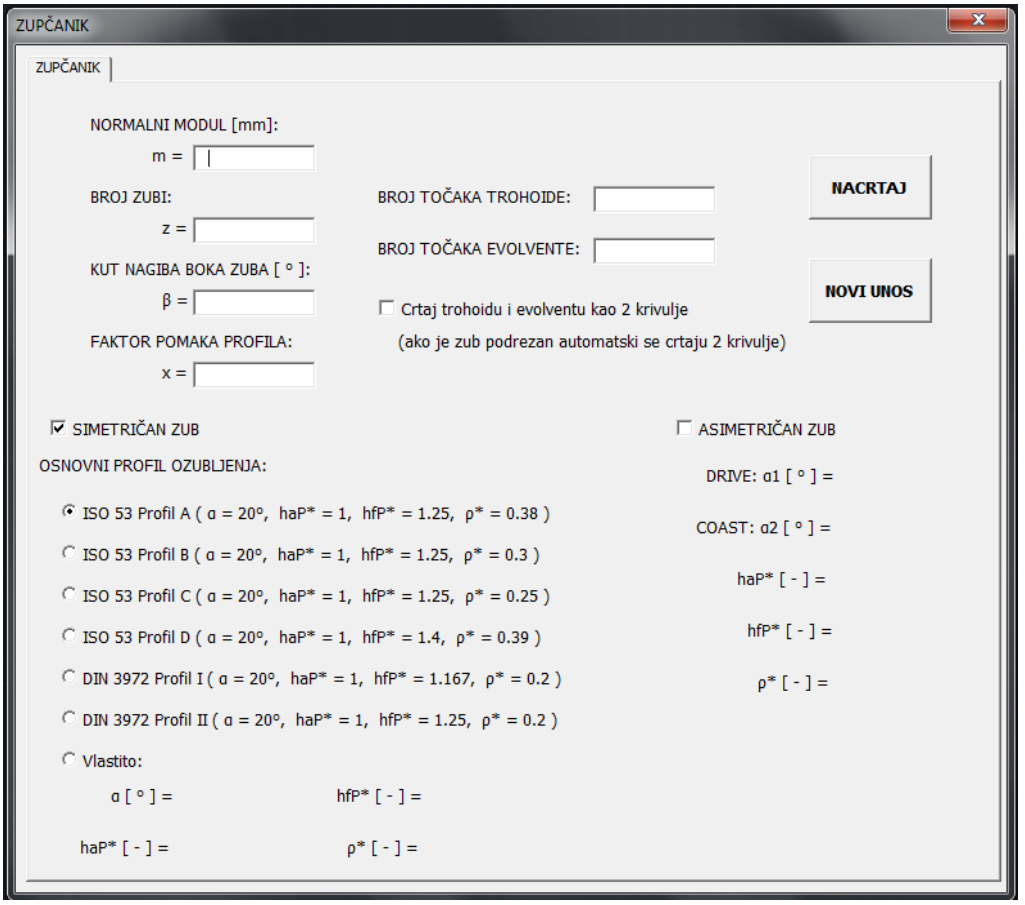


Slika 3. *Parametar trohoide* [3]

3 PROGRAMSKA PROCEDURA

Za izradu programske procedure izabran je Visual Basic for Application modul unutar programskog paketa AutoCAD 2014 zbog jednostavnosti pristupanja naredbama unutar samog programa, ali i zbog želje da se aplikacija može koristiti na ranijim i kasnijim verzijama programskog paketa AutoCAD. Jednako tako, programski paket AutoCAD omogućuje pohranjivanje crteža u različitim formatima koje je moguće otvarati i koristiti u ostalim programskim paketima za 3D modeliranje i analizu metodom konačnih elemenata što onda omogućuje daljnje modeliranje trodimenzijskog modela zupčanika i provedbu numeričke analize. Programska procedura omogućuje modeliranje dvodimenzijskog modela zupčanika s evolventnim ozubljenjem u čeonoj ravnini i to s ravnim simetričnim i asimetričnim zubima te kosim (helikoidnim) simetričnim i asimetričnim zubima.

Pokretanjem programske procedure unutar AutoCAD crteža otvara se korisničko sučelje koje prikazuje Slika 4.



Slika 4. *Korisničko sučelje*

Kao što je vidljivo na Slici 4, pokretanjem programske procedure automatski je odabrana opcija modeliranja zupčanika sa simetričnim zubima. Ako korisnik želi modelirati zupčanik s asimetričnim zubima, mora odabrati opciju "ASIMETRIČAN ZUB" nakon čega polja za unos parametara asimetričnog zuba postaju dostupna, a sve opcije vezane za simetričan zub postaju nedostupne. Ako se ponovno odabere opcija "SIMETRIČAN ZUB", sva polja za unos podataka asimetričnog zuba postaju nedostupna, a sve opcije vezane za simetričan zub ponovno dostupne.

Nakon što su odabrane željene opcije i unesene vrijednosti svih potrebnih parametara, pritiskom na tipku "NACRTAJ" izvršava se kod programske procedure koji koristi jednadžbe iz [3] za izračunavanje koordinata točaka evolvente i trohoide koje čine profil boka zuba prema odabranim i zadanim parametrima. Koordinate točaka se izračunavaju u polarnom koordinatnom sustava, a zatim se transformiraju u koordinate pravokutnog koordinatnog sustava koji se koristi u programskom paketu AutoCAD.

S obzirom da je u najopćenitijem slučaju potrebno omogućiti modeliranje asimetričnog zuba kod kojeg kut zahvatne crte α nije jednak za oba boka (simetrični se zub može promatrati kao poseban slučaj asimetričnog zuba kojem je kut zahvatne crte oba boka jednak), u ovoj programskoj proceduri zasebno se računaju koordinate točaka jednog i drugog boka. U skladu s nomenklaturom asimetričnog zuba i radi lakšeg opisa jedan se bok naziva DRIVE, a drugi COAST.

Prilikom transformacije koordinata točaka DRIVE boka iz polarnog u pravokutni

koordinatni sustav svaka se točka pomiče u smjeru kazaljke na satu za kut *γ*, tako da iz početnog položaja koji prikazuje Slika 6a dobivenog jednadžbama evolvente i trohoide iz [3] bok zuba prelazi u položaj prikazan na Slika 6b. U tom novom položaju simetrala simetričnog zuba s oba DRIVE boka jest os *x*. Razlog tome je što je kut *γ* ustvari kut između simetrale simetričnog zuba i osi *x* (Slika 5). Taj se kut izračunava pomoću sljedećih izraza:

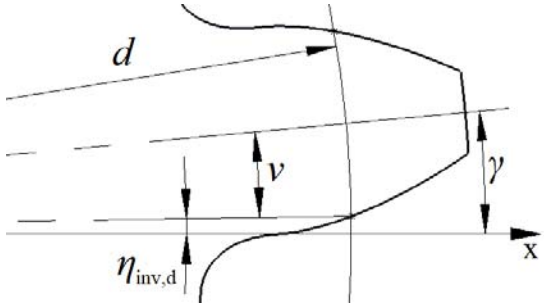
$$\nu = \frac{s/2}{d/2} = \frac{s}{d}, \tag{9}$$

$$\xi_{\mathrm{d}} = \sqrt{\left(\frac{d}{d_{\mathrm{b}}}\right)^2 - 1}, \tag{10}$$

$$\eta_{\mathrm{inv,d}} = \xi_{\mathrm{d}} - \arctan \xi_{\mathrm{d}}, \tag{11}$$

$$\gamma = \nu + \eta_{\mathrm{inv,d}}. \tag{12}$$

Jednadžbom (9) izračunava se kut koji odgovara luku na diobenoj kružnici čija je duljina jednaka polovici širine zuba s na diobenom promjeru. Jednadžbe (10) i (11) su jednadžbe evolvente prema [3], a izračunavaju kut točke evolvente čiji je polumjer jednak polumjeru diobene kružnice, dakle kut točke sjecišta evolvente i tjemene kružnice.



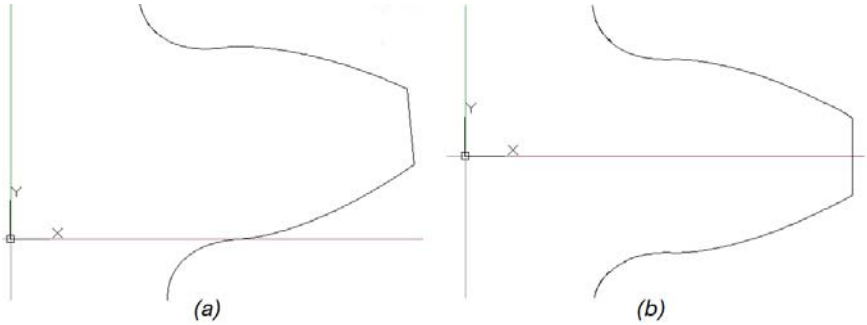
Slika 5. *Kut simetrale simetričnog zuba*

Jednadžbe transformacije koordinata točaka DRIVE boka tada su:

$$x_{\mathrm{D}} = r \cdot \cos(\eta - \gamma), \tag{13}$$

$$y_{\mathrm{D}} = r \cdot \sin(\eta - \gamma), \tag{14}$$

pri čemu *r* i *η* predstavljaju koordinate u polarnom koordinatnom sustavu i poprimaju vrijednosti r_{tro} i η_{tro} za dio boka koji opisuje trohoida, odnosno r_{inv} i η_{inv} za dio boka koji opisuje evolventa.



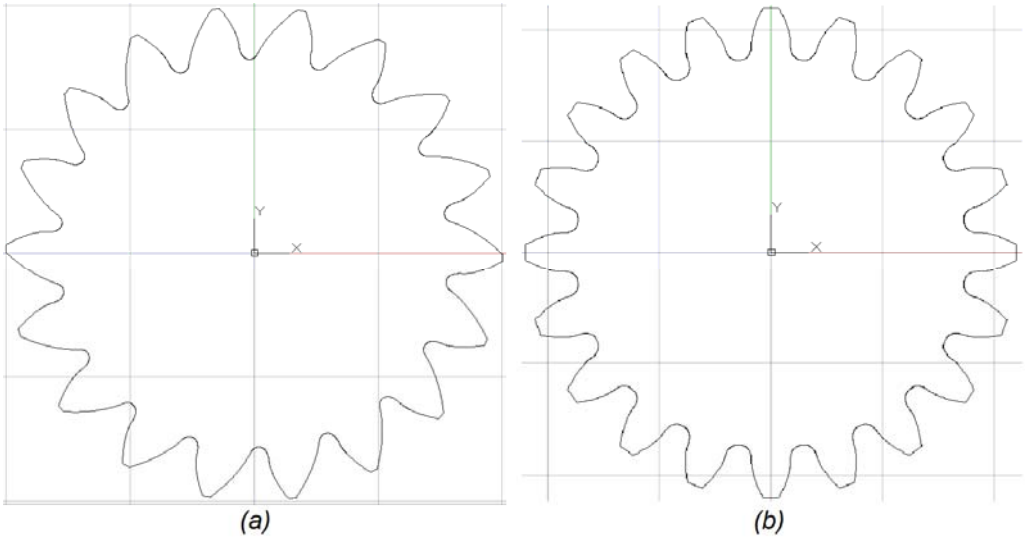
Slika 6. *Položaj simetričnog zuba bez pomaka (a) i s pomakom za kut γ (b)*

Kao što je ranije rečeno, kako kod asimetričnog zuba DRIVE i COAST bok imaju različite kutove zahvatne crte α, tako imaju i različite kutove $\eta_{\text{inv,d}}$. Štoviše, ako se radi o zupčanicima s asimetričnim zubima s pomakom profila, razlikovat će se i kutovi v jer širina zuba na diobenom promjeru zupčanika s pomakom profila ovisi o kutu zahvatne crte. To znači da fiktivni zubi s oba DRIVE, odnosno oba COAST boka u općenitom slučaju kada se nalaze u početnom položaju određenom jednadžbama evolvente i trohoide iz [3] bez pomaka za kut γ nemaju zajedničku simetralu, odnosno položaji njihovih simetrala nisu isti. To onemogućava modeliranje asimetričnog zuba preslikavanjem COAST boka preko njegove simetrale. Zbog toga je potrebno pomicanje bokova za kut γ, čime os x postaje simetrala i fiktivnog zuba s oba DRIVE boka i fiktivnog zuba s oba COAST boka. Sada je moguće modelirati asimetrični zub preslikavanjem COAST boka iz položaja nakon pomaka za kut γ (Slika 6b) preko zajedničke simetrale, odnosno osi x, dok DRIVE bok ostaje u svom položaju pomaknut za kut γ. Preslikavanje oko osi x izvodi se tako da se koordinati y promijeni predznak, dok koordinata x ostaje ista. Potpune jednadžbe transformacije koordinata točaka COAST boka iz polarnog u pravokutni koordinatni sustav, uz istovremeno preslikavanje preko osi x, tada glase:

$$x_{\text{C}} = r \cdot \cos(\eta - \gamma), \tag{15}$$

$$y_{\text{C}} = -r \cdot \sin(\eta - \gamma). \tag{16}$$

Koordinate točaka trohoide i evolvente koje opisuju bokove zuba dobivene jednadžbama (13) do (16) pohranjuju se u odgovarajuće nizove vrijednosti koji onda služe kao skup točaka kroz koje se crta *spline* krivulja. Nakon što su nacrtani, bokovi se povezuju lukom tjemene kružnice i tako tvore potpuni profil zuba. Zupčanik nastaje kopiranjem i rotiranjem tako modeliranog zuba oko središta tako da je svaki sljedeći zub od prethodnog udaljen za kut $2\pi/z$.



Slika 7. *Model zupčanika s asimetričnim (a) i simetričnim (b) zubima izrađen pomoću programske procedure*

4 ZAKLJUČAK

Napredak industrije zahtijeva proizvodnju zupčanika koji prenose sve veće snage uz što manju dimenziju i masu, što dovodi do znatnog porasta naprezanja zuba

zupčanika. Eksperimentalne metode kojima bi se ispitivali takvi novi zupčanici skupe su, zahtijevaju puno rada, a obično su i dugotrajne. Napredak računalne tehnologije, kako fizičkih komponenti računala tako i programskih paketa, omogućuje provedbu sve složenijih numeričkih analiza i simulacija u sve kraćem vremenu, što znači da se sve češće koriste umjesto eksperimenata.

Pri proračunu i oblikovanju zupčanika sve se više koriste numeričke metode, poglavito metoda konačnih elemenata, za koju je potrebno izraditi trodimenzijski model zupčanika. Takav model treba biti što sličniji stvarnom zupčaniku kako bi i rezultati numeričke analize bili što kvalitetniji. Temelj svakog trodimenzijskog modela je dvodimenzijski model u ravnini. Kao temelj, dvodimenzijski model mora biti što precizniji kako bi se omogućila izrada kvalitetnog trodimenzijskog modela i provedba numeričke analize koja će dati točne rezultate. Ručna izrada dvodimenzijskih modela spora je i podložna greškama. Programska procedura izrađena u sklopu ovog rada rješava upravo taj problem jer omogućuje brzo i točno parametarsko modeliranje dvodimenzijskog modela zupčanika uzimajući u obzir relevantne parametre kao što su normalni modul, faktor pomaka profila, kut nagiba boka zuba itd.

NOMENKLATURA

A pomoćni faktor u jednadžbi trohoide, mm
B pomoćni faktor u jednadžbi trohoide, mm
d promjer, mm
h visina, mm
m modul, mm
r polumjer, mm
x faktor pomaka, -
x koordinata, mm
y koordinata, mm

Grčki alfabet

α kut zahvatne crte, °
β kut nagiba boka, °
γ kut simetrale zuba, rad
ε pomoćni faktor u jednadžbi trohoide, -
η polarna koordinata/kut točke evolvente, rad
θ pomoćni faktor u jednadžbi trohoide, -
ν kut luka poluširine zuba na diobenoj kružnici, rad
ξ parametar evolvente, -

Subskripti i superskripti

b temeljno
d diobeno
fP podnožni dio zuba osnovnog profila
inv evolventa
tro trohoida

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DESIGN OF THE MACHINE FOR PIPE SHAPING WITH BENDING

Tale Geramitcioski[1], Ljupco Trajcevski[2], Stefan Talevski[3]

Abstract: This paper presents a developed design of a pipe shaping machine composed of a supporting structure and metal rolls that serve to bend the pipe placed between them. Two sets of motions are processed in this design. The first motion is by the manually driven machine and the second is driven by a motor with a reducer. Mainly, this type of a machine is used for shaping by bending standard L-profiles for construction, standard screws, pipe nuts, etc. composed of materials such as high quality steel, aluminum and high quality chromium.The budget for this project realization is set up to 4.000 $USD.

Key words: machine design, pipe shaping machine, tube bending

1. INTRODUCTION

Tube bending is the umbrella term for metal forming processes used to permanently form pipes or tubing. One must differentiate between form-bound and free form-bending procedures, as well as between heat supported and cold forming procedures [2].

Form bound bending procedures like “press bending” or “rotary draw bending” are used to form the work piece into the shape of a die. Straight tube stock can be formed using a bending machine to create a variety of single or multiple bends and to shape the piece into the desired form. These processes can be used to form complex shapes out of different types of ductile metal tubing [1]. Freeform-bending processes, like three-roll-push bending, shape the work piece cinematically, thus the bending contour is not dependent on the tool geometry. Generally, round stock is used in tube bending. However, square and rectangular tubes and pipes may also be bent to meet job specifications. Other factors involved in the bending process are the wall thickness, tooling and lubricants needed by the pipe and tube bender to best shape the material, and the different ways the tube may be used (tube, pipe wires) [3].

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The three-roll push bending (TRPB) is the most commonly used freeform-bending process to manufacture bending geometries consisting of several plane bending curves. Nevertheless, 3D-shaping is possible. The profile is guided between bending-roll and supporting-roll(s), while being pushed through the tools. The position of the forming-roll defines the bending radius. The bending point is the tangent-point between tube and bending-roll. To change the bending plane, the pusher rotates the tube around its longitudinal axis. Generally, a TRPB tool kit can be applied on a conventional rotary draw bending machine. The process is very flexible since with a unique tool set, several bending radii values Rm can be obtained, although the geometrical precision of the process is not comparable to rotary draw bending [4]. Bending contours defined as spline- or polynomial-functions can be manufactured [5].

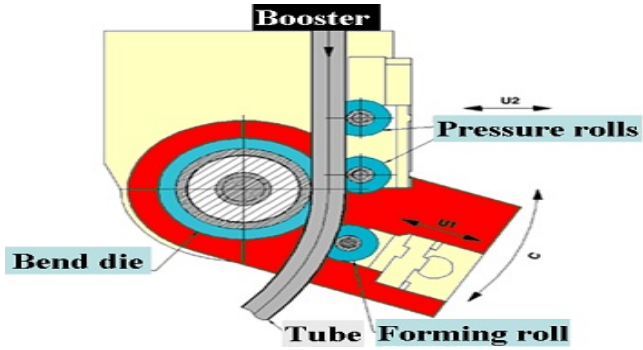


Figure1. *Three-roll push bending process*

On Figure 2, there are several offered tube bending machines at Alibaba's cheapest market with the similar characteristics and the price demanded by the client.

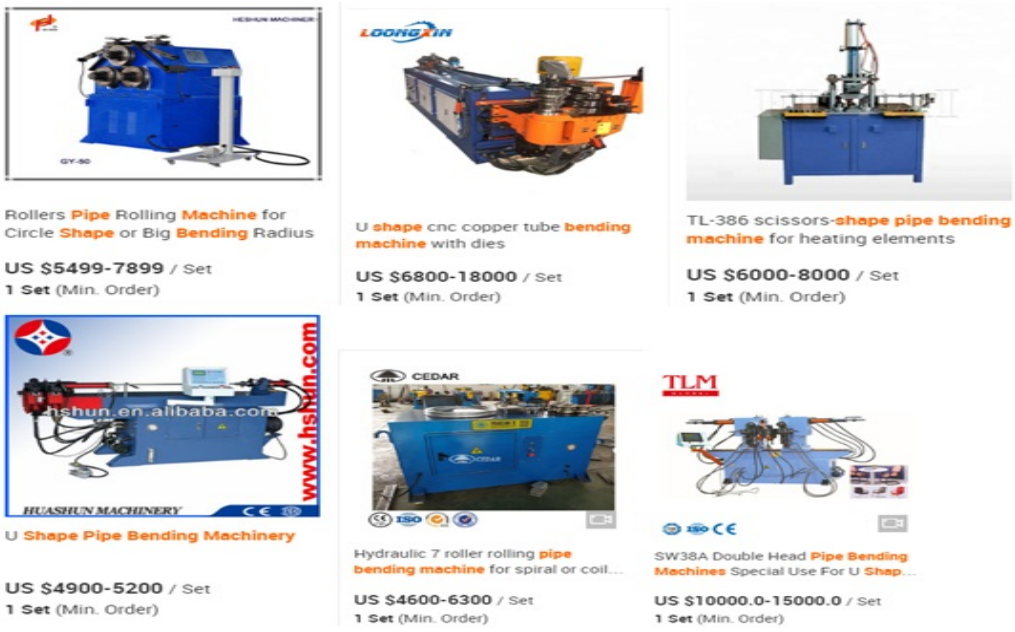


Figure 2. *Several offers of tube bending machines at Alibaba's cheapest market*

Upon a client request, it's obliged to develop a machine that can be used in craft workshops, for the purpose of bending various type of tubes with a maximum of up to five millimetars thiknes by using circular or square cross sections. Initially, the idea was to develop a process and the concept that would work with a manual turn of a large wheel (1st motion). That will be connected to one of the rolls in order to pull the pipe (2nd motion).

There were challenges that had to be overcome, but the problem was interesting and practical. The main problem was to find a way of how to adjust the rising level of the spinning rolls. In addition, a detailed review of the two motions of the machine followed by its advantages and disadvantages.

2. MATERIAL AND METHOD

Considering the client expectations, together it was made a several models which were used to compare each other with detail calculations. The purpose of that activity was to create the final version. The picture on Figure 3 is a draft-drawing sketch made for the client, presenting the idea of how the final product should look like.

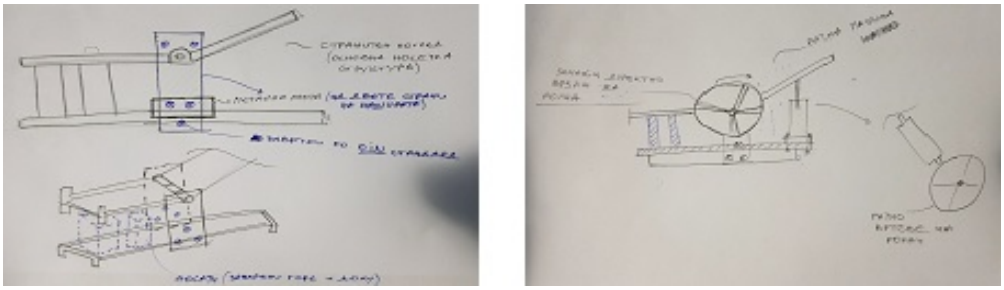


Figure 3. *The draft-drawing sketch of the initial idea from the client*

In order to establish a systematic design procedure, the discursive design method according to directive VDI 2221 was selected (VDI 2221, 1993). The directive divides the engineering process into seven fundamental working steps. Depending on the problem for each of these steps, several specific methods are recommended. The steps and the referring results are shown in Figure 4 [6-10]. For step one, the “searching matrix” method proposed by Roth (Roth, 1994) was used, resulting in several detailed requirement lists. For step two, directive VDI 2222 was selected (VDI 2222, 1997). For step three the method of VDI-engineering morphology was used (VDI 2222, 1997). Referring to Pal/Baits (Pal et. al., 2005) an own pre-evaluation method was developed. Applying the pre-evaluation method, the principle solutions were combined to two promising general concepts. These were constructed in step four and five. Then these two competing preliminary embodiment designs were evaluated by using technical and economic aspects according to Kesselring and VDI – directive “Technisch-wirtschaftliches Konstruieren” (VDI 2225, 1998; VDI 2223, 2004; VDI 2222, 1982). The best design was selected and finalized in step six.

Certainly, the idea has to be modified from what we received as a client’s request - the base, the body and the mechanism itself are fully developed, all parts are solidified in Solid Works and an assembly is made to consider the final result of the work.

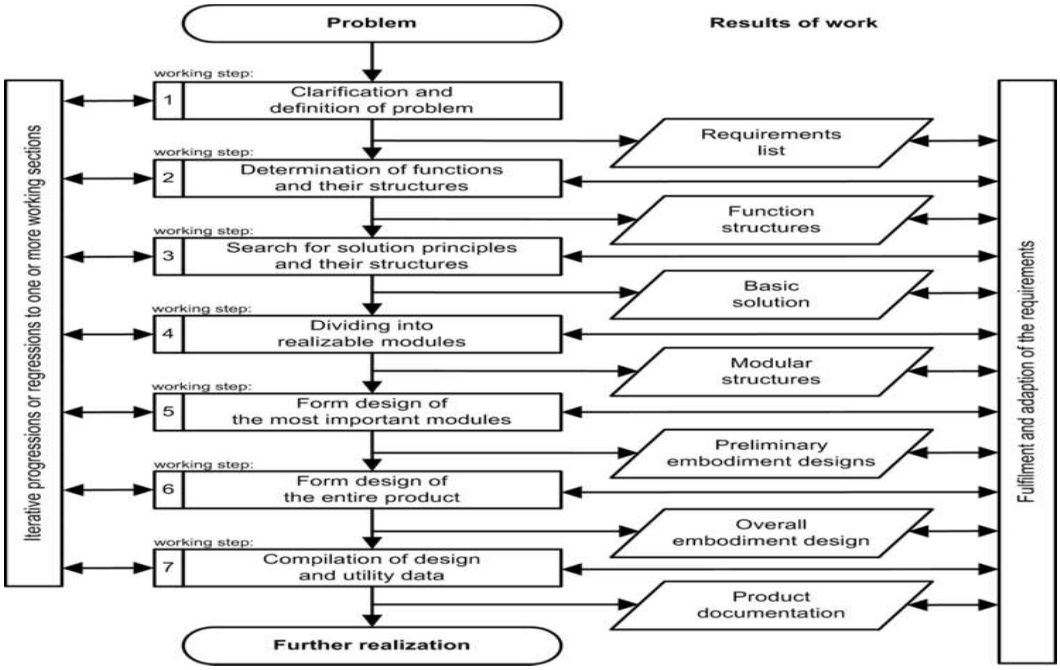


Figure 4. *General VDI-procedure of systematic development and design (VDI 2221)*

2.1 Main Function, partial function and requests

Main function: Bending circular pipes with a 5 mm diameter or greather
Main requests:

- Fast and efficient bending
- A budget of maximum $ 4.000
- Possibility of twisting two tubes at the same time
- Minimazing vibrations and reducing noise
- Increasing speed of up to 2 (m/s) - speed per second of the rolls
- Adjusting the required angle of bending

Partial functions:

- Position the pipe in the machine layer
- Transporting the pipe to the bending tool (rollers)
- Bending the pipe with the requested angle
- Move the pipe off the machine after bending

2.2 The constructive variants

There were two established concepts for different driving of the machine: the first one was with a manual force, and the second was with the motor- belt reducer.

Concept 1



Figure. 5a -*Manual driving machine*

Advantages:

- Budget with reasonable cost
- Folding pipes with a 5mm diameter or larger
- Vibration – as a result of the manual rotation there is no significant vibrations
- Adjusting the bending angle

Disadvantages:

- Requires great power to bend two tubes at the same time
- Lack of fast and efficient bending
- The precisely defined bending speed (2 rpm)

Concept 2

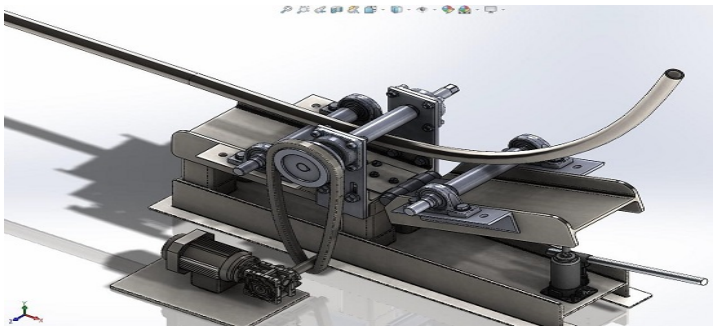


Figure .5b - *Machine with a motor drive - belt reducer*

The second concept was a machine driven by an electric motor with a reducer. The goal was to achieve more satisfied initial requirements, so it was one of the possibilities. In addition follows the input parameters and appropriate calculation:

$P1 = P2 = 7.5kW = 7500W$ - maximum power of the electric motor (1)
$Mt1 = 2Nm$ - input torque (2)
$Mt2 = 900Nm$ - output torque (3)

Calculating for n1 =? ; n2 =?

$P1 = 2\pi n1 \times Mt1 \Rightarrow \boldsymbol{n1 = 500\ rot / sec}$ (4)
$P2 = 2\pi n2 \times Mt2 \Rightarrow \boldsymbol{n2 = 1.31\ rot / sec}$ (5)

The conclusion was that it need an electric motor with a reducer that can

reduce the torque to ratio 1.31. The calculation was necessary in order to know the limits of the motor –belt reducer.

Benefits:

- Budget - up to $ 4.000 while our concept is $ 3.800 (details can be seen in the cost valuation document of the entire machine)
- Folding pipes with a 5mm diameter or greather
- Vibration- still it has, but we have a solution for the maximum reducing vibration
- Adjusting the bending angle
- It is about driving from an electric motor with a reducer, and the power itself to the input the machine, ie, the output from the motorreductor is larger than the input power the man. It means that it satisfies the bending of two tubes at the same time
- Fast and efficient bending
- Required rolling rpm (1.31 revolutions per second)

If figure has a two or more parts, authors should put the labels “(a)”,“(b)”… as its part. Images should still be understandable in black and white printings.

3. RESULT AND DISCUSION

The machine serves for bending pipes with a circular cross-section. It consists of a supporting structure composed of 3 bearing plates, joined together by means of 4 pillars welded on the upper and lower touch surfaces. The upper bearing structure is supported by 3 rolls using standard bearings. The upper carrying structure, unlike the lower one (which is one at full length), consists of two halves coupled with a specially designed mechanism that allows a relative turn of one against the other for a certain angle (as needed).

On the right upper half of the supporting structure, there is also one of the rolls, which, together with the right half, rises for a certain angle.

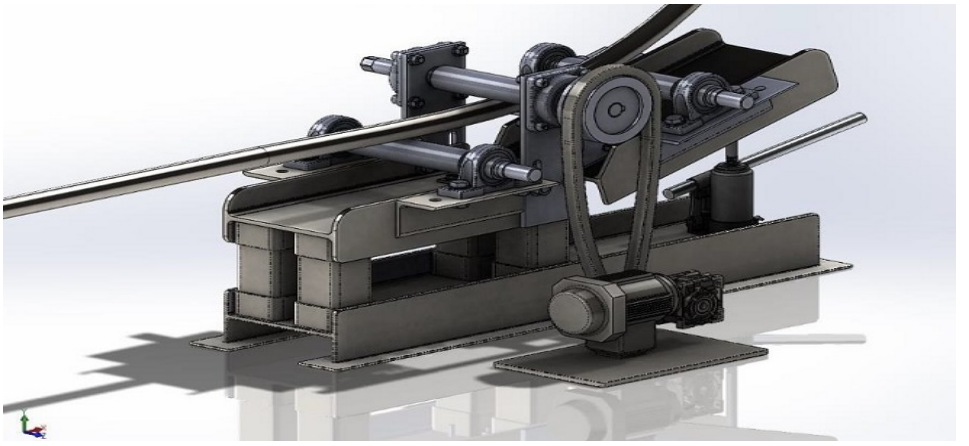


Figure 6. *New construction of the machine for shaping the pipes*

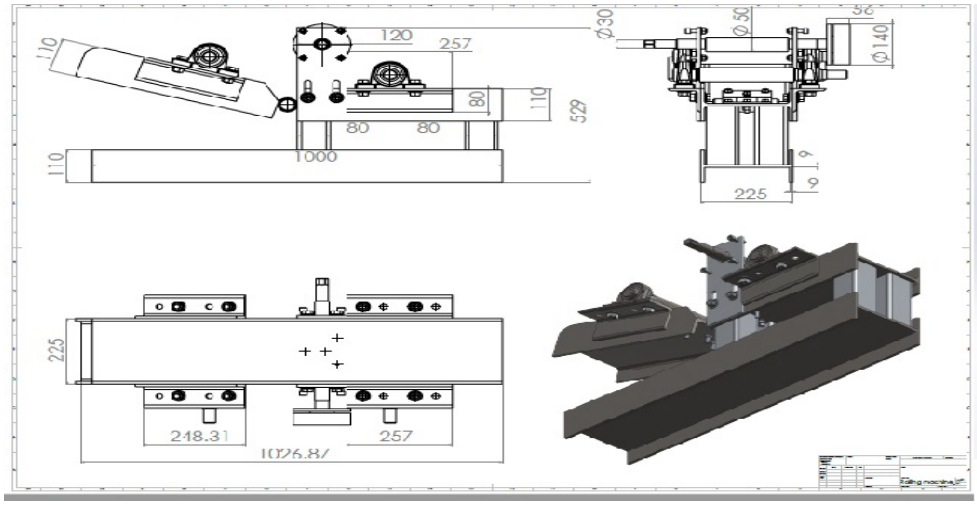


Figure 7. T*echnical documentation (dimensions, cross sections, views)*

Analysis the stress-strain field on the vital parts of the machine was the next step. On the Figure 4a) it can be seen the stress distribution on the vital main steel profile carriage, and on the Figure 4b), the stress field distribution on the roll/bearing/shaft mechanisam for bending the pipes. This part of the construction evaluation was done using FEM package as a much suitable method for discavering the the wickness details of the preloaded mechanisms.

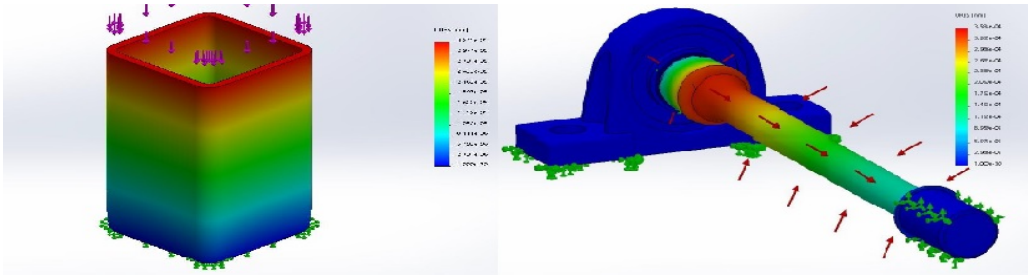


Figure 8. *a) FEM Stress analysis of the main steel structure b) Roll bearing simulation (FEM Analysis)*

4. CONCLUSION

The aim of this paper is to present a problem-solving approach according to the norms of VDI 2221 where the unconditional requests by the buyer are not to be changed. In such immutable requirements, it is necessary to find a proper execution of partial functions of the machine that often are not presenting the best technical solution.

The project budget is set up to a maximum of 4.000 USD. The goal is to bend circular pipes with a 5 mm diameter or greather with a set of technical preconditions such as easy portability, manual operation, light construction, etc., as well as overall construction simplicity.

Using the VDI 2221 procedures, an optimal solution was found that meets the client requirements and most importantly, meets his design and the other conceivable conditions.

According to overall analysis, research, calculations, simulations and detailed examination of the cost, it was finally able to come up with the final model with a total cost of 3.800 US dollars. Detailed list of the items and their cost can be seen in a separate documentation.

From the simulations with the given calculations of the model, the maximum tensile strength of the steel constructions when the rolls does not cross eachother does not reach the point of tear in the diagram of stretch-stretching. Eventualy, it can be conclude that the design is functional, feasible and practica safe to operate preserving all safety standards. All of the materials, elements and parts are selected according to the standards of the already existing ones and can be found in every proper store.

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ENERGY CONSUMPTION AND ECONOMIC ANALYSIS OF DIFFERENT HEATING SYSTEMS IN SERBIAN BUILDING

Danijela Nikolić[1], Jasmina Skerlić[2], Blaža Stojanović[3], Radoslav Tomović[4], Dragan Cvetković[5], Saša Jovanović[6]

Abstract: Energy consumption in buildings at the global level is 20 - 40% of total energy consumption, while in Serbia it is at the level even of 50 %. This consumption is related to the exploitation conditions of buildings, where the largest consumer is heating system with ratio of 50 - 60 %. This paper represents the investigations in simulation of different heating systems in typical Serbian building. It is analyzed the electric space heating, district heating, gas heating and coal central heating, for typical Serbian building with variable thermal insulation thickness. The investigated building was located in Kragujevac, Serbia. The building is simulated in software EnergyPlus while Open Studio plug-in Google SketchUp was used for building design. Paper shows the real consumption of primary and final energy in Serbian building. Finally, the economic analysis was performed for different heating systems, which shown that the gas heating system is the most effective heating systems for the Serbian building – it has a small primary energy consumption and it is cost effective.

Key words: Building, Heating, EnergyPlus, Energy consumption, Economic analysis

1 INTRODUCTION

In recent years, question of energy security and stability has become the cardinal question of the entire world economy, economic and social system. The rapid population growth on Earth causes a steady increase of energy needs. Therefore, humanity is in constant researching of new energy sources that would cover the growing energy needs. The world currently covered their energy needs with conventional energy sources, mainly fossil - nonrenewable energy sources, which have a large number of negative impacts, especially on the environment.

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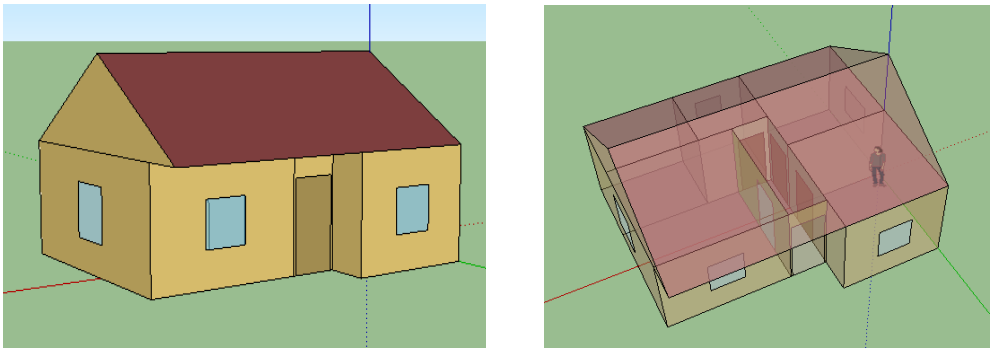
In Serbia, the building sector consumes more than 50% of the total energy consumption [1]. As the buildings consume a significant part of energy, it is necessary to investigate all aspects of energy consumption in order to minimize the total final and primary energy consumption. In developed countries heating systems consume around a third of the total building energy consumption, while in Serbia it is at the level of even 60 % [2]. The rest part of energy consumption is related to the ventilation, lighting and electrical appliances. The main reason for this is a great number of energy inefficient buildings in Serbia, with annual energy consumption of 220 kWh/m^2, while the European average energy consumption is 60 kWh/m^2. The building envelope is a critical component for the energy losses and heating energy consumption. So it is very important to design energy efficient buildings or implement the principles for improving energy efficiency of already existing buildings.

This paper presents the investigations of the possibilities to decrease primary energy consumption of Serbian residential buildings with different heating systems, through the variation of thermal insulation thickness and implementation of real parameters in calculation of total energy consumption. It is analyzed four type of heating system. Also, an economic analysis was performed.

The investigated building was located in Kragujevac, Serbia. Heating system operated from October 15th to April14th next year. In this paper, the EnergyPlus software was used for building energy simulation [3], while Open Studio plug-in in Google SketchUp [4] was used for building design.

2 MODEL OF ANALYZED BUILDING

The modeled residential building is shown in Figure 1. The building is one-store building and it contains from 5 conditioned zones (living room, hall, bathroom and two bedrooms). The total floor area of the building is 98.8 m^2. The windows are double glazed. The concrete building envelope, roof, and the floor were thermally insulated by polystyrene. In this investigation, the polystyrene thickness varied (0.05 m, 0.1 m and 0.15 m).



a) b)

Figure 1. *Modeled building in EnergyPlus (a – north facade; b – X ray mode view)*

Generally, electricity is consumed for lighting, domestic hot water (DHW) and appliances. It is analyzed the electric space heating, gas heating, coal central heating and district heating, and also real energy consumption (final and primary energy) in the residential building. First, it will be given the required heating energy for the modeled building, in the cases of different thermal insulation thickness.

3 REQUIRED HEATING ENERGY

The amount of required heating energy E_h in the analyzed residential building is obtained by simulations in software package EnergyPlus (Table 1). The heating energy is independent of the heating system. The results below show the amount of heating energy E_h, as well as the total final energy consumption E_f (annually), in the case of different thermal insulation thickness: 0.05 m, 0.1 m and 0.15 m.

Table 1. *Building final energy consumption for different thermal insulation thickness*

Energy	*Energy consumption (kWh)*		
	0.05 m	*0.1 m*	*0.15 m*
Heating (Eh)	*7180.88*	*6503.32*	*6206.15*
Lighting	*593.19*	*593.19*	*593.19*
Electric equipment	*1552.76*	*1552.76*	*1552.76*
Water heating	*2384.62*	*2384.62*	*2384.62*
Total energy consumption	*11711.45*	*11.033.89*	*10736.72*

Based on Table 1 it can be concluded that the consumption of heating energy depends on the thickness of the thermal insulation. Heating energy consumption is the lowest in case of maximum thermal insulation thickness. Figure 2 shows a comparison of the energy consumption in the building, depending on the insulation thickness.

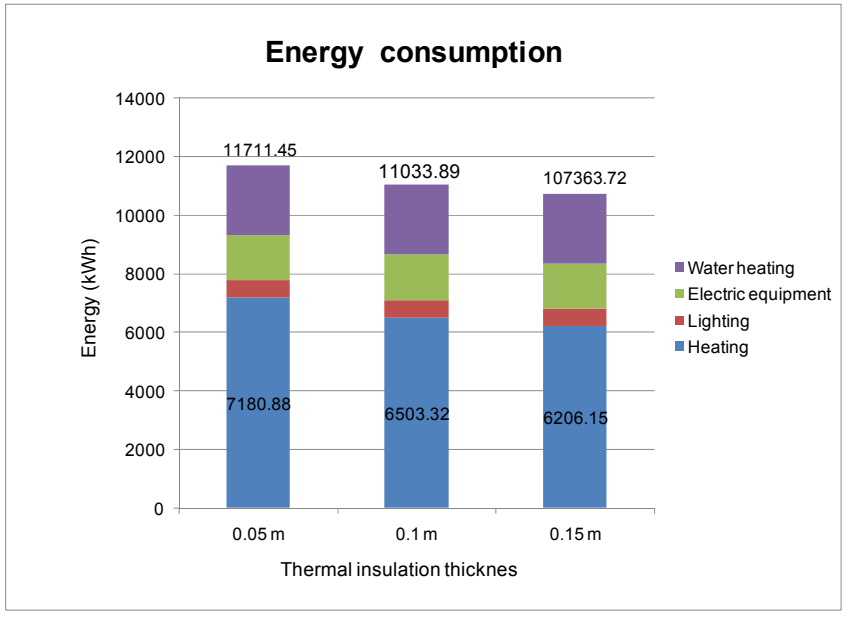


Figure 2. *Structure of energy consumption in modeled building*

In the further investigations, it will be discuss the case of building with 0.15 m thermal insulation thickness, becouse it is the most favorable case from the aspect of energy efficiency. In this case, the required heating energy has the lowest value; heating losses are the smallest, as the U value through the building envelope. By implementation of some other principles of energy efficiency, building energy consumption could be reduce even more. Also, incorporation of renewable energy sources has a significant role in the reduction of total building energy consumption.

4 REAL HEATING ENERGY CONSUMPTION

The amount of real heating energy consumption (E_{fin}) depends of different values of some efficiency coefficients. These coefficients are related to baseboard efficiency, boiler efficiency, pump efficiency and heat exchanger efficiency. Some of these coefficients figure in terms of real energy consumption calculating, and they are different for different space heating system, like equiation for real energy consumption [5, 6] .

4.1 Electric space heating (EH)

Electric space heating means convective electric baseboard in every conditioned zone (room). Real consumption of electric energy for heating, in electric space heating system is:

$$E_{fin} = \frac{E_h}{\eta_{er}} \tag{1}$$

where η_{er} stands for efficiency of convective electric baseboard (η_{er}=0.95, [7]).

4.2 Gas heating system (GH)

Real energy consumption in gas heating system (with gas boiler in the building) is given in next equation:

$$E_{fin} = \frac{E_h}{\eta_{kpg}} + \frac{E_p}{\eta_p} \tag{2}$$

where E_p stands for electricity for circulation pump, η_{kpg} stands for efficiency of gas boiler (η_{kpg}=0.85, [8]) and η_p stands for circulation pump efficiency (η_p=0.87, [9]).

4.3 Coal central heating (CH)

Real energy consumption in coal central heating system (with coal boiler) is given in equation (3):

$$E_{fin} = \frac{E_h}{\eta_{ku}} + \frac{E_p}{\eta_p} \tag{3}$$

where η_{ku} stands for efficiency of coal boiler (η_{ku}=0.68, [8]).

4.4 District heating (DH)

Real energy consumption for district heating system in building is given in equation (4):

$$E_{fin} = \frac{E_h}{\eta_{raz} \cdot \eta_{cm} \cdot \eta_a} + \frac{E_p}{\eta_p} \tag{4}$$

where η_{raz} stands for heat exchanger efficiency (η_{raz} =0.84), η_{cm} stands for pipeline efficiency (η_{cm} =0.95) and η_a stands for fittings efficiency (η_a=0.95) [8].

4.5 Real consumption of final and primary heating energy

According to the above coefficients and equations, it can be calculated real final heating energy consumption (E_{fin}) for all analyzed heating system in modelled building. Primary heating energy consumption (E_{prim}) is calculated by multiplying the real final heating energy consumption with the corresponding primary conversion multiplier. For Serbia, primary conversion multiplier for electricity is 3.04, for district heating it is 2.03, for coal heating it is 1.3 and for gas it is 1.1 [10].

Next table (Table 2) shows the results for real consumption of final and primary heating energy, for all types of analyzed heating systems in the modelled building.

Table 2. *Building real final and primary heating energy consumption for different heating systems*

	Energy consumption (kWh)			
	EH	*DH*	*CH*	*GH*
Heating energy (Eh)	*6206.15*	*6206.15*	*6206.15*	*6206.15*
Real final heating energy (Efin)	*6532.78*	*8187.42*	*9148.12*	*7322.79*
Primary heating energy (Eprim)	*19859.68*	*16642.12*	*11929.87*	*8096.65*

Graphical presentation of results for building energy consumption in cases of different heating systems is presented on Figure 3.

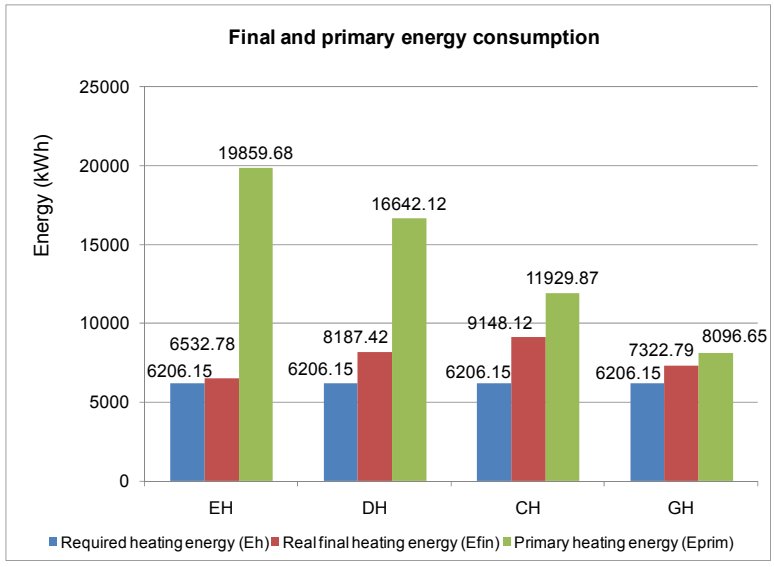


Figure 3. *Required heating energy, final and primary heating energy consumption in modeled building for different heating systems*

Primary energy consumption is influenced by the efficiency of devices that transform the final energy form into a useful energy form, and the final energy conversion multiplier in the primary energy.

From Table 2 and Figure 2, it can be concluded that the real final heating energy consumption has the highest value for coal heating, becouse of the low value of the coal boiler efficiency. Also, real final heating energy consumption is lowest for electric space heating. Primary energy consumption is the greatest for electric space heating (primary conversion multiplier has the highest value for electricity, 3.04), and it is lowest for gas heating (primary conversion multiplier has the value only 1.1). From the aspect of energy efficiency, according to the primary energy consumption, gas heating is the most advantageous heating system, which, also, have the smallest influence to the environment and greenhouse gas emission.

5 ECONOMIC ANALYSIS

For the economic analysis of energy consumption and the final price paid for heating during the heating season in a modelled house, real energy prices in Serbia were used. The price of electricity of the single-tariff meter in the blue zone in Serbia is 7.658 din/kWh [11]. The amount of natural gas, as well as the coal required for heating the object, is calculated according to the procedures described in [5] and [6]. Taking into account that the price of natural gas for category 1 (p < 6 bar) is 32.28 din/m^3 [12], and the price of dark coal to which the corresponding lower thermal power is 14.000 din/t [13], the heating price for modelled house is given below (Table 3). The price of district heating is given on the basis of the average price of district heating in the city of Kragujevac, for a building area of 100 m^2.

Table 3. *Total cost for building heating for different heating systems*

Heating system	*Efin*	*Required amount*	*Unit price*	*Total cost (din)*
Electric heating (electricity)	*6532.78*	*6532.78 kWh*	*7.658 din/kWh*	*50029*
Gas heating (gas)	*7322.79*	*796,51 m^3*	*32.38 din/m^3*	*25791*
Coal heating (coal)	*9148.12*	*1.830 t*	*14 000 din/t*	*25620*
District heating	*8187.42*	*8187.42*	*-*	*54795*

Economic analysis shows that the most economical heating systems are coal heating and gas heating, while currently, the district and electric heating are more expensive heating systems in Serbia. District heating and electric heating have approximately the same price, but this price is significantly higher than the cost of gas and coal heating. When choosing a heating system, it should taking into account the pollution of the environment, which is the biggest with fossil fuels combustion (e.g. coal). Coal heating is very difficult as well as the process of its servicing, so it should be considered too. It should not always look only the price, but consider all the other factors in choosing a proper heating system.

At the end, it can be concluded that the gas heating system is favourable and the most economic heating system in Serbia – it is the cheap and clear and it has a smallest primary energy consumption.

Figure 4 represent graphically the total cost for heating energy in the analyzed building, for different heating system.

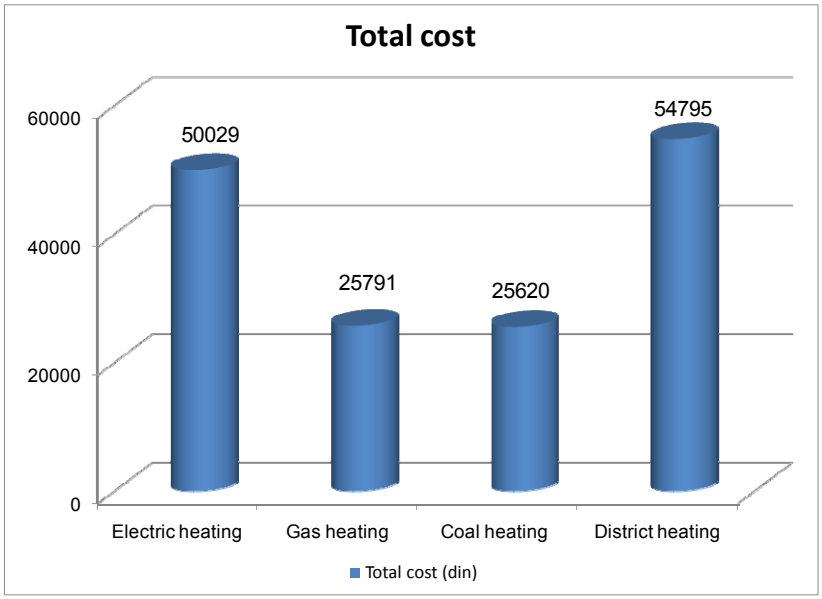


Figure 4. *Total cost for heating energy for different heating systems*

6 CONCLUSION

This paper represents investigation of real final and primary energy consumption for residential Serbian building. First, required heating energy (final energy) was obtained by EnergyPlus software for analyzed building. Then, real heating energy consumption was calculated, taking into account different values of some efficiency coefficients which refer to heating system installation. Obtained results showed that the real final heating energy consumption has the highest value for coal heating and it is lowest for electric space heating. Primary energy consumption is the greatest for electric space heating and it is lowest for gas heating (primary conversion multiplier has the value only 1.1).

After energy analyses, the economic analyses was made, which showed that for analyzed Serbian building, the most economical heating systems are coal heating and gas heating system.

According to all these facts, the conclusion is that the best solution for heating in Serbian building is gas heating which is very cheap, clear and very convenient to the environment. It also has a lowest primary energy consumption.

ACKNOWLEDGMENT

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NOMENCLATURE

E energy, kWh

p pressure, bar

Greek symbols

η	efficiency

Subscripts and superscripts

a	fittings
cm	pipeline
er	electric baseboard
f	final energy
fin	real final heating energy
h	heating
kpg	gas boiler
ku	coal boiler
p	pump
prim	primary heating energy
raz	heat exchanger

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MOGUĆNOST KORIŠTENJA GEOTERMALNE ENERGIJE U BOSNI I HERCEGOVINI

Gordana Tica[1], Danijela Kardaš[2], Petar Gvero[3]

Rezime: Obnovljivi izvori energije će u budućnosti sasvim sigurno zauzimati sve više važnosti u istraživanju i korištenju. Isti scenariji se predviđaju i za Bosnu I Hercegovinu. Scenarija za budućnost podrazumijevaju ekološku varijantu korištenja nefosilnih goriva, odnosno nastojanje da se sve intenzivnije istražuju i koriste domaći alternativni izvori energije. U taj scenario treba da se uklopi i naša zemlja, jer za to postoje objektivno povoljni uslovi u okviru cijele Bosne I Hercegovine. Hidro - geotermalna potencijalnost sjeverozapadnog dijela Republike Srpske odavno je prognozirana i samom spoznajom da je to područje postojanja bivšeg i davno potonulog Panonskog mora. Još prije davnih 40-50 godina ukazivano je na potrebu utvrđivanja uslova i mogućnosti korištenja geotermalne energije podzemnih voda u našoj zemlji.

Ključne riječi: obnovljivi izvori energije, geotermalna energija, geotermalni izvori

POSSIBILITY OF USE OF GEOTHERMAL ENERGY IN BOSNIA AND HERZEGOVINA

Abstract: Renewable energy sources will in the future certainly become increasingly important in research and use. The same scenarios are foreseen for Bosnia and Herzegovina. The scenario for the future implies an ecological variation of the use of non-phosphine fuels, ie the attempt to explore and use more intense alternative domestic sources of energy. In this scenario, our country needs to be integrated as there are objective favorable conditions for it throughout Bosnia and Herzegovina. The hydro - geothermal potential of the northwestern part of the Republika Srpska has long been forecasted by the very knowledge that this is the area of existence of the former and long sunken Pannonian Sea . More than 40-50 years ago, it was pointed out the need to determine the conditions and the possibility of using geothermal energy of groundwater in our country.

Key words: renewable energy sources, geothermal energy, geothermal sources

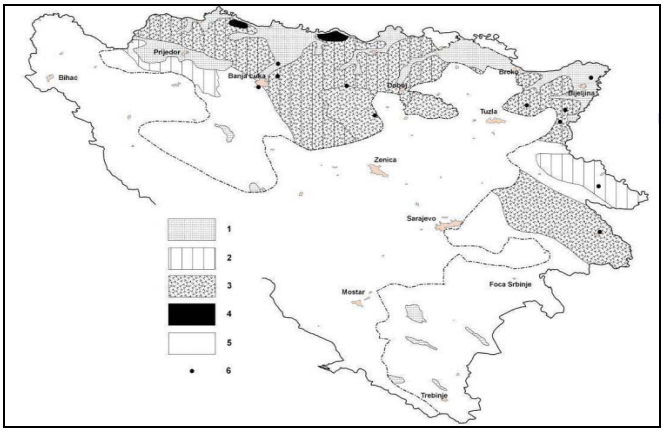
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1 UVOD

Geotermalnom energijom smatramo onu energiju koja se može dobiti iz Zemljine unutrašnjosti i koristiti je u energetske ili neke druge svrhe. Geotermalni gradijent je jedan od prvih pokazatelja koji upućuje na potencijalno ležište. Srednja vrijednost geotermalnog gradijenta za Evropu iznosi 0,03 °C/m, dok je u Bosni i Hercegovini, te Republici Srpskoj (za područje Panonskog dijela) veći od 0,04 °C/m, [1,2]. Svjetski geotermalni potencijal je veliki, gotovo 35 milijardi puta veći nego što iznose današnje potrebe za energijom. Međutim, tek se vrlo mali dio potencijala te energije može energetski- ekonomski- efikasno iskorištavati (E^3), i to do dubine 5000 m.

2 POTENCIJAL GEOTERMALNE ENERGIJE U BOSNI I HERCEGOVINI

Istorija korištenja geotermalne energije za različite potrebe datira iz davne prošlosti. Bosna i Hercegovina je, zasada, svoj geotermalni potencijal u smislu *proizvodnje električne energije* potpuno zanemarila. S druge strane se geotermalna energija koristi već dugi niz godina, posebno u banjskim i rekreativnim objektima. Takođe je velika iskoristivost toplotnih pumpi, te u toplifikaciji. U principu ne postoje standardna rješenja korišenja i metoda za npr.proizvodnju električne energije, već se za svako geotermalno polje i bušotine određenih kapaciteta, temperatura, te fizičko-hemijskog sastava fluida, nalaze posebna optimalna rješenja za tipične uslove. Geotermalni potencijal Bosne i Hercegovine, za grijanje prostora, je procijenjen na oko 33 MWth. Sjeverni dio teritorije Republike Srpske je veoma perspektivan u pogledu prisustva resursa geotermalne energije, odnosno geotermalanih voda. Glavna geotermalna nalazišta nalaze se u trijaskim i krednim krečnjacima i čine ih akumulacije geotermalnih voda temperature od 35 do 150 °C. Na slici 1 je prikazana mapa sa mestima pogodnim za iskorištenje geotermalne energije u Republici Srpskoj [3,4].



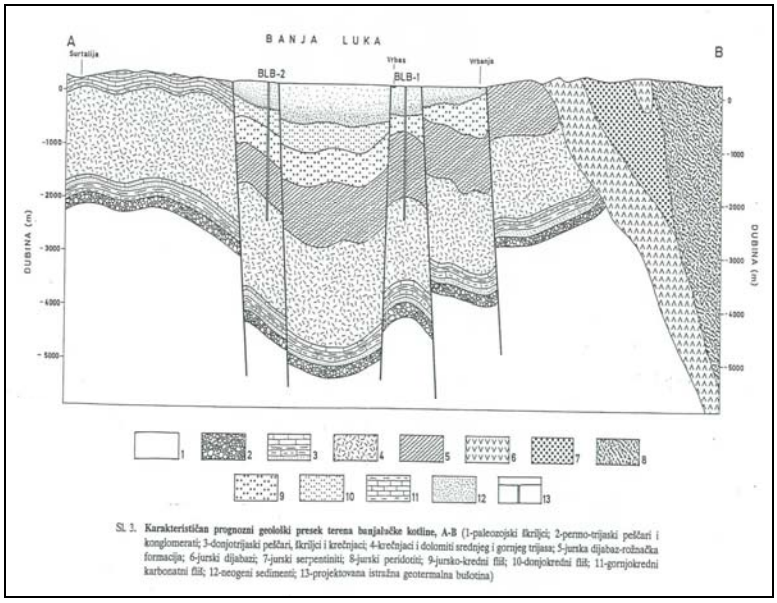
Slika 1. *Nalazišta geotermalne energije u Republici Srpskoj [3]*

1– hidrogeotermalno nalazište u aluvijalnim sedimentima čija se geotermalna energija može koristiti toplinskim pumpama

2– hidrogeotermalno ili petrogeotermalno nalazište u nekarstnim terenima do dubine od 300 m čija se geotermalna energija može koristiti pomoću vertikalnih izmjenjivača toplote i toplotnih pumpi

3– hidrogeotermalno nalazište u trijaskim i krednim vapnencima i dolomitima čija se geotermalna energija može direktno koristiti
4- petrogeotermalno nalazište u granitoidnim stenama čija se geotermalna energija može koristiti za proizvodnju električne energije
5– područje bez značajnijih geotermalnih nalazišta
6– područje sa značajnijom pojavom geotermalnih voda.

Temperatura na lokacijama u Bosanskom Šamcu (85 °C), Kaknju (54 °C) i Sarajevu (58 °C) je preniska za pokretanje proizvodnje električne energije što je glavni razlog zašto se ove reserve uzimaju u razmatranje samo kada je u pitanju eksploatacija toplotne energije. Ovdje se željelo pokazati da postoje rezultati dosadašnjih saznanja o potencijalu geotermalnih voda i njihovoj eksploataciji u Bosni i Hercegovini, te Republici Srpskoj. Izvršena su opsežna geološka istraživanja, iz praktično svih oblasti geologije, tj. ukazala su na realan potencijal. Prema pomenutoj karti, vrijednosti toplotnog toka za banjalučku kotlinu i njenu okolinu su 60 mW/m^2. To je i prosječna vrijednost toplotnog toka za kontinentalni dio Evrope. Ostali parametri, čije se vrijednosti poklapaju sa vrijednostima određenim geološkim kartiranjem (OGK karta), su debljina zemljine kore 32 do 33 km, a dubina do baze sedimenta 2 do 4 km.



Sl. 3. **Karakterističan prognozni geološki presek terena banjalučke kotline, A-B** (1-paleozojski škriljci; 2-permo-trijaski pešćari i konglomerati; 3-donjotrijaski pešćari, škriljci i krečnjaci; 4-krečnjaci i dolomiti srednjeg i gornjeg trijasa; 5-jurska dijabaz-rožnačka formacija; 6-jurski dijabazi; 7-jurski serpentiniti; 8-jurski peridotiti; 9-jursko-kredni fliš; 10-donjokredni fliš; 11-gornjokredni karbonatni fliš; 12-neogeni sedimenti; 13-projektovana istražna geotermalna bušotina)

Slika 2. *Karakteristični prognozni geološki presjek terena banjalučke kotline*

Hidrogeotermalne pojave na području i u okolini banjalučke kotline su u vidu termalnih i termomineralnih izvora na poznatim lokalitetima: Gornji Šeher, Slatina, Laktaši, Priječani. To su prije svega površinske vode koje se koriste u balneologiji i za rekreacione svrhe. Određene su temperature, i do 35 ^{o}C. eološka i seizmološka ispitivanja koja su sprovođena na širem području grada. Akumulacija se nalazi na pretpostavljenoj dubini, izvjesnoj do 2000m. Na sadašnjem nivou saznanja u najdubljim dijelovima rezervoara u području banjalučke kotline mogu se očekivati max temperature 100 do 110 ^{o}C. Dostupni potencijal geotermalne energije se može

eksploatisati uz današnju tehnologiju i postojeće ekonomske uslove, uz pretpostavku da se količine nalaze u poznatim ležištima. Geotermalna energija termalnih voda, temperature od 80 do 100 °C, je, po literaturnim podacima, akumulisana u sedimentima stijena mezozojske starosti na dubini oko 2 do 3 km i predstavljaju glavni geotermalni resurs Republike Srpske. Za područje Banjalučke kotline procijenjene su rezerve na oko 7 x 10^6 tona ekvivalentne nafte, samo u termalnoj vodi. Smatra se da se glavni hidrogeotermalni potencijal i rezerve geotermalne energije nalaze u Sjevernim dijelovima Republike Srpske, u Posavini, te da se u njemu može očekivati voda prosječne temperature oko 100 °C. Za termalne vode sa temperaturom većom od 80 °C, najperspektivnija područja za istraživanje, eksploataciju i intenzivno korištenje te geotermalne energije, su Banjalučka kotlina, Lijevče polje, okolina Brčkog, Dervente, Odžaka, Broda, Gradiške i Dubice, [3, 4,5].

Procjena korištenja geotermalne energije za Republiku Srpsku u budućnosti je takva, da je moguća tehnologija korištenja geotermalnih resursa u nekoliko oblasti, a to su: u poljoprovredi za proizvodnju ekološki vrijedne hrane (agro i akvakultura), u komunalnoj sferi za grijanje, u zdravstvenoj industriji i industriji za njegu ljudskog tijela – balneoterapija, u turističke svrhe, te a proizvodnju električne energije putem mini - elektrana. Procjenjena snaga geotermoelektrana može iznositi oko 630 MW, raspoređenih po cijelom banjalučkom području. Potencijal banjalučkog rezervoara, izračunat pomoću zapreminske metode, [5,13], je:

$$E_u = E_s + E_v = (1-n)\cdot c_s \cdot \rho_s \cdot V \cdot (t - t_0) + n \cdot c_v \cdot \rho_v \cdot V \cdot (t - t_0) \quad (1)$$

gdje je :

E_s = 4 x 10^{15} kJ - prognozirana količina geotermalne energije u stijenskoj masi rezervoara. Njena toplotna energija je ekvivalentna oko 950 miliona tona nafte.

E_v = 0,4 x 10^{15} kJ - prognozirana količina geotermalne energije u termalnoj vodi u rezervoaru. Njena toplotna energija je ekvivalentna oko 95 miliona tona nafte.

E_u - ukupna energija akumulisana u rezervoaru koja može se odrediti na osnovu zapreminske metode

n - ukupna efektivna poroznost rezervoara, n = 0,5%

V - zapremina rezervoara, V = P x D

P - površina rezervora, P = 500 km^2

D - debljina rezevoara, D = 500 do 1000 m

c_s - prosječna specifična toplota stijenske mase rezervoara, c_s = 0,86 kJ/kg °C

c_v - prosječna specifična toplota temalne vode u rezervoaru, c_v = 4,180 kJ/kg °C

ρ_s - prosječna gustina stijenske mase rezervoara, ρ_s= 2600 kg/m^3

ρ_v - prosječna gustina geotermalne vode reervoara, ρ_v = 1000 kg/m^3

t - prosječna temperatura stijenske mase i termalne vode u rezervoaru,
t = 85 °C

t_o - referentna temperatura, t_o = 12 °C.

Trenutno se koriste četiri osnovna tipa geotermalnih elektrana:

- Princip suve pare (Dry steam) – koristi se isključivo vruća para, tipično iznad 235 °C (445 °F). Ta para se koristi za direktno pokretanje turbina generatora;
- Metoda flash princip (Flash steam) – Princip separacije pare (flash steam) - koristi se vruća voda iz geotermalnih rezervoara koja je pod velikim pritiskom i na temperaturama iznad 182 °C
- "Hot-draj-rok" metoda - To je je savremena metoda dobivanja geotermalne energije, u kojoj se voda pumpa kroz jednu bušotinu u slojeve vrućih stijena i kroz drugu bušotinu izlazi vodena para temp. 170 °C, koja služi za proizvodnju

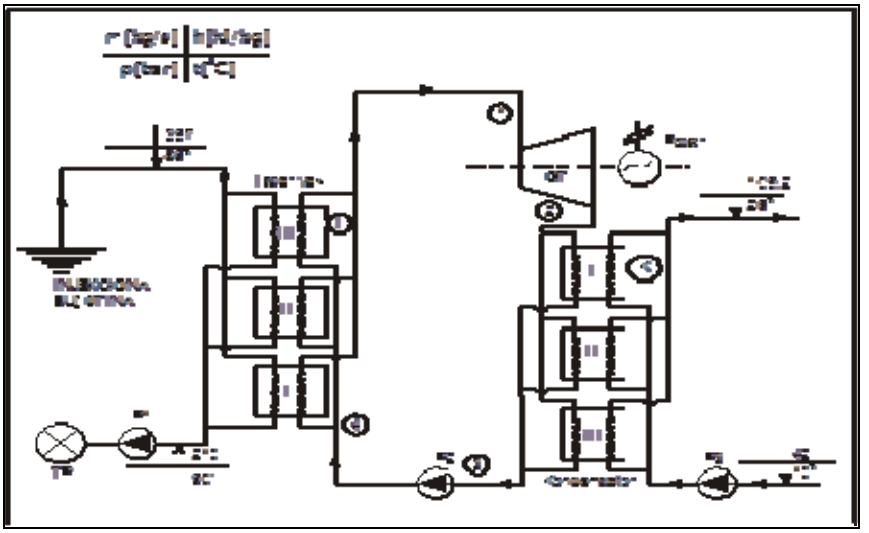
električne struje;

- Binarni princip (Binary cycle) **–** Proizvodnja električne energije koristeći binarni ciklus (Binary cycle). Voda koja se koristi kod binarnog principa je hladnija od vode koja se koristi kod ostalih principa generisanja električne energije iz geotermalnih izvora. Kod binarnog principa vruća voda se koristi za grjanje tekućine koja ima znatno nižu temperaturu vrelišta od vode, a ta tekućina isparava ne temperaturi vruće vode i pokreće turbine generatora. Prednost tog principa je veća efikasnost postupka, a i dostupnost potrebnih geotermalnih rezervoara je puno veća nego kod ostalih postupaka. Dodatna prednost je potpuna zatvorenost sistema budući da se upotrijebljena voda vraća natrag u rezervoar pa je gubitak toplote smanjen, a gotovo da i nema gubitka vode. Većina planiranih novih geotermalnih elektrana koristiće ovaj princip.

Postrojenja sa binarnim ciklusom mogu da koriste i izvore nižih temperatura. Postoje dva nezavisna strujna kruga. U drugom strujnom krugu je fluid niže tačke ključanja u odnosu na vodu. Obično se gradi nekoliko manjih jedinica snage od nekoliko MW.

3 KORIŠTENJE GEOTERMALNE ENERGIJE ZA PROIZVODNJU ELEKTRIČNE ENERGIJE U REPUBLICI SRPSKOJ

Kao Prilog Katedre za Termotehniku i termoenergetiku prikazan je plan – primjer za proizvodnju električne energije iz geotermalne energije, [3, 4]. Na slici 3. je prikazana tehnološka šema binarnog postrojenja snage 1 MW za proizvodnju električne energije. Izračunata količina geotermalne energije rezervoara banjalučke kotline, [3] ukazuje na opravdanost idejnog projekta postrojenja za proizvodnju elektrinčne energije. Pošto je temperatura geotermalne vode manja od 100 ^{o}C, za proizvodnju se može upotrijebiti binarni ciklus, pretvaranjem toplotne energije vode u mehaninčku energiju i onda, putem generatora u električnu energiju. U termodinamičkom Rankinovom zatvorenom ciklusu između dva toplotna resursa (geotermalna voda više temperature i rashladna voda niže temperature), treba da protiče radni fluid koji se bira vodeći računa o više aspekata. Radni fluid treba da posjeduje određene termotehničke i fizičke osobine (da nema opasnosti od eksplozije, nije zapaljiv, nije toksičan, pristupačna cijena). Termodinamička efikasnost rada zavisi od izabranog radnog fluida. Da bi se determinisao optimalni termodinamički ciklus primjenjuju se poznate termodinamičke metode. Za optimizaciju binarnog postrojenja kao ilustracija u ovom primjeru prikazana je radno sredstvo CO_2 ,ugljen dioksid (R-744), čija je kritična temperatura manja od temperature geotermalne vode (proces isparavanja u nadkritičnim uslovima). Izbor ovog radnog sredstava je bio presudan zbog Montrealskog protokola. Opis tehnološke šeme (slika 3): Proces ekspanzije pare u turbini se vrši adijabatski do linije zasićenja. Zasićena para se kondenzuje rashladnom vodom, koja se dovodi iz površinskih izvora ili najbliže rijeke. Radno sredstvo u tečnom stanju se dalje pumpom transportuje u isparivač, te se tako nastavlja kružni process. Optimizacija postrojenja se vrši s obzirom na izbor najpovoljnijeg radnog sredstva. Kriterij za izbor radnog sredstva je da postrojenje ima najveću eksergijsku i termodinamičku korisnost.



Slika 3. *Tehnološka šema binarnog postrojenja snage 1 MW za proizvodnju električne energije(I- isparivač, GT - gasna turbina, G - generator, K - kondenzator, P_1 - pumpa geotermalnog fluida, P_2 - pumpa radnog sredstva , P_3 - pumpa rashladne vode, TP - toplotni potrošač) [4]*

Parametri stanja geotermalne i rashladne vode na ulazu i na izlazu iz postrojenja su definisani određenim termodinamičkim vrijednostima [4]. I parametri radnog sredstva CO_2 za binarno postrojenje su definisani na osnovu dijagrama za dotični radni fluid i na osnovu termodinamičkih zakonitosti, kao i promjena, a definisani su pomoću: dijagrama (p - i) , (t - s) i (i - s). Nakon sprovedog složeog terodinamičkog proračuna, na osnovu veličine stanja CO_2 u karakterističnim tačkama procesa, dobivena je vrijednost dovedenih korisno upotrijebiljenih eksergija, kao i obezvrijeđenih. Tako se ovom metodom odredi suma eksergija koje ulaze i izlaze iz postrojenja, te se eksergijski stepen korisnosti može izraziti kao odnos tih suma:

$$\eta_{ex} = \frac{\sum E_{izl}}{\sum E_{ul}} \tag{2}$$

Tako se na osnovu složenog proračuna dobije da je eksergijski stepen korisnog dejstva procesa dobivanja električne energije iz geotermalne energije, ako se u postrojenju koristi CO_2, je:

$$\eta_{ex} = \frac{\sum E_{korod}}{\sum E_{do}} = \frac{1408,4}{2876,1} = 0,49 \tag{3}$$

gdje je:
E_{korod} *- odvedena korisna eksergija*
E_{do} *– dovedena eksergija*

odnosno, da se 49% dovedenih eksergija korisno upotrijebi, a 51% obezvrijedi.

4 ZAKLJUČAK

Mogućnost korištenja geotermalne energije u Bosni i Hercegovini je velika, sa naglaskom analizirane mogućnosti proizvodnje električne energije. U primjeru je primijenjena eksergetska metoda termodinamičke analize binarnog ciklusa. Njena osnova se zasniva na analizi svih tokova koji prolaze kroz proces, ocjenom gubitaka u odnosu na vrijednost eksergije prije i poslije procesa. Vrujednosti dobivene u proračunu su dosta visoke. Prednost binarnog ciklusa je mogućnost ekonomične proizvodnje električne energije iz niskotemperaturnih termalnih voda. S tim je omogućeno i veće iskorištenje raspoložive toplotne energije, jer se otpadna voda ispušta na nižoj temperaturi. Naravno, cilj je da se omogućava i max zaštita životne okoline.

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UPGRADING A MEASURING PIPE LINE IN HEATING POWER PLANT BY CFD TECHNOLOGY

Valentino Stojkovski[1], Zvonimir Kostikj[2] Filip Stojkovski[3]

Abstract: The main purpose of this paper is to show a technical solution for development a measuring pipe line for the purposes of the Heating Power Plant in Eastern Skopje. The main goal was to obtain a hydraulic solution to catch the increased flow capacities of the plant through the new measuring pipe line, as also the pipe line to be fitted in the available building space, and also to give good flow conditions for the installed flow meter. As the flow and thermal problems were complex, 3D CFD simulations were performed to obtain solutions. By modelling different geometries for the measuring pipe line, in this paper, the final model is presented, which is installed in the plant. Later that model, was developed and reshaped for the thermal distribution purposes of the plant. In this paper, CFD results are given for the flow conditions, and they are compared with real measuring results on site, to prove that this upgrade of the measuring pipe line is sufficient for the purposes of the plant and it delivers the requested parameters, such as flow diversion, thermal distribution etc. This paper should point out a new way of designing measuring lines, as from constructive point of view, and also by engineering designing approach with using CFD methods, which shows good and reliable results as a base for future designing problems.

Key words: CFD, measuring pipeline, water flow, heat power plant

1 INTRODUCTION

This work was part from a project for increasing the capacity of the Heating Power Plant in Eastern Skopje. As the capacity was planned to be increased, so the flow through the plant increased for about 35-40%. On the existing measuring line, a flow meter was already installed for the primary design flow, so this had to be upgraded for measuring the increased amounts of flow. In a limited building space and the all other limitations which the flow meters are determining for exact measurements, a solution was developed by upgrading the existing measuring pipe line with a parallel pipe line, extracting an amount of flow around 35-40% from the existing pipe line and diverging it to the parallel pipeline for measuring purposes.

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The part of the system is composed from a main measuring pipe line where it has an inflow of water from one side and on the other side is closed with a blind flange at the end of it, where 3 outlet pipes (noted as A, B and C) have percentage weighted amount of outflowing water, and 2 injecting pipes (BP-1 and BP-2) which are injecting water in the distributive collector pipe. The existing system is shown on fig.1.

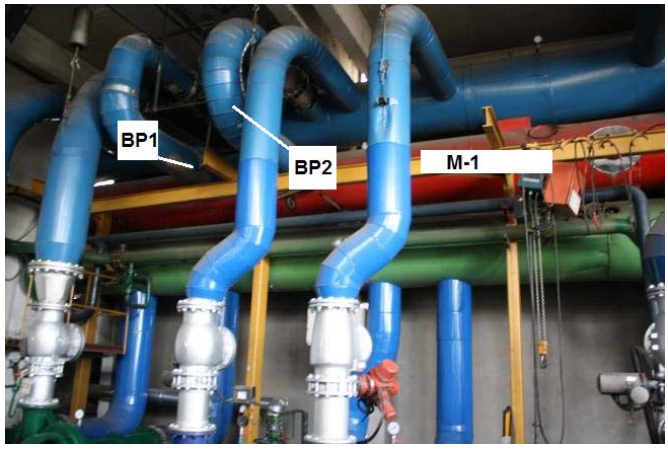


Figure 1. *Existing measuring pipeline (BP-1 and BP-2 injecting pipes, M-1 measuring line flow meter location)*

The parallel measuring line which was planned to be installed had some initial conditions which had to be taken into account:

- In case of increased flow capacity in the system, the new installed parallel measuring pipe line has to accept those amounts of water flow
- The parallel measuring pipe line has to be fitted in the available space of the pump station
- The parallel measuring pipe line to consider the needs of the new flow meter for exact measurements

2 SOLUTION DEVELOPMENT

As it was said in the introduction, the amount of increased flow in the system was about 30-40%. The main idea considering the previously mentioned initial conditions, was to develop a parallel pipeline for measuring purposes, so several ideas and models were created and tested with CFD analysis [1]. As the last developed model gave satisfactory results, it is described in this paper. The main idea was to insert a “suction” elbow of a pipe to diverge the amount of flow to the parallel measuring pipeline from the main measuring pipeline. The main measuring pipeline had a diameter of DN800, so in cases of increased flow of about 35%, the suction elbow was developed as a percentage of the full cross section of the main pipeline (fig.2.).

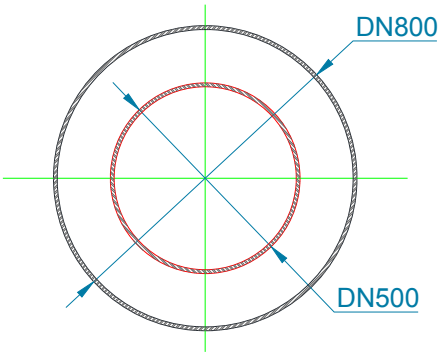


Figure 2. *Defining the suction elbow diameter DN500*

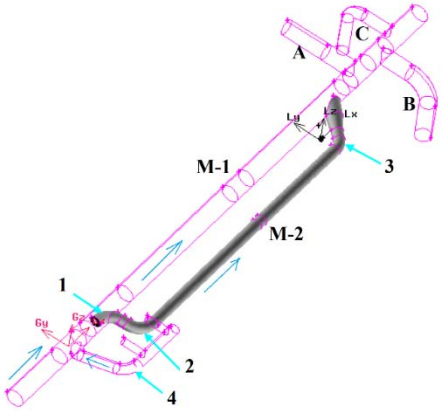


Figure 3. *Numerical Model (1 – suction elbow,2- parallel measuring pipeline, 3 – diffusor at the outlet, 4- BP-1 and BP-2 collecting in a single pipe and injecting to the main measuring line, M-1 existing flowmeter, M-2 flowmeter on the parallel pipeline)*

The suction elbow diameter was selected as the ratio of the cross section surfaces:

$$D500;\ A_2 = \frac{{D_2}^2\pi}{4} = 0{,}196\ [m^2] \approx 0{,}2\ [m^2]$$

$$DN800;\ A_1 = \frac{{D_1}^2\pi}{4} = 0{,}5024\ [m^2] \approx 0{,}503\ [m^2]$$

$$\frac{A_2}{A_1} = 0{,}398 \approx 40\%$$

The ratio is showing that 40% of the full flow area it will be taken for flow increased amounts, as it was described earlier. According to this, a numerical model was built and tested for various working conditions of the system.

3 CFD MODEL

The CFD model was built in the CAD software Gambit and the CFD simulations were made in Fluent. The operating and the boundary conditions set were defined as:

a) Numerical solver:
- Stationary flow condition
- Turbulent model k-ε

b) Initial conditions:
- Different input flow in the main measuring pipeline, presented by the average velocity in the range of 2, 3, 4 and 5 m/s.
- Different flow input from the 2 injecting pipes (BP-1 and BP-2) to the main measuring pipeline presented by the average velocities in the range of 0 – no input, 1, 2, 3, 4, 5 and 6 m/s.

- Weighted outflow through the 3 pipes (pipe A-42%, pipe B-36% and pipe C-22% - the percentage outflow is settled as it was obtained from the measured exploitation conditions in the plant)

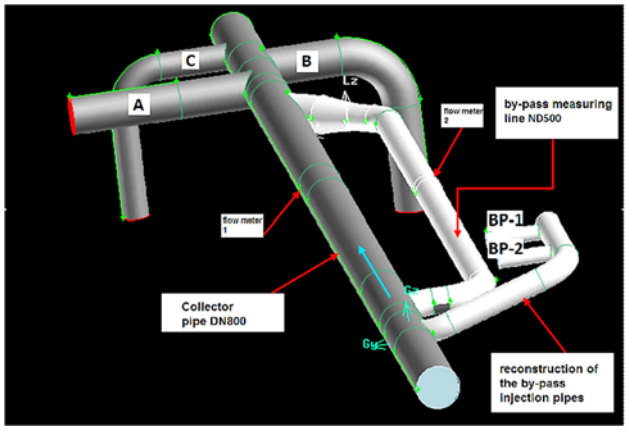


fig.4. Numerical Model

The results of the model are presented by the flow parameters which are described in the table below:

Table 1. *Description of the Flow parameters*

Symbol	**Flow Parameter Meaning**
Qs	System Flow
Qv-M1	Flow through the existing measuring line (DN800) i.e. the flowmeter 1
Qv-M2	Flow through the parallel measuring line (DN500) i.e. flowmeter 2
Qc	Entrance flow into the main pipeline DN800
Qbp1	Flow injected through BP-1
Qbp2	Flow injected through BP-2
Qbp1=Qbp2	Symmetrical flow injected through BP-1 and BP-2
vc	Average velocity through the main measuring pipe line
vbp	Average velocity of the pipe injector BP-1 and BP-2
Qv-M2/Qs	Flow ratio of the volumetric flowrate through the by-pass measuring line and the system flowrate
Qbp/Qc	Flow ratio of the injected flow through the injector pipes and the main measuring pipe line

With the preformed numerical simulations, a flow distribution is obtained in the both measuring lines DN800 and DN500. In the charts below, the results are given for the flow distribution for different exploiting conditions of the system, where the amount of flow which is diverted through the parallel measuring pipeline DN500 is presented as percentage value, a ratio with the full system flow (Qv-M2/Qs) and in a ratio with the by-pass flow in a relation with the entrance flow through the DN 800 pipe (Qbp/Qc).

The solution for upgrading the measuring system should provide a diversion of part of the water to the parallel measuring pipeline DN500 in an amount sufficient to avoid overcoming the measuring range of the existing measuring line ND800 (Qmax = 7600 m^3/h) under conditions of exploitation where the pump station capacity is increased, and on the other hand, in the current exploitation conditions of the system, the two flowmeters will be in the range of the measurement area.

From the performed numerical simulations for the distribution of the flow between the existing measuring pipeline DN800 (Qv-M1) and the parallel measuring pipeline DN500 (Qv-M2), through the interpolation averaged value, the following flow distribution of the system flow can be expected:

- with 33% in the upgraded measuring line DN500 (Qv-M2)
- with 67% of the existing measuring line DN800 (Qv-M1), regardless of the conditions of openness of by-pass pipelines. The results are given in the figures below.

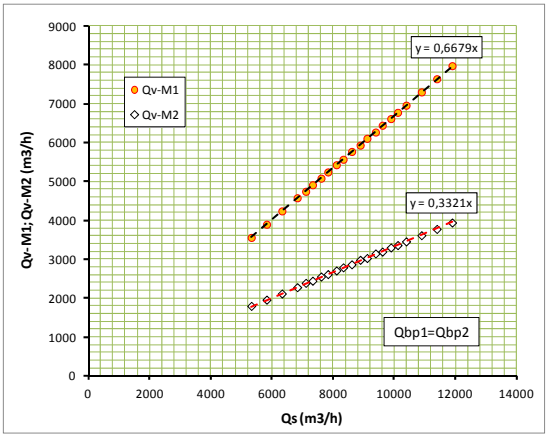


Figure 5. *Distribution of flows in the existing and the parallel pipeline*

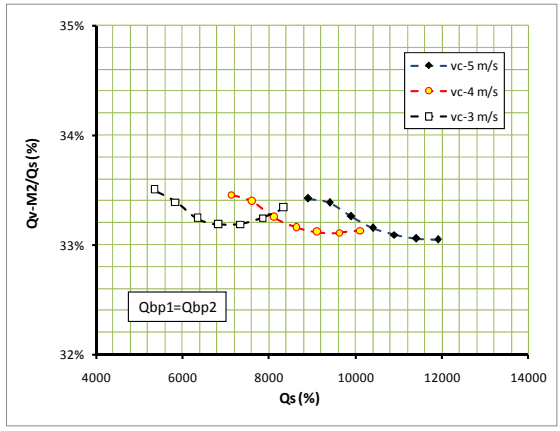


Figure 6. *Relative distribution of the flow to the parallel measuring pipeline for different operating conditions of the measuring system*

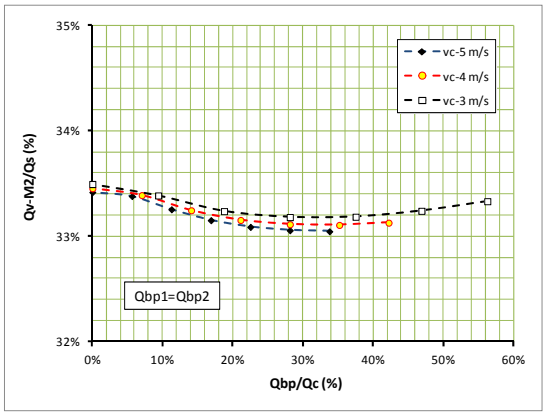


Figure7. *Relative distribution of the flow to the parallel measuring pipeline for a different ratio of the flow of by-pass pipelines and the flow of the existing measuring pipeline*

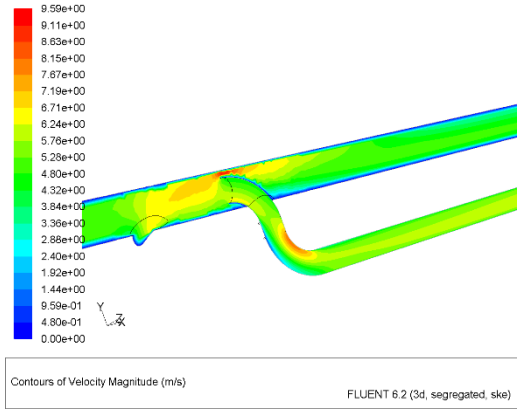


Figure 8. *Velocity magnitude contours in the area of the suction elbow of the parallel upgraded measuring line*

On this model which showed that the hydraulic flow parameters are satisfactory, the energy model was added to the CFD analysis, also to define the temperature distribution in the system. It was shown that the injecting water from the BP-1 and BP-2, because of the cooler temperature of the water and the short injecting distance to the suction elbow, has to be displaced by several meters backwards (fig.9. and fig.10.)

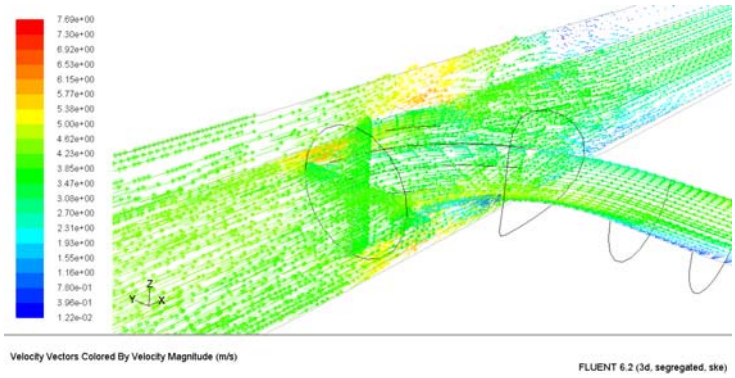


Figure 8.1. *Vectors at the inlet of the suction elbow*

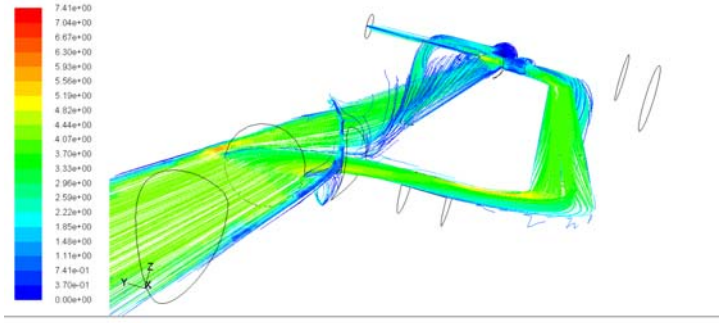


Figure 8.2. *Streamlines in the system*

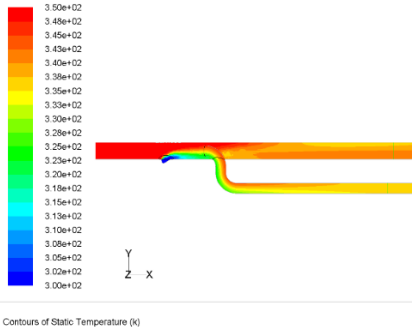


Figure 9. *Temperature imbalance in front of the suction elbow*

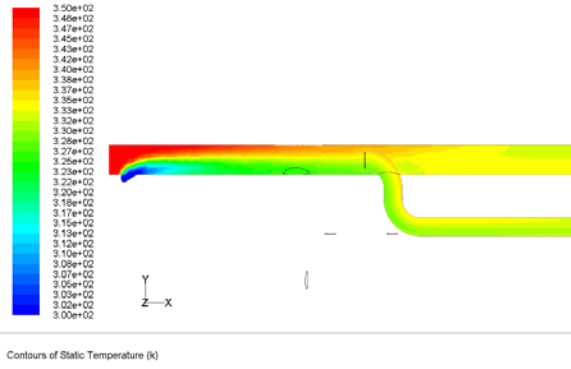


Figure 10. *Displaced injecting water pipe for 4,5 [m] backwards – achieved temperature balance in front of the suction elbow*

Table 2 *Flow and temperature results*

		Qv_M1 [m3/s]	Qv_M2 [m3/s]	Qs [m3/s]	Qv_M2 [%]	T_M1 [K]	T_M2 [K]	ΔT_M [°C]	T_A [K]	T_B [K]	T_C [K]	ΔT_ABC [°C]
1	Basic Model	1,385	0,691	2,076	33,29	336,3	327,1	9,2	333,1	331,2	335,2	2
2	Dislocated by-pass injection 4,5 [m]	1,3635	0,7124	2,076	34,32	333,82	332,27	1,546	333,3	332,97	333,56	0,3

From the table it can be concluded that with dislocating the injecting water from the by-passes do not disturb the flow distribution previously obtained, and it gives better temperature distribution in the system.

4 EXPLOITING CONDITIONS

According to these results, the pipe line system was upgraded in the Heating Power Plant with this parallel measuring pipeline (fig.10.)

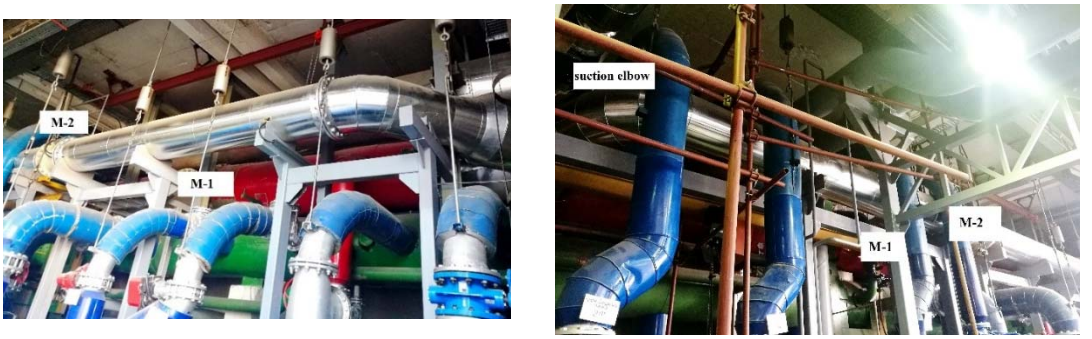


Figure10. *Installed parallel measuring pipeline*

As this measuring pipeline was installed, measurements were made during the working period from 17th October to 30th of November 2017, when the heating season started. The flowmeters collected data for every 3 minutes. This data is presented on the charts below. From the charts, it can be concluded that the average amount of diverted flow is about 35-40%. The points outside of the points in the nest are transitional working regimes, so it can be concluded that this system is working correctly, because the nest is thicker in the regions of stationary working regimes.

The next chart is showing compared results where the diverted amount of flow is compared with the CFD results and it can be concluded that the measuring results are higher than the numerical results, shown by the nest points which are above the CFD results (fig.11. and fig.12.).

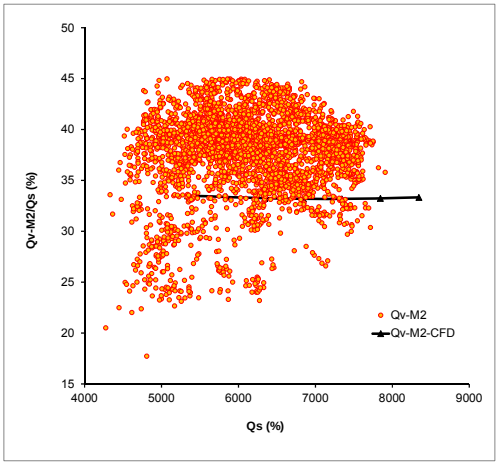


Figure11. *Percentual ammount of diverted flow compared with numerical results*

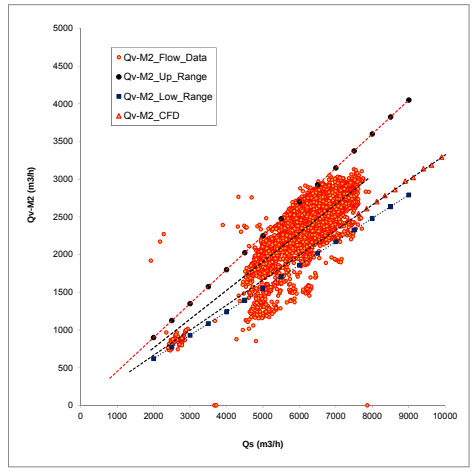


Figure12. *Range of diverted ammount of flow*

5 CONCLUSIONS

This paper is showing a practical experience with a scientific approach to develop a pipeline measuring system which does not disturb the existing system, and also, it satisfies all the needs and requirements for it. By taking into account of the limitations, which were from physical character, and also the equipment and space limitations, a system upgraded with a parallel pipe installed in an existing measuring pipeline was developed for measuring the increased amounts of flow.

The developed system, from the CFD results and also compared with the exploiting data, shows that this solution satisfies the needs for the Heating Power Plant, by diverting an amount of flow exact to the increased flow capacity of the plant, and measured correctly for the plant needs.

The solution presented in this paper has to provide an introduction to the readers about new type of system developed for measuring flow which on the first look it seems unusual. With analytical and numerical approach, it was determined that a CFD approach is needed for the 3D flow phenomenon and heat transfer which cannot be calculated with regular approach.

This work should point out a new ways of designing measuring lines, as from constructive point of view, and also by engineering approach with using CFD methods.

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SOLARNI SISTEM U KOMBINACIJI SA KOTLOM NA PIROLIZU U SISTEMU TOPLOTNOG SNABDIJEVANJA OBJEKTA

Nemanja Koruga[1], Mirko Dobrnjac[2]

Rezime: Potrebe za energijom u svijetu iz dana u dan rastu, a zalihe konvencionalnih goriva su sve manje. Obnovljivi izvori energije kao i tehnologije sagorijevanja sa višim stepenom iskorištenja dobivaju na značaju. Piroliza i solarna energija idu u prilog tim činjenicama i zahtijevaju posebno razmatranje. Ovaj rad daje uvid u grijanje stambenog objekta pirolitičkim kotlom i solarnim sistemom kao dopunskim, čime su postignuti efekti ne samo sa ekonomskog, nego i sa ekološkog stanovišta. Kotlovi na pirolzu imaju veći stepen iskorišćenja pri sagorijevanju biomase, pa su i produkti sagorijevanja ekološki prihvatljiviji u odnosu na klasične koltove, na taj način teži se ekonomski i ekološki održivoj zgradi.

Ključne riječi: ekologija, ekonomija, piroliza, solarni sistem.

SOLAR SYSTEM IN COMBINATION WITH A PYROLISIS BOILER IN THE SYSTEM OF HEAT SUPPLY OF THE BUILDING

Abstract: Energy demand in the world is increasing from day to day, and conventional fuel supplies are getting smaller. Renewable energy sources and combustion technologies with a higher degree exploitation are gaining importance. Pyrolysis and solar energy are in favor of these facts and requires special consideration. This paper gives insights into the heating of a residential object with pyrolytic boiler and solar system as a supplementary, which has achieved effects not only from the economic, but also from ecological point of view. The pyrolysis boilers have a higher degree of biomass utilization, so the combustion products are environmentally friendly then conventional boilers, and in this way it is aimed at an environmentally and economically acceptable building.

Key words: ecology, economy, pyrolysis, solar system.

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1 UVOD

Energetska efikasnost podrazumijeva više djelatnosti koje vode ka racionalnijoj potrošnji energije (grijanje/hlađenje, struja, topla voda) u objektu. Ključna područja u kojima se mogu primijeniti mjere energetske efikasnosti su: toplotna izolacija objekta (zidovi, krov, pod), *grijanje*, hlađenje, *priprema tople potrošne vode,* i sl.

Osnovni element sistema centralnog grijanja je kotao. U novije vrijeme teži se korištenju kotlova na pirolizu, čime se povećava energetska efikasnost objekta.
Piroliza, kao proces gasifikacije, može koristiti raznovsnu biomasu koja je dostupna (drveni otpad, slama, kukuruzovina, ...) i ne zahtijeva posebnu pripremu, dovoljno je smanjiti vlažnost u gorivu na 15 do 20 procenata. Kao podrška kotlovskom sistemu ovdje je pridodat solarni sistem kojim se potpomaže i grijanje objekta i zagrijavanje potrošne tople vode u periodu kad ima dovoljno Sunčeve energije.

Sunčevo zračenje na području Grada Banja Luke nije dovoljno da osigura grijanje objekta tokom grejne sezone, i zbog toga se solarni sistem izvodi u sprezi sa konvencionalnim sistemom grijanja. Za pripremu tople potrošne vode koristi se akumulacioni sistem sa bivalentnim akumulatorom u kojem se preko izmjenjivača toplote zagrijava voda solarnim kolektorima, uz podršku pirolitičkog kotla kad je intenzitet Sunčevog zračenja nedovoljan. Ovom kombinacijom, solarnog sistema i kotla na pirolizu, ostvarena je ušteda energije, čime se dobija energetski efikasna, ekološki i ekonomski prihvatljiva zgrada.

2 SISTEM SNABDIJEVANJA ZGRADE ENERGIJOM

2.1 Opis objekta

Stambena zgrada se nalazi na području Grada Banja Luke sa umjereno kontinentalnom klimom. Sastoji se od negrijanog podruma u kome se nalazi kotlarnica, i šest etaža. Sistem grijanja je izveden kao jednocijevni, sa projektovanim temperaturnim režimom 90/70 ^{o}C. Projekat je osmišljen kao alternativno – dopunski tako da se topla potrošna voda zagrijava Sunčevom energijom sistemom sa termalnim solarnim kolektorima, a u periodu kad nema dovoljno sunčanih dana topla potrošna voda se grije kombinovano ili samo kotlom. Podaci za objekat su dati u tabeli 2.1.

Tabela 2.1 *Karakteristike objekta [5]*

Tip objekta	*stambeni*
Korisna površina, m^2	*1950*
Lokacija	*Banja Luka*
Godišnja potrošnja drveta (G), kg	*29388*
Broj stambenih jedinica	*42*

2.2 Solarni sistem

Solarni sistem se sastoji od cirkulacionog kruga u kome su glavni elementi: termalni pločasti kolektori površine 62 m^2 usmjereni ka jugu uz fiksni ugao nagiba kolektora od 33 ^{o} i akumulator toplote zapremine 9 m^3. Ovaj sistem može funkcionisati samostalno pa ljeti zagrijava TPV. U najtoplijem periodu godine kad se i pored pripreme i potrošnje tople potrošne vode javlja višak prikupljene energije, toplu vodu će koristiti veš mašine u domaćinstvima. U prosjeku, sedmično su potrebna dva pranja veša, to znači da bi za mjesec dana potrošnja bila 8 kWh po domaćinstvu. Očigledne su uštede koje ovaj sistem ostvari. Podaci za klasični i solarni sistem su dati u tabeli 2

Tabela 2.3 *Energetski bilans [5]*

Izvor toplote	*Pirolitički kotao, kapacitet:*	*175* kW
Kotlarnica	*Temperaturni režim*	*90/70* °C
Toplota za grijanje objekta	*121470.6* kWh/god	
Toplota za toplu potrošnu vodu za 1 dan	*150* kWh*, godišnje 54750* kWh	
Toplota dobijena solarnim sistemom za TPV	*38 000* kWh/god	
Toplota dobijena solarnim sistemom za potrebe veš mašina	*4506.9* kWh/god	

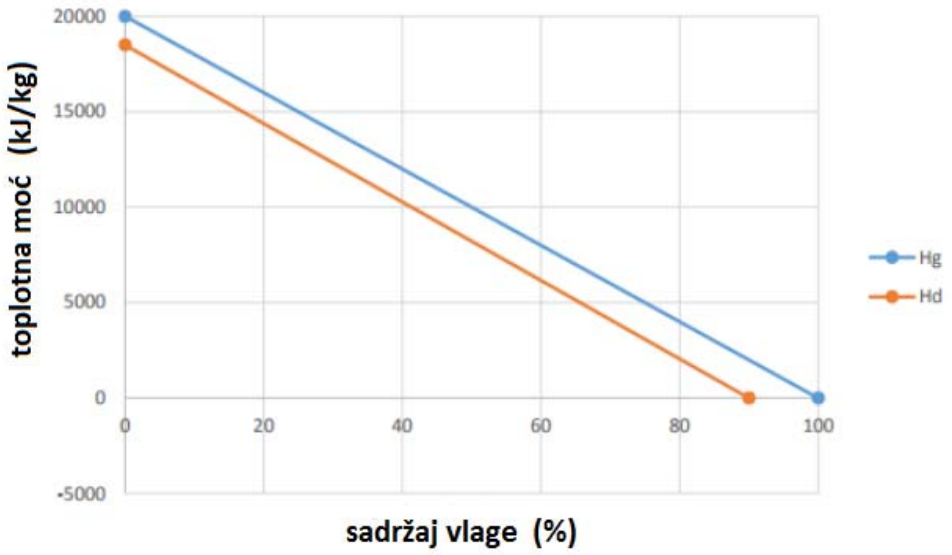
2.3 Snabdijevanje energijom iz kotlarnice

Za dobijanje toplotne energije iz biomase, koristi se kotao na pirolizu. Piroliza se razlikuje od drugih procesa kao što su sagorijevanje i hidroliza, po tome što u njoj ne učestvuje kiseonik, voda ili bilo koji drugi reaktant. U praksi nije moguće ostvariti potpuno odsustvo kiseonika, tako da ipak dolazi do male oksidacije. Piroliza predstavlja toplotno raspadanje energenta (biomase) na temperaturama iznad 100 °C, i time se počinju izdvajati gasovi koji prvi sagorijevaju u kotlu. Piroliza, kao proces gasifikacije, može koristiti raznovrsnu biomasu koja je dostupna (drveni otpad, slama, kukuruzovina, ...) i ne zahtijeva posebnu pripremu, dovoljno je smanjiti vlažnost u gorivu na 15 do 20 procenata.

Drvo korišteno pri rasplinjavanju sadrži oko 50.6% ugljenika, 6.0% vodonika, 0.3% azota, 41.7% kiseonika i 1.4% pepela, a gornja toplotna moć mu je 23 000 kJ/kg (vrijedi za suho drvo). Kako drvo koje se koristi u pirolitičkom kotlu nikada nije apsolutno suho, prava toplotna moć se mora izračunati uzimanjem u obzir vlažnost drveta. Ako je poznata gornja toplotna moć drveta, vlažnost i udio vodonika u strukturi, donja toplotna moć se računa prema izrazu:

$$H_d = H_g \cdot \left(1 - \frac{w}{100}\right) \cdot 20300 \cdot \frac{h}{100} - 2260 \cdot \frac{w}{100}\ , \qquad (1)$$

gdje je *w* vlažnost izražena u procentima, *h* udio vodonika izražena u procentima.
Kao što se može očekivati, sa povećanjem udjela vlage, smanjuje se donja toplota moć i potrošnja drvne biomase je veća. Zavisnost gornje H_g i donje H_d toplotne moći od sadržaja vlage prikazana je na sljedećem dijagramu:



Slika 1. *Zavisnost toplotne moći od sadržaja vlage u gorivu*

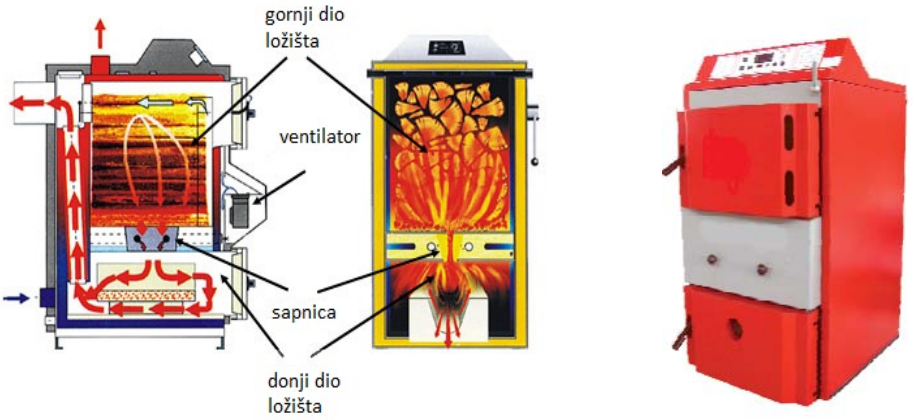
Kod standardnih kotlova na biomasu stepen iskorištenja se kreće od 65% do 70% međutim, kod kotlova na pirolizu ovaj stepen je veći i do 20 procenata. Period do narednog loženja može biti i do 12 sati, ostaci sagorijevanja su dosta manji, što sve pruža veći komfor pri opsluživanju navedenih kotlova. Budući da kotlovi na pirolizu zahtijevaju velike zapremine akumulatora toplote (preporučuje se 50 litara po kW snage kotla), opravdano je uz postojeći sistem grijanja instalirati dopunski, kao što je ovaj solarni, i tako postići veće uštede energije i povećati efikasnost sistema.

Na račun povećanog stepena iskorištenja pirolitičkog kotla u odnosu na klasnični postiže se povećanje energetske efikasnosti (odnosno smanjenje potrošnje goriva) koje se određuje prema sljedećem izrazu:

$$\Delta G = \frac{(G_s - G_n)}{G_s} = 1 - \frac{G_n}{G_s} = 1 - \frac{\eta_s}{\eta_n}, \tag{2}$$

gdje je ΔG smanjenje potrošnje goriva (kg), G_s potrošnja goriva standardnog kotla na biomasu (kg), G_n potrošnja pirolitičkog kotla (kg), η_s stepen iskorištenja standardnog kotla na biomasu i η_n stepen iskorištenja pirolitičkog kotla.

Uz pretpostavku da klasični kotao na biomasu ima stepen iskorištenja 68%, a dati pirolitički 89% [2], ušteda goriva, odnosno povećanje enrgetske efikasnosti samog toplotnog izvora iznosi 23.5%. Izgled i presjek kotla prikazani su na narednoj slici:

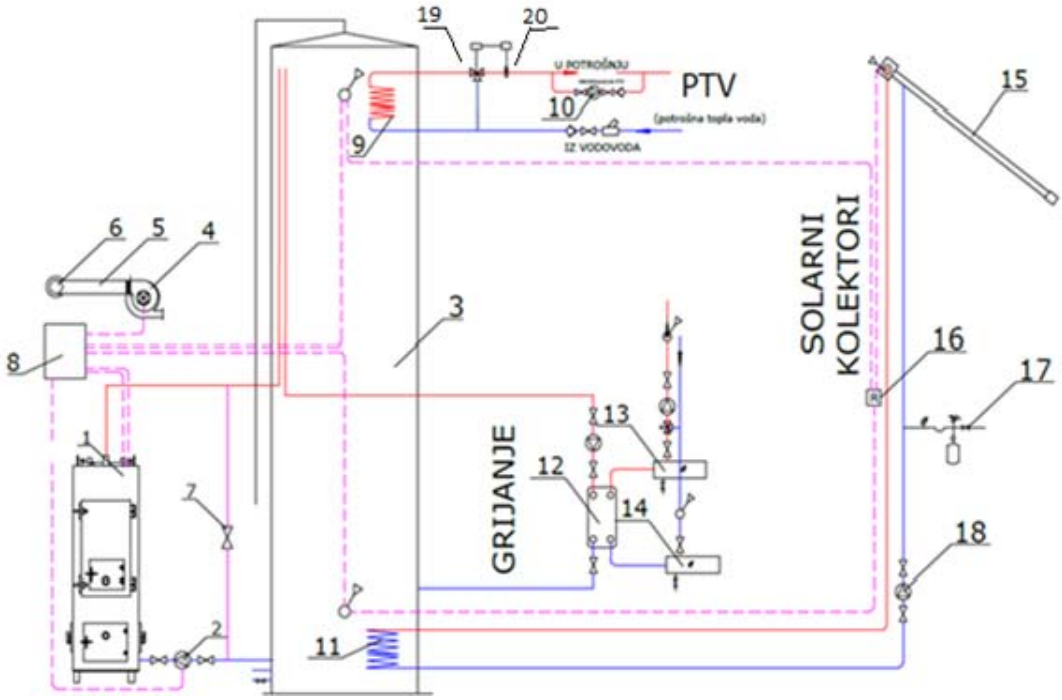


(a) (b)

Slika 2. *Presjek (a) i izgled (b) kotla na pirolizu [5]*

Ovi kotlovi imaju dvodjelno ložište i ventilator sa promjenljivim brojem okretaja. U gornjem dijelu ložišta dolazi do sušenja biomase, toplotne razgradnje i stvaranja žara. Ventilator u gornji dio ložišta dovodi zrak pri čemu u području žara dolazi do rasplinjavanja, odnosno do intenzivnog stvaranja drvnog gasa. Količina dovedenog primarnog vazduha u gornji dio ložišta dovoljna je za rasplinjavanje, ali ne i za potpuno sagorijevanje. Potpunost sagorijevanja obezbjeđuje se sekundarnim vazduhom koji se dovodi kroz sapnicu (slika 2).

Na narednoj šemi prikazano je povezivanje elemenata sistema. Kao veza između solarnog i kotlovskog sistema služi akumulator toplote prikazan brojem 3 (slika 3). Akumulator toplote će uskladištiti toplotnu energiju za vrijeme sunčanih dana koja može biti korištena tokom oblačnog vremena ili perioda sa nedovoljnom solarnom energijom. Solarni sistem zagrijava TPV u periodu sa dovoljno Sunčeve energije (ljeti), u prelaznom periodu (kad počinje i završava grejna sezona) oba sistema će zagrijavati vodu i u tom slučaju imamo veliki doprinos solarne energije u sistemu grijanja objekta. U najhladnijem periodu godine, zagrijavanje TPV i grijanje objekta, će se vršiti samo kotlom. Preko izmjenjivača toplote (broj 9 na slici 3) zagrijava se topla potrošna voda, a da bi na izlijevnom mjestu bila osigurana TPV temperature 45 ^{o}C ugrađen je trokraki miješajući ventil u kojem se topla voda miješa sa hladnom vodom iz vodovoda. Trokraki ventil je upravljan elektromotornim servo motorom.



Slika 3. *Šema povezivanja elemenata [5]*

Legenda:

1 – Pirolitički kotao
2 – Pumpa
3 - Akumulator toplote
4 – Ciklon C 2K
5 – Dimovodna instalacija
6 - Dimnjak
7 – By – pass
8 – Upravljačka kutija
9 – Izmjenjivač PTV
10 – Pumpa za recirkulaciju PTV
11 – Izmjenjivač za solarne kolektore
12 – Izmjenjivač za grijanje
13 - Razdjelnik
14 - Sabirnik
15 – Solarni kolektori
16 – Automatika solara
17 – Sigurnosna grupa solara
18 – Pumpa solara
19 – Trokraki ventil
20 – Termometar

3 EKOLOŠKA I EKONOMSKA ANALIZA

Zagrijavanje vode za veš mašine, ovim solarnim sistemom možemo uštedjeti oko 300 KM za godinu dana. Topla potrošna voda zagrijana solarnim sistemom doprinosi uštedama od 1670 KM/god. Pirolizom, potrošnja goriva G će se smanjiti za 23 % [2], i u tom slučaju će biti potrebno oko 22 000 kg/god. Pored toga, mjere energetske efikasnosti smanjuju emisije stakleničkih gasova, uključujući i CO_2. S obzirom na smanjenje potrebe za primarnom energijom, energetska efikasnost se može gledati i kao novi izvor energije. U odnosu na troškove investicije i u odnosu na godišnje uštede, ovaj solarni sistem će se otplatiti za 7 godina, nakon toga imamo čisti profit.

4 ZAKLJUČCI

Zalihe uglja i nafte u svijetu su sve manje, zato se nameće potreba većeg ulaganja u razvoj i istaživanje korištenja obnovnjivih izvora energije. Solarni sistemi su, po pravilu, skuplji od konvencionalnih koji se uglavnom koriste, ali njihova osnovna prednost je ekološka čistoća. Uzme li se u obzir da veš mašina u prosjeku potroši 3 kWh energije za jedno pranje veša, od kojih 1 kWh spada u zagrijavanje vode, solarim zagrijavanjem tople vode za veš mašine se može znatno uštedjeti.

Treba napomenuti da je akumulator toplote, koji pripada klasičnom sistemu grijanja (kotlom), ujedno korišten solarnim sistemom i na taj način ne ulazi u troškove investicije solarnog sistema. Sagorijevanje u pirolitičkom kotlu je efikasnije i samim tim je smanjena potrošnja goriva. Pored navedenog, piroliza daje veći komfor pri rukovanju kotlovskim postrojenjem. Period između dva loženja je produžen, ostaci pepela su manji, produkti sagorijevanja ekološki prihvatljiviji i na taj način se teži ekološki i ekonomski prihvatljivoj zgradi. Ulaganje u štednju energije doprinosi velikim uštedama u periodu od svega nekoliko godina.

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TOPLOTNI I MATERIJALNI BILANS PROCESA SUŠENJA U TUNELSKOJ SUŠARI

Mirko Dobrnjac[1], Radoslav Grujić[2], Dragana Dragojević[3], Miloš Marković[4]

Rezime: Sušenje je jedna od najvažnijih operacija u prehrambenoj i procesnoj industriji, prije svega zbog održanja kvaliteta namirnica namijenjenih za čuvanje i korištenje u dužem vremenskom periodu. Proces sušenja se zbog toga opravdano koristi svugdje gdje je to moguće, sušenje voća, povrća, gljiva, ljekovitog bilja, itd. U radu su na primjeru tunelske sušare prikazani proračuni toplotnog i materijalnog bilansa sušare. Takve vrste proračuna, sa dobijenim eksperimentalnim podacima, daju osnov za konstruktivno unapređenje i modernizaciju tunelskih sušara. To u konačnici dovodi do najboljih tehničko-ekonomskih pokazatelja ne samo procesa sušenja, nego i kompletne prerade date sirovine.

Ključne riječi: materijalni bilans, prenos toplote, sušara, sušenje, toplotni bilans

HEAT AND MATERIAL BALANCE OF DRYING PROCESS IN THE TUNNEL DRYER

Abstract: Drying is one of the most important operations in the food and processing industry, primarily because of maintaining the quality of foods intended for storage and use over a longer period of time. The drying process is therefore reasonably used wherever possible, drying fruits, vegetables, mushrooms, medicinal herbs, etc. Calculations of the heat and material balance of the dryer are presented in this paper on the example of a tunnel dryer. These types of calculations, with the obtained experimental data, provide the basis for the constructive improvement and modernization of tunnel dryers. This ultimately leads to the best technical and economic indicators not only of the drying process, but also of the complete processing of the raw material.

Key words: material balance, heat transfer, dryer, drying, heat balance

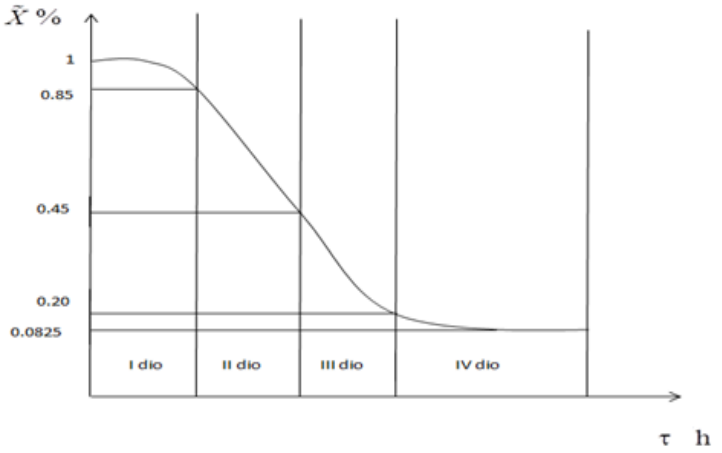
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1 UVOD

Proces sušenja sirove šljive zahtijeva niz neophodnih radnji, kao što su: kontrola zrelosti sirovih plodova, grubo mehaničko čišćenje, pranje, priprema za sušenje, sušenje, separacija suvih plodova po veličini, mikrobiološka kontrola proizvoda. Ovaj rad obrađuje fazu sušenja [1,2]. Sušenje vlažnih materijala je tehnološki proces, ili tačnije, skup procesa prenosa toplote i supstance, praćenih strukturno mehaničkim, a u većem broju slučajeva, i hemijskim promjenama materijala koji se suši. Sušenje se može izvoditi u sušarama različitih tipova i veličina, koje su kroz istoriju doživljavale određene izmjene.

Jedan od osnovnih zadataka pri projektovanju tunelske sušare je izrada materijalnog i toplotnog bilansa. Materijalni bilans sušare je dio temičkog proračuna sušare koji zavisi od načina dovođenja toplote materijalu koji se suši. Kod konvektivnog načina sušenja, režim sušenja se definiše temperaturom, brzinom sušenja i relativnom vlažnošću. Termički proračun zavisi i od tipa i konstrukcije sušare [3]. Proračun se vrši sa preporučenim vremenom sušenja iz literature za tunelsku sušaru. Da bi se tunelska sušara periodičnog tipa svela pri proračunu na kontinualnu sušaru vrijeme sušenja se, na osnovu preporuke iz literature, dijeli na četiri jednaka intervala [4,5].

U ovom radu razmatran je proces sušenja u tunelskoj sušari sa recirkulacijom vazduha, i to sa 10%, 30% i 50% recirkulisanog izlaznog vazduha. Vrijeme sušenja τ_p=19 h je usvojeno prema preporukama iz literature, a trajanje svakog od četiri vremenska intervala je τ_1=4,75 h. Na slici 1. je prikazan termogram sušenja šljive pri navedenim uslovima.



Slika 1. *Termogram sušenja šljive za τ_p=19 h*

2 MATERIJALNI BILANS PROCESA SUŠENJA

Materijalni bilans procesa sušenja je rađen na bazi sljedećih ulaznih podataka:

- $m_1 = 500\ \text{kg}$ – kapacitet sušare, masa sirovog materijala na ulazu u sušaru,
- V=19,71 m^3 - zapremina sušare
- $\tilde{x}_1 = 0,80\ \frac{\text{kg}_\text{v}}{\text{kg}_\text{vm}}$ - maseni udio vlage u materijalu na ulazu (usvojena vrijednost),

- $\tilde{x}_2 = 0,25 \ \frac{\mathrm{kg_v}}{\mathrm{kg_{vm}}}$ - maseni udio vlage u materijalu na izlazu (usvojena vrijednost),
- $\tilde{X}_1 = \frac{\tilde{x}_1}{1-\tilde{x}_1} = \frac{0,80}{1-0,80} = 4 \ \frac{\mathrm{kg_v}}{\mathrm{kg_{sm}}}$ - vlažnost materijala na ulazu u sušaru,
- $\tilde{X}_2 = \frac{\tilde{x}_2}{1-\tilde{x}_2} = \frac{0,25}{1-0,25} = 0,33 \ \frac{\mathrm{kg_v}}{\mathrm{kg_{sm}}}$ - vlažnost materijala na izlazu iz sušare.

Za proračun materijalnog bilansa korišteni su sljedeći izrazi:

Masa suvog materijala na ulazu

$$m_{sm} = \frac{m_1}{1+\tilde{X}_{1I}} \ \mathrm{kg_{sm}} \tag{1}$$

Vlaga koja se izdvojila u toku procesa sušenja

$$\Delta m_v = m_{sv} \cdot \left(\tilde{X}_{1I} - \tilde{X}_{2I}\right) \ \mathrm{kg_v} \tag{2}$$

Maseni protok vlage koja se izdvojila u toku procesa sušenja

$$\Delta \dot{m}_v = \frac{\Delta m_v}{\tau_1} \ \frac{\mathrm{kg_v}}{\mathrm{h}} \tag{3}$$

Maseni protok suvog materijala na ulazu

$$\dot{m}_{sm} = \frac{\Delta \dot{m}_v}{\left(\tilde{X}_{1I} - \tilde{X}_{2II}\right)} \ \frac{\mathrm{kg_{sm}}}{\mathrm{h}} \tag{4}$$

Maseni protok vlažnog materijala na ulazu

$$\dot{m}_1 = \dot{m}_{sm} \cdot \left(1+\tilde{X}_{1I}\right) \ \frac{\mathrm{kg_{vm}}}{\mathrm{h}} \tag{5}$$

Maseni protok vlažnog materijala na izlazu

$$\dot{m}_2 = \dot{m}_{sm} \cdot \left(1+\tilde{X}_{2I}\right) \ \frac{\mathrm{kg_{vm}}}{\mathrm{h}} \tag{6}$$

Vlaga u materijalu na ulazu u jedinici vremena

$$\dot{m}_{v1} = \dot{m}_{sm} \cdot \tilde{X}_{1I} \frac{\mathrm{kg_v}}{\mathrm{h}} \tag{7}$$

Vlaga u materijalu na izlazu u jedinici vremena

$$\dot{m}_{v2} = \dot{m}_{sm} \cdot \tilde{X}_{2I} \frac{\mathrm{kg_v}}{\mathrm{h}} \tag{8}$$

Maseni protok suvog vazduha

$$\dot{m}_{sv} = \frac{\Delta \dot{m}_v}{x_2 - x_1} \ \frac{\mathrm{kg_{sv}}}{\mathrm{h}} \tag{9}$$

Maseni protok vlažnog vazduha na ulazu

$$\dot{m}_{vv1} = \dot{m}_{sv} \cdot \left(1+x_1\right) \ \frac{\mathrm{kg_{vv}}}{\mathrm{h}} \tag{10}$$

Maseni protok vlažnog vazduha na izlazu

$$\dot{m}_{wv2} = \dot{m}_{sv} \cdot (1 + x_2) \ \frac{\text{kg}_{\text{vv}}}{\text{h}} \tag{11}$$

Vlaga u vazduhu na ulazu u jedinici vremena

$$\dot{m}_{wv1} = \dot{m}_{sv} \cdot x_1 \ \frac{\text{kg}_{\text{v}}}{\text{h}} \tag{12}$$

Vlaga u vazduhu na izlazu u jedinici vremena

$$\dot{m}_{wv2} = \dot{m}_{sv} \cdot x_2 \ \frac{\text{kg}_{\text{v}}}{\text{h}} \tag{13}$$

2.1 Materijalni bilans sušare pri recirkulaciji 10%

- Karakteristike okolnog vazduha

Temperatura (usvojena vrijednost) $t_0 = 20\ ^\circ\text{C}$

Relativna vlažnost (usvojena vrijednost) $\varphi_0 = 70\ \%$

Apsolutna vlažnost vazduha $x_0 = 0,01021 \ \frac{\text{kg}_{\text{v}}}{\text{kg}_{\text{sv}}}$

Specifična entalpija $h_0 = 46 \ \frac{\text{kJ}}{\text{kg}_{\text{sv}}}$

Specifični toplotni kapacitet suvog vazduha $c_{psv} = 1,005 \ \frac{\text{kJ}}{\text{kg}_{\text{sv}}}$

Specifični toplotni kapacitet vodene pare $c_{pv} = 1,86 \ \frac{\text{kJ}}{\text{K} \cdot \text{kg}}$

Toplota isparavanja $r = 2500 \ \frac{\text{kJ}}{\text{kg}_{v}}$

- Karakteristike vazduha na izlazu iz sušare (10% recirkulacija)

Temperatura $t_2 = 62\ ^\circ\text{C}$

Relativna vlažnost $\varphi_2 = 13\ \%$

Apsolutna vlažnost vazduha $x_2 = 0,01790 \ \frac{\text{kg}_{v}}{\text{kg}_{sv}}$

Parcijalni pritisak vodene pare vlažnog vazduha na liniji zasićenja $\hat{p}_v = 218,4 \cdot 10^{-3}\ \text{bar}$

Specifična entalpija na izlazu iz sušare $h_2 = 109,12 \ \frac{\text{kJ}}{\text{kg}_{\text{sv}}}$

Apsolutna vlažnost mješavine okolnog vazduha i izlaznog vazduha iz sušare pri 10% recirkulacije $x_m = 0,01096 \ \frac{\text{kg}_{\text{v}}}{\text{kg}_{\text{sv}}}$

- Karakteristike vazduha na ulazu u sušaru (10% recirkulacija)

Temperatura $t_1 = 82\ ^\circ\text{C}$

Relativna vlažnost $\varphi_1 = 3\ \%$

Specifična entalpija $h_1 = 111{,}81\ \frac{\text{kJ}}{\text{kg}_{\text{sv}}}$

Materijalni bilans pri recirkulaciji od 10% izlaznog vazduha prikazan je u tabeli 1.

Tabela 1. *Materijalni bilans pri recirkulaciji od 10% izlaznog vazduha* (S_r=10%)

Vremenski interval	I		II		III		IV	
Ulaz/izlaz toplote	ulaz	izlaz	ulaz	izlaz	ulaz	izlaz	ulaz	izlaz
Maseni protok suvog vazduha, kg_{sv}/h	1819,88		5515,85		5416,43		3961,10	
Ukupno vlažan vazduh i vlažan materijal, kg/h	1945,23	1945,08	5681,6	5681,5	5581,09	5581,04	4109,81	4109,79
Vlažnost materijala, kg_v/kg_{sm}	4,0	3,4	3,4	1,8	1,8	0,8	0,8	0,33
Apsolutna vlažnost vazduha, kg_v/kg_{sv}	0,01096	0,01790	0,01096	0,01790	0,01096	0,01790	0,01096	0,01790

2.2 Materijalni bilans sušare pri recirkulaciji 30%

- Karakteristike vazduha na izlazu iz sušare (30% recirkulacija)

Temperatura $t_2 = 62\ ^\circ\text{C}$

Relativna vlažnost $\varphi_2 = 15\ \%$

Apsolutna vlažnost vazduha $x_2 = 0{,}02079\ \frac{\text{kg}_v}{\text{kg}_{sv}}$

Parcijalni pritisak vodene pare vlažnog vazduha na liniji zasićenja $\hat{p}_v = 218{,}4 \cdot 10^{-3}\ \text{bar}$

Specifična entalpija na izlazu iz sušare $h_2 = 116{,}68\ \frac{\text{kJ}}{\text{kg}_{\text{sv}}}$

Apsolutna vlažnost mješavine okolnog vazduha i izlaznog vazduha iz sušare pri 30% recirkulacije $x_m = 0{,}01338\ \frac{\text{kg}_{\text{v}}}{\text{kg}_{\text{sv}}}$

- Karakteristike vazduha na ulazu u sušaru (30% recirkulacija)

Temperatura $t_1 = 82\ ^\circ\text{C}$

Relativna vlažnost $\varphi_1 = 4\ \%$

Specifična entalpija $h_1 = 117{,}491\ \frac{\text{kJ}}{\text{kg}_{\text{sv}}}$

Materijalni bilans pri recirkulaciji od 30% izlaznog vazduha prikazan je u tabeli 2.

Tabela 2. *Materijalni bilans pri recirkulaciji od 30% izlaznog vazduha* (S_r=30%)

Vremenski interval	I		II		III		IV	
Ulaz/izlaz toplote	ulaz	izlaz	ulaz	izlaz	ulaz	izlaz	ulaz	izlaz
Maseni protok suvog vazduha, kg_{sv}/h	1704,45		5165.99		5072.87		3709.85	
Ukupno vlažan vazduh i vlažan materijal, kg/h	1832.56	1832.51	5340.41	5340.39	5246.05	5245.99	3864.43	3864.77
Vlažnost materijala, kg_v/kg_{sm}	4	3.4	3.4	1.8	1.8	0.8	0.8	0.33
Apsolutna vlažnost vazduha, kg_v/kg_{sv}	0.01338	0.02079	0.01338	0.02079	0.01338	0.02079	0.01338	0.02079

2.3 Materijalni bilans sušare pri recirkulaciji 50%

- Karakteristike vazduha na izlazu iz sušare (50% recirkulacija)

Temperatura $t_2 = 62\ °C$

Relativna vlažnost $\varphi_2 = 18\ \%$

Apsolutna vlažnost vazduha $x_2 = 0,02511\ \frac{kg_v}{kg_{sv}}$

Parcijalni pritisak vodene pare vlažnog vazduha na liniji zasićenja $\hat{p}_v = 218,4 \cdot 10^{-3}\ bar$

Specifična entalpija na izlazu iz sušare $h_2 = 127,98\ \frac{kJ}{kg_{sv}}$

Apsolutna vlažnost mješavine okolnog vazduha i izlaznog vazduha iz sušare pri 50% recirkulacije $x_m = 0,01766\ \frac{kg_v}{kg_{sv}}$

- Karakteristike vazduha na ulazu u sušaru (50% recirkulacija)

Temperatura $t_1 = 83\ °C$

Relativna vlažnost $\varphi_1 = 5\ \%$

Specifična entalpija $h_1 = 129,88\ \frac{kJ}{kg_{sv}}$

Materijalni bilans pri recirkulaciji od 50% izlaznog vazduha prikazan je u tabeli 3.

Tabela 3. *Materijalni bilans pri recirkulaciji od 50% izlaznog vazduha* (S_r=50%)

Vremenski interval	I		II		III		IV	
Ulaz/izlaz toplote	ulaz	izlaz	ulaz	izlaz	ulaz	izlaz	ulaz	izlaz
Maseni protok suvog vazduha, kg_{sv}/h	1695.30		5138.26		5045.64		3689.93	

Ukupno vlažan vazduh i vlažan materijal, kg/h	1830.54	1830.49	5334.29	5334.28	5240.05	5240	3860.42	3860.40
Vlažnost materijala, kg_v/kg_{sm}	4	3.4	3.4	1.8	1.8	0.8	0.8	0.33
Apsolutna vlažnost vazduha, kg_v/kg_{sv}	0.01766	0.02511	0.01766	0.02511	0.01338	0.02079	0.01338	0.02079

3 TOPLOTNI BILANS PROCESA SUŠENJA SA 10%, 30% I 50% RECIRKULISANOG VAZDUHA

Za svaki vremenski interval (dio), koji iznosi 4,75 h, računa se posebno toplotni bilans, prema sljedećim izrazima:

Količina toplote unijeta vazduhom za sušenje u jedinici vremena

$$\dot{Q}_{v1} = \dot{m}_{sv} \cdot h_1 \ \frac{\text{kJ}}{\text{h}} \tag{14}$$

Količina toplote unijeta vlažnim materijalom u jedinici vremena

$$\dot{Q}_{m1} = \dot{m}_{sv} \cdot c_{sm1I} \cdot t_{m1} + \dot{m}_{sm} \cdot X_{1I} \cdot c_{v1} \cdot t_{m1} \ \frac{\text{kJ}}{\text{h}} \tag{15}$$

Količina toplote unijeta transportnim sredstvom u jedinici vremena

$$\dot{Q}_{t1} = \dot{m}_{kol.} \cdot c_{c1} \cdot t_{t1} + \dot{m}_{ljesa} \cdot c_{al.1} \cdot t_{t1} \ \frac{\text{kJ}}{\text{h}} . \tag{16}$$

Količina toplote iznijeta vazduhom za sušenje u jedinici vremena

$$\dot{Q}_{v2} = \dot{m}_{sv} \cdot h_2 \ \frac{\text{kJ}}{\text{h}} \tag{17}$$

Količina toplote iznijeta vlažnim materijalom u jedinici vremena,

$$\dot{Q}_{m2} = \dot{m}_{sm} \cdot c_{sm2I} \cdot t_{m2} + \dot{m}_{sm} \cdot X_{2I} \cdot c_{v2} \cdot t_{m2} \ \frac{\text{kJ}}{\text{h}} \tag{18}$$

Količina toplote iznijeta transportnim sredstvom u jedinici vremena

$$\dot{Q}_{t2} = \dot{m}_{kol.} \cdot c_{c2} \cdot t_{t2} + \dot{m}_{ljesa} \cdot c_{al.2} \cdot t_{t2} \ \frac{\text{kJ}}{\text{h}} \tag{19}$$

Količina toplote koja odlazi u okolinu u jedinici vremena

$$\dot{Q}_o = \dot{q}_o \cdot A_s \ \frac{\text{kJ}}{\text{h}} \tag{20}$$

Izračunati toplotni bilans za pojedine vremenske intervale (dijelove) dat je tabelarno za sva tri stepena recirkulacije izlaznog vazduha.

Tabela 4. *Toplotni bilans pri recirkulaciji od 10% izlaznog vazduha (S_r=10%)*

Dio vrem. intervala	Ulaz/izlaz toplote	Količina unesene/iznesene toplote u jedinici vremena, kJ/h				
		Vazduh	Vlažni materijal	Transportna sredstva	Gubici	UKUPNO
I	ulaz	203480,78	8572,40	502,01	0	212555,19
	izlaz	198585,31	20629,25	1420,53	3035,30	217599,79
II	ulaz	616727,19	8544,06	502,01	0	625773,26
	izlaz	601889,55	14657,70	1420,53	3035,30	621003,08
III	ulaz	605611,04	8389,64	502,01	0	614502,69

	izlaz	591040,84	14391,11	1420,53	3035,30	609887,78
IV	ulaz	442890,59	8160,99	502,01	0	53553,59
	izlaz	432235,23	16078,57	1420,53	3035,30	452769,63

Tabela 5. *Toplotni bilans pri recirkulaciji od 30% izlaznog vazduha* (S_r=30%)

Dio vrem. intervala	Ulaz/izlaz toplote	Količina unesene/iznesene toplote u jedinici vremena, kJ/h				
		Vazduh	Vlažni materijal	Transportna sredstva	Gubici	UKUPNO
I	ulaz	200257.54	8572,40	502,01	0	209331.95
	izlaz	198875.23	20629,25	1420,53	3035,30	223960.31
II	ulaz	606957.33	8544,06	502,01	0	616003.40
	izlaz	602767.71	14657,70	1420,53	3035,30	621881.24
III	ulaz	596016.57	8389,64	502,01	0	604908.22
	izlaz	591902.47	14391,11	1420,53	3035,30	610749.41
IV	ulaz	435873.99	8160,99	502,01	0	444536.99
	izlaz	432865.30	16078,57	1420,53	3035,30	453399.70

Tabela 6. *Toplotni bilans pri recirkulaciji od 50% izlaznog vazduha* (S_r=50%)

Dio vrem. intervala	Ulaz/izlaz toplote	Količina unesene/iznesene toplote u jedinici vremena, kJ/h				
		Vazduh	Vlažni materijal	Transportna sredstva	Gubici	UKUPNO
I	ulaz	220185.56	8572,40	502,01	0	229259,97
	izlaz	216964,49	20629,25	1420,53	3035,30	242049,57
II	ulaz	667357,21	8544,06	502,01	0	676403,28
	izlaz	657594,51	14657,70	1420,53	3035,30	676708,04
III	ulaz	655327,72	8389,64	502,01	0	664219,37
	izlaz	645741,01	14391,11	1420,53	3035,30	664587,95
IV	ulaz	479248,11	8160,99	502,01	0	487911,11
	izlaz	472237,24	16078,57	1420,53	3035,30	492771,64

4 ZAKLJUČAK

Na osnovu dobijenog materijalnog i toplotnog bilansa može se zaključiti da porastom stepena recirkulacije vazduha u procesu sušenja opada protok suvog vazduha i raste količina toplote u jedinici vremena unijeta vazduhom. Pri tome količina toplote koja odlazi u okolinu ne zavisi od stepena recirkulacije. Takođe se može zaključiti da sa porastom stepena recirkulacije rastu ulazna i izlazna apsolutna vlažnost vazduha i ulazna i izlazna entalpija vazduha.

Najznačajniji podaci, dobijeni iz materijalnog i toplotnog bilansa sušare, su maksimalne vrijednosti protoka suvog vazduha, količine toplote unijete u jedinici vremena i količina toplote u jedinici vremena koja odlazi u okolinu. Prema tim parametrima se projektuje potreban kapacitet i vrsta izvora toplote, te vrši hidraulički proračun, a sve u cilju maksimalne optimizacije procesa sušenja.

NOMENKLATURA

m masa, kg
V zapremina, m^3,
$\tilde{x}$ maseni udio, kg/kg

$\tilde{X}$ vlažnost materijala, kg/kg
$\dot{m}$ maseni protok, kg/h
t temperatura, °C
x apsolutna vlažnost, kg/kg
h specifična entalpija, kJ/kg
c_p specifični toplotni kapacitet, kJ/kg
r toplota isparavanja, kJ/kg
$\hat{p}$ parcijalni pritisak, bar
$\dot{Q}$ količina toplote u jedinici vremena, kJ/h

Grčki alfabet

τ vrijeme, h
φ relativna vlažnost, %

Subskripti i superskripti

v vlaga
sm suvi materijal
sv suvi vazduh
vv vlažni vazduh
wv vlaga u vazduhu
o okolina

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ANALIZA OSJETLJIVOSTI SNABDIJEVAČKIH LANACA DRVNIM PELETOM ZA REALNE USLOVE KOJI ODGOVARAJU BOSNI I HERCEGOVINI

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Rezime: Biomasa predstavlja značajan obnovljivi resurs. Posebno ako se njenom korišćenju prilazi sistematski i uz dobro planiranje. Drvna biomasa je najznačajniji predstavnik biomase koji se već uveliko koristi u proizvodnji peleta. S obzirom da je veliki broj mašina, postrojenja, ljudi i opreme uključen u proizvodni lanac peleta, potrebno je ustanoviti koji to faktori i koliko utiču na ovaj proces. Prije svega misli se na konačno formiranje cijene drvnog peleta i njegove zavisnosti od drugih energenata, cijena sirove biomase, transportnih distanci, cijene električne energije i slično. Ovaj rad je spojio proizvodni lanac peleta sa postrojenjem i distribucijom toplote u objekat preko odgovarajućeg matematičkog modela. Upravo smo u prošle dvije godine bili svjedoci nedostataka drvnog peleta i naglog porasta njegove cijene na tržištu. To svakako dodatno promoviše ovu problematiku i daje joj smisao za istraživanje. Postavlja se pitanje šta su realni uslovi pri kojima treba da dođe do povećanja cijena peleta na tržištu i za koliko? Odgovore na to daje ovaj rad.

Ključne reči: drvni pelet, proizvodnja, lanac snabdijevanja, proizvodni trošak, energetska efikasnost, emisija CO_2, analiza osjetljivosti

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SENSITIVITY ANALYSIS OF WOOD PELLETS SUPPLY CHAIN FOR REAL CONDITIONS CORRESPONDING TO BOSNIA AND HERZEGOVINA

Abstract: Biomass represents a significant renewable resource. Especially if its use is approaching systematically and with good strategic planning. Wood biomass is the most important representative of biomass and already used in pellet production. Given that a large number of machines, plants, people and equipment are included in the pellet production chain, it is necessary to determine which factors and how much they have influence this process. First of all, it refers to the final formation of the price of wood pellets and its dependence on other fuels, prices of raw biomass, transport distances, electricity prices and something like these. This work has linked together the pellet production chain with the heat plant and distribution of heat in the object through an appropriate mathematical model. We have just witnessed the defects of wood pellets and the sudden rise in its price in the past two years. This certainly further promotes this issue and gives it a sense of research. The question is, what are the real conditions in which the price of pellets should increase in the market and for how much? The answer to this is given by this paper.

Key words: wood pellet, production, supply chain, production cost, energy efficiency, CO_2 emissions, sensitivity analysis.

1 UVOD

Proizvodnja goriva od biomase posebno je intezivirana u poslednje vrijeme. Za to postoje različiti razlozi kako energetskog, ekološkog ali i ekonomskog karaktera. Tržište gorivima od biomase u BiH je veoma neuređeno i ne postoje ni jasni ni precizni podaci o količinama ovih goriva koliko su zastupljeni i učestvuju na domaćem tržištu a koje se količine u obliku peleta izvoze u inostranstvo. S obzirom da se drvni pelet uglavnom prozivodi od ostataka od prerade iz primarne i sekundarne drvne industrije onda su i količine tog ostatka ograničene i usko vezane sa drvnom industrijom. Proizvodnja drvne sječke kao biogoriva uglavnom potiče takođe iz primarne i sekundarne prerade iz drve industrije. Na neki način ova dva tipa biogoriva nalaze se u suprostavljenom položaju jer koriste iste izvore ostatka od prerade drveta. Na taj način sa instalacijom novih postrojenja za proizvodnju peleta ugrožavaju se količine drvnog ostatka porebne za snabdijevanje toplana i energena koje kao gorivo koriste drvnu sječku. Iz razloga što još u BiH ne postoje mogućnosti postizanja ugovornog snabdijevanja drvnim ostatkom od sječe sa javnim preduzećima koja gazduju šumama, to dovodi do značajnog nedostataka drvnog ostatka i za fabrike peleta i za toplane koje koriste drvnu sječku. Upravo smo u 2017 godini bili svjedoci nedostataka drvnog peleta i naglog porasta njegove cijene na tržištu. To svakako dodatno promoviše ovu problematiku i daje joj smisao za istraživanje.

Pored svih prethodno nabrojanih problema koji se javljaju pri korišćenju peleta kao goriva, postoje: tehnički, energetski, ekonomski ali i ekološki parametri koji ograničavaju primjenu drvnog ostatka za proizvodnju peleta. Prvenstveno, misli se na transportne distance, vlagu, cijene fosilnih goriva, dostpunost resursa, kapaciteti mehanizacije, investicioni troškovi, itd. Ukoliko se uzmu svi ovi parametri u obzir onda se može dobiti značajno jasnija slika o mogućnostima korišćenja ovog biogoriva. S obzirom da se radi o jako velikom broju zavisnosti i elemenata koji sačinjavaju proizvodni lanac drvnog peleta, potrebno je napraviti matematički model svih elemenata lanca snabdijevanja ovim gorivom.

Vrednovanje snabdijevačkih lanaca proizvodnje drvnih peleta uključuje određivanje vrijednosti povezanih sa svakom fazom lanca snabdevanja, koji uključuje

nabavku sirovina, ulaznu logistiku sirovina, preradu sirovina u pelete i izlaznu logistiku prema krajnjem potrošaču [1].

Planiranje transportne logistike je veoma bitan faktor u lancu snabdijevanja drvnim peletom, zajedno sa cijenama goriva za pokretanje mehanizacije i cijenom rada pojedinih izvršioca na mašinama koje učestvuju u lancu snabdijevanja. To sve zahtijeva izbor optimalne transportne logistike i optimalne logistike prikupljanja biomase. Pettersson and Segerstedt [2] definišu troškove logistike parcijalno kao dio troškova koji se odnosi na transport ili distribuciju i dio troškova koji se odnosi na skaldištenje.

Nije moguće ekonomično prevoziti drvne ostatke poput strugotine, piljevine i / ili drvne sječke na velika rastojanja zbog njihovih malih nasipnih gustina [3, 4]. Predvidjeno je da se transportuju presovani peleti od drveta većih energetskih gustina. Međutim, duža rastojanja svakako, za transport sirovina ili gotovih peleta, manje su ekonomski isplativa za proizvođača. [4].

Transport željeznicom je vrlo ekonomičan transport vrlo pogodan za distribuciju peleta. Međutim, željeznica nije dostupna svim proizvođačima peleta. Transport peleta željeznicom u Kanadi doprinosi vrlo progresivnom razvoju ekonomičnog tržišta peleta u ovoj državi [5].

Pojam koncepta energetskog lanca definisan je kao putanja energetskih transformacija od izvora goriva pa sve dokrajnih korisnika [6].

Biogoriva se identifikuju kao potencijalno rješenje za trošenje i nedostatak rezervi fosilnih goriva, rastuće i promjenjive cijene nafte, ali i obezbjeđuju čist, obnovljiv izvor energije. Glavna prepreka koja sprečava komercijalizaciju lignoceluloznih biorafinerija je složen proces konverzije i njihov odgovarajući lanac snabdijevanja koji treba biti uspostavljen i jasno definisan na lokalnom nivou primjene. Efikasno upravljanje lancem snabdijevanja lignoceluloznom biomasom je ključni za uspjeh biogoriva druge generacije. Rad [7], sistematski opisuje energetske potrebe, energetske ciljeve, sirovine biogoriva, procese konverzije i konačno pruža sveobuhvatan pregled projektovanja i modelovanja lanca snabdijevanja biomasom (BSC-biomass supply chain). Od posebnog značaja je to što je ovim radom dat detaljan pregled matematičkih modela programiranja razvijenih za lanac snabdijevanja biomasom i identifikacija ključnih izazova za potencijalna buduća istraživanja. Pregled ovog rada pruža polaznu tačku za razumijevanje sirovina biomase za proizvodnju biogoriva, kao i detaljnu analizu projektovanja i modelovanja lanca snabdijevanja biomasom.

2 MODELIRANJE PROCESA PROIZVODNJE DRVNOG PELETA

Za proces proizvodnje drvne sječke, briketa ili peleta, potrebno je prvo usitniti početni drvni ostatak na određenu granulaciju, zatim osušiti. Ako se proizvodi drvna sječka onda se proizvodna linija završava na mašinama za grubo sitnjene drveta na određenu granulaciju. Ukoliko želimo proizvesti drvni briket ili pelet nakon grubog usitnjavanja, dobijena drvna sječka se suši u rotacionim sušarama, zatim se dodatno fino usitnjava da bi se kasnije briketirao ili peletirao. Da bi se mogla da procijeni ukupna potrošnja energije u energetskom lancu za proizvodnju goriva i energije uopšte, neophodno je izračunati sve utrošene energije svedene na oblik primarne energije (toplotnu moć). Na taj način, moguće je izvršiti sumiranje svih utrošenih oblika energije i goriva u energetskom lancu proizvodnje. To praktično znači da sve energetske konverzije koje se dešavaju u mašinama i postrojenjima u energetskom lancu definisane su odgovarajućim faktorima efikasnosti uopšte.

Modeliranje energetskih lanaca treba da se zasniva na modularnosti. To praktično znači da je neophodno da se matematički izmodelira svaki element energetskog lanca kao nezavisan entitet kojiće sam za sebe predstavljati elemetarni matematički model i učestvovati u komponovanju strukture energetskog lanca. To modeliranje elemenata snabdijevačkog lanaca gorivima uključuje nekoliko različitih kriterijuma kao što su tehničke, logistike, energetske, ekonomske ili faktore uticaja na životnu sredinu. Ovo je dobar pravac za opis bioenergetskih lanaca. Pristup modeliranju svih elemenata lanca trebalo bi da je baziran sa aspekta utrošene energije u svakom elementu lanca. Proračun svih drugih kriterijuma svodi se na proračun troškova proizvodnje, emisije CO_2, investicionih troškova svedenih na vrijednost instalisane snage svih potrošača u energetskom lancu, kao i kvaliteta energetske forme koju taj lanac proizvodi.

Za proizvodnju biogoriva od drvne biomase potrebno je angažovati: različite tipove mehanizacije, postrojenja za preradu biomase u upotrebljivo gorivo, ljudske i druge resurse.

U nastavku se daje matematički pristup opisu pojedinih elemenata snabdijevačkog lanca biogorivima u skladu prema usvojenom konceptu za izračunavanje funkcija (f1j, f_{2j}, f_{3j}, f_{4j}), gdje su: f_{1j} energetska efikasnost snabdijevačkog lanaca biogorivima, f_{2j} proizvodni trošak po 1 kWh dobijenog goriva, f_{3j} specifična emisija ugljendioksida prema 1 kWh proizvedenog goriva i f_{4j} specifični investicioni trošak u sve elenente i uređaje snabdijevačkog lanca biogorivima . U nastavku ovog teksta biće ukrtatko nešto rečeno o ova četiri parametra.

2.1. Energetska efikasnost snabdijevačkog lanca

Ukupni faktor energetske efikasnosti kompletnog lanca, uključujući energetsko postrojenje, gubitke u prenosu energije putem mreže i naravno sve nivoe transformacija, definisan je sa [8]:

$$f_{1j} = \left(1 - \sum_{k=1}^{q} \frac{e_{ckj}}{e_{pkj}}\right) \cdot \mu_{bj} \cdot \mu_{ej} \cdot \mu_{tj} \cdot \mu_{gj} \cdot \mu_{dj} \cdots \mu_{end,usej}, \quad (1)$$

gdje je:

- e_{cqj} - primarna energija utrošena u jednom elementu lanca izražena u kWh,
- e_{pqj} - donja toplotna moć one količine biomase procesuirane u jednom elementu lanca u kWh,
  - k - brojač elemenata u energetskom lancu,
  - q - ukupni broj elemenata u energetskom lancu,
  - j - broj energetskih lanaca,
  - $\mu_{bj} \cdot \mu_{ej} \cdot \mu_{tj} \cdot \mu_{gj} \cdot \mu_{dj} \cdots \mu_{end,usej}$ - faktori energetske efikasnosti za: kotlove, razmjenjivače toplote,turbine, generatore, distribuciju energije, krajnje elemente korištenjai drugo [9].

2.2. Proizvodni trošak snabdijevačkog lanca energijom

Proizvodni troškovi (operativni i održavanje) sračunati su i podijeljeni na ukupne godišnje fiksne i varijabilne troškove. Za tehnologije proizvodnje struje, uključujući kombinovanu proizvodnju toplotne i električne energije dominantan je kapacitet proizvodnje elektriciteta. Za tehnologiju proizvodnje toplote dominantan je

toplotni kapacitet i proizvodnja toplote. Ukupni proizvodni troškovi dati su tipično u jedinicama €/MWh ili €/kW [9]:

$$f_{2j} = \frac{\left(\sum_{k=1}^{q}(Op_{kj} + Mp_{kj}) + Cr_j\right)\cdot t}{Ep(gorivo/\ toplota/\ struja)_j \cdot t}, \quad (2)$$

gdje je:

- $(Op_{kj} + Mp_{kj})$ - suma svih operativnih i troškova održavanja u svim elementima energetskog lanca definisana po godini [€/h],
- Cr_j troškovi (biomase) [€/h],
- $Ep(gorivo/\ toplota/\ struja)_j$ - produktivnost različitih energetskih formi definisanih posmatranom lancu [kwh/god, MWh/h],
- j - broj energetskih lanaca,
- t - vrijeme rada postrojenja [h] [9].
- Operativni i troškovi održavanja takođe, uključuju troškove ljudskog rada svedene na kWh proizvedene energije.

2.3. Specifična emisija ugljendioksida po snabdijevačkom lancu toplote

Emisija gasova staklene bašte određenih vrsta često se prati zbog svojih nepovoljnih ekoloških posljedica koje izazivaju: fotohemijski smog, kisele kiše, globalno zagrijavanje oštećenje ozonskog omotača itd. Detalji i standardne metode koje se koriste za mjerenje štetnog uticaja, GWPs (Global Warming Potentials) su definisane prema (IPCC 2003). Za mjerenje uticaja na životnu sredinu nekog energetskog sistema, rezultati su izraženi kroz masu emisije ugljen-dioksida ekvivalentne po jedinici nekog izlaza (npr. kgCO2/ kWhe).Sljedeći izraz se može koristiti za procjenu emisije gasova staklene bašte od sagorijevanja za svaku vrstu goriva po definisanom energetskom lancu [13]. Faktor speecifične emisije ugljendioksida je onda:

$$f_{3j} = \frac{\left(\sum_{k=1}^{q}\frac{m_{kj}\cdot ec_{kj}\cdot e_{fkj}}{3.6}\right)\cdot t}{Ep(gorivo/\ toplota/\ struja)_j \cdot t}, \quad (3)$$

7)

gdje je:

- m_{kj} - količina potrošnje određenog tipa goriva u jednom elementu energetskog lanca [kg/h],
- ec_{kj} - toplotna moć definisana za svako gorivo [MJ/kg],
- e_{fkj} - emisioni faktor za svaki gas (u ovoj tezi razmatran je CO_2) za različite tipove goriva [kg/kWh], [10].
- $Ep(gorivo/\ toplota/\ struja)_j$ - produktivnost energetskog lanca za različite energetske forme definisano po satu [kwh/h, MWh/h],
- j - broj energetskih lanaca,
- t - vrijeme rada postrojenja (energetskog lanca) [h] [9].
-

2.4. Specifični investicioni trošak po snabdijevačkom lancu toplote

Specifični investicioni trošak u energetskom lancu je odnos između ukupne ivesticije u lanac (sve njegove sastavne elemente) i ukupno instalisane snage u lancu od svih elemenata:

$$f_{4j} = \frac{\sum_{k=1}^{q} I_{kj}}{\sum_{k=1}^{q} P_{kj}}, \tag{4}$$

gdje su:

- $\sum_{k=1}^{q} I_{kj}$ - suma svih investicija u elemente energetskog lanca [€],
- $\sum_{k=1}^{q} P_{kj}$ -suma svih instalisanih snaga u energetskom lancu [kW, MW],
- q - broj elemenata energetskog lanca,
- k - brojač indeksiranja elemenata u energetskom lancu,
- j - broj energetskih lanaca.

2.5. Mašine i postrojenja za prikupljanje i preradu biomase u gorivo u snabdijevačkom lancu

Mašine za prikupljanje biomase, preradu su elementi u snabdijevačkom lancu od kojih počinje čitav proces snabdijevanja biomasom. Različite operacije u prikupljanju drvne biomase zahtijevaju različite mašine čiji izbor za korištenje u praksi zavisi od uslova primjene. U strukturi analiziranih energetskih lanaca koji se analiziraju u ovom radu koriste se sljedeće mašine: motorna pila, traktor, kamion, hidraulična dizalica, mobilni iverač, forvarder, postrojenja za sitnjenje, peletiranje, sušare, proizvodnju toplotne energije. Za sve proizvodne mašine čija se potrošnja goriva izražava u litrima po satu, (l/h), i radna proizvodnost u zapreminskoj jedinici po satu, (m^3/h), važe sledeće relacije iz [11], a koje sam djelimično koristio u svom proračunu uz odgovarajuću modifikaciju. Radi ilustracije kako se dolazi do izračunavanja ukupnog utroška energije po proizvedenom 1 kWh toplotne moći goriva, proizvodnog troška mašine ili uređaja, specifične emisije i investicije date je sljedeće formulacije:

$$f_{1ij} = \frac{\sum_{q=1}^{n_1} \frac{\rho_{Fij} \cdot Fc_{ijq} \cdot t_{ijq}}{1000} \cdot Hv_{ijq}}{\sum_{q=1}^{n_1} Hd \cdot Pr_{ijq} \cdot t_{ijq} \cdot (SVF)_{ijq}}, \tag{5}$$

$$f_{2ij} = \frac{\sum_{q=1}^{n_1} Fc_{ijq} \cdot t_{ijq} \cdot c_{ijq}}{\sum_{q=1}^{n_1} Hd \cdot Pr_{ijq} \cdot t_{ijq} \cdot (SVF)_{ijq}}, \tag{6}$$

$$f_{3ij} = \frac{\left(\rho_{Fij} \cdot Hv_{ijq} \cdot \frac{e_{Fij}}{10^6}\right) \cdot \sum_{q=1}^{n_1} Fc_{ijq} \cdot t_{ijq}}{\sum_{q=1}^{n_1} Hd \cdot Pr_{ijq} \cdot t_{ijq} \cdot (SVF)_{ijq}}, \quad (7)$$

$$f_{4ij} = \frac{\sum_{q=1}^{n_1} I_{Mijq}}{\sum_{q=1}^{n_1} P_{Mijq}}, \quad (8)$$

gdje su:

- $q=1...n_1$ - broj mašina uključenih u rad,
- Fc_{ijq} - specifična potrošnja goriva posmatrane radne mašine [l/h],
- Pr_{ijq} - produktivnost radne mašine [m^3/h],
- t_{ijq} - vrijeme rada mašine [h],
- Hv_{ijq} - donja toplotna moć goriva (benzina ili dizel goriva zavisno od vrste goriva koje koristi mašina) [MJ/kg],
- Hd - donja toplotna moć drvne biomase [MJ/kg],
- $(SVF)_{ijq}$ - faktor zapreminske ispunjenosti [0,...1],
- c_{ijq} - cijena jednog litra goriva (benzina ili dizel goriva) u [€],
- ρ_{Fij} - gustina goriva pri atmosferskim uslovima [kg/m^3],
- e_{Fij} - koeficijent emisije ugljen-dioksida za različita goriva, [kg CO_2/GJ],
- I_{Mijq} - cijena jedne radne mašine [€],
- P_{Mijq} - maksimalna snaga radne mašine, [kW], pri čemu je j=n,

Mora se napomenuti da prethodni izrazi važe samo za radne mašine čija se produktivnost izražava u radnim časovima.

Uticaj od svih elemenata iz snabdijevačkih lanaca se sumira i uzima u obzir po pitanju prethodno pomenutih parametara (f_{1j}, f_{2j}, f_{3j}, f_{4j}), kao najinteresantnijih pokazatelja njihovog kvaliteta i primjene. Ovi parametri se izračunavaju za svaki element lanca snabdijevanja toplotnom energijom i na kraju se sabiraju za svaku kategoriju u ova 4 osnova.

3 TESTIRANJE MODELA PREMA DEFINISANOM SNABDIJEVAČKOM LANCU DRVNIM PELETOM

Testiranje razvijenog matematičkog modela za snabdijevački i potrošački lanac drvnim peletom odnosi se na izračunavnje parametara kao što su energetska efikasnost, proizvodni trošak dobijene toplotne energije i emisija ugljendioksida a sve to u odnosu na promjenu cijene goriva (benzina i nafte), promjenu cijene el energije, transportne

distance, kao i cijene biomase (drvnog ostatka). Model je napravljen u programskom paketu Matlab. U modelu se zadaju pojedinačno svaka od ovih prethodno nabrojanih promjena sa njihovim povećanjem do 50 % u odnosu na usvojene polazne parametre. Na taj način se dobijaaju se različiti scenariji promjena energetske efikasnosti, proizvodnog troška i emisije ugljendioksida u integralno posmataranom modelu koji uzima u obzir i toplanu (energetsko postrojenje) ali i proizvodni lanac drvnog peleta. Na taj način način može se dobiti i odgovor koji od variranih parametara najvše utiče na promjenu cijene proizvedene toplotne energije i u kom procentu uzimajući u obzir i potrošački dio lanca (kotao sa distribucijom toplotne energije) kao i proizvodni dio lanca drvnog peleta. Na taj način dobija se integralna cjelina i vrlo upotrebljivi rezultati. Kao polazne vrijednosti za testiranje modela uzete su:

- Cijena nafte i benzina 1.11 [EUR/litru]
- Cijena el. en. 0.08 [EUR/kWh]
- Dužina transporta peleta 100 [km]
- Cijena drvnog ostatka 40 [EUR/m3]
- Polazna vlažnost drvnog ostatka 50 [%]
- Vlažnost drvnog peleta 12 [%]
- $\eta = \eta_c \cdot \eta_k \cdot \eta_r = 0.98 \cdot 0.90 \cdot 0.95 = 0.7938$, ukupni stepen efikasnosti isporuke toplotne energije
- $\eta_c = 0.98$ – stepen korisnosti cijevne mreže
- $\eta_k = 0.90$ – stepen korisnosti kotla
- $\eta_r = 0.90$ – stepen korisnosti regulacionog sistema
- Ostale vrijednosti uzete iz [12].

Kao krajnje vrijednosti za testiranje modela uzete su prethodne prve četiri uvećanje za 50 % od početnih i to:

- Cijena nafte i benzina 1.65 [EUR/litru]
- Cijena el. en. 0.12 [EUR/kWh]
- Dužina transporta peleta 150 [km]
- Cijena drvnog ostatka 60 [EUR/m3]

Iz sledeće tabele mogu se vidjeti vrijednosti promjene posmatranih faktora f_{1u}, f_{2u}, f_{3u}, i f_{4u} od vrijednosti promjene cijene goriva, cijene električne energije, cijene drvnog ostatka i promjene dužine transporta peleta. Jasno se vidi da na specifični proizvodni trošak f_{3u} najveći uticaj ima cijena drvnog ostatka. Povećanjem cijene drvnog ostatka za 50%, specifični proizvodni trošak raste za 14,22 %. Nakon toga, slijede uticaji cijene električne energije (9,55%) i cijene goriva (7,32%). Za opseg dužina transporta 100-150 km, promjena dužine transporta peleta ima najmanji uticaj na ukupni trošak proizvodnje toplote iz peleta od (1,5%).

Uticaji svih ovih navedenih promjena imaju jako mali ili nikakav uticaj na energetsku efikasnost i specifičnu emisiju CO_2. U ukupnom iznosu uticaj svih promjena: cijena goriva, cijene el energije, cijene drvnog ostatka i dužine transporta za 50% povećanja, povećava cijenu 1kWh dobijene toplote za 32,5%.

Tabela 1. *Rezultati proračuna u Matlabu*

	Početne vrijednosti	Promjena cijene goriva	Promjena cijene el. energije	Promjena dužine transporta peleta	Promjena cijene drvnog ostatka
Cijena nafte i benzina [EUR]	1.11	1.65	-	-	-
Cijena el. en. [EUR]	0.08	-	0.12	-	-
Dužina transporta peleta [km]	100	-	-	150	-
Cijena drvnog ostatka [EUR]	40	-	-	-	60
f_{1u}	0.478925	0.478925	0.478925	0.47697	0.478925
Smanjenje u %	-	ne utiče	ne utiče	0.408205878	ne utiče
f_{2u}	5771.5146	5771.5146	5771.5146	5771.5146	5771.5146
	-	ne utiče	ne utiče	ne utiče	ne utiče
f_{3u}	0.024922	0.026748	0.027304	0.025295	0.028468
Povećanje u %	-	7.326859803	9.5578204	1.496669609	**14.22839258**
f_{4u}	0.052785	0.052785	0.052785	0.053471	0.052785
Povećanje u %	-	ne utiče	ne utiče	1.299611632	ne utiče

4 ZAKLJUČAK

Biomasa ima veliku perspektivu korišćenja, posebno u oblasti proizvodnje toplotne energije na područjima koja obiluju sa drvnim ostatkom. U ovom radu napravljen je vrlo upotrebljiv scenario ponašanja matematičkog modela snabdijevanja drvnim peletom koji je uvezan zajedno sa potrebama korišćenja toplotne energije dobijene iz peleta. Snabdijevački lanac proizvodnje drvnog peleta sadrži više faktora od koji su svi matamatički uzeti u obzir preko energetske efikasnosti, proizvodnog, investicionog troška i emisije ugljendioksida. U radu je posebno stavljen akcenat na proizvodni trošak i njegovu varijaciju u skladu sa promjenama cijena goriva, drvnog ostatka, transportne distance peleta. Naravno, postoji tu i ljudski rad, ali njegova promjena nije uzimata u obzir u ovoj analizi. Analiza je pokazala da najveći uticaj u procentualnom smislu na cijenu proizvedene toplote iz drvnog peleta ima cijena drvnog ostatka, nakon nje slijedi uticaj promjene cijene električne energije, goriva i tek na kraju transportne distance peleta. Model je izvršavan pojedinačno za određene početne vrijednosti od svih prethodno pobrojanih zavisnosti: cijene drvnog ostatka, el. energije, goriva i transportne distance, koje odgovaraju trenutnom stanju cijena u Bosni i Hercegovini. Zatim je vršena pojedinačna promjena za 50% vrijednosti svakog od prethodno navedenih i tako se došlo do zaključka koja od ovih veličina najviše utiče. Ovako dobijeni rezultati su pokazali da proizvodni trošak drvnog peleta po trenutnim početnim cijenama koje se odnose na BiH, ne bi trebao biti veći od 220 KM. Tako da za povećanje svih prethodnih parametara za 50%, zbirno uticaj na proizvodni trošak cijene tone peleta ne bi trebao prelaziti više od 300 KM. Ako se uzme u obzir da je posljednjih godinu dana cijena peleta u grejnoj sezoni izlazila i do 700 KM po toni onda se vidi da su to bila vrlo nerealna povećanja koja nisu tehničke već ekonomske prirode, ili izazvata zbog nestašice drvnog ostatka. Opšti je zaključak da prepuštanje tržišta

biomase samom sebi da se reguliše na bazi opšte potražnje i ponude je usmjerena protiv održivosti korišćenja ovog resursa.

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IMPROVING THE QUALITY OF INNOVATIVE PROCESSES IN THE CONSTRUCTION OF ELV RECYCLING EQUIPMENT

Lozica Ivanović[1], Andreja Ilić[2], Aleksandar Aleksić[3], Miroslav Vulić[4]

Abstract: Considering the increasingly stringent regulations in the field of environmental protection, one of the main goals of the car manufacturers is to improve the design of the vehicle through the use of light metal materials. A light vehicle plays an important role in increasing fuel economy, supporting the increased usage of aluminium in the production of cars. The benefits of using aluminium are not only in a significant reduction in weight compared to other materials, but also in the fact that it can be recycled without loss of quality. Because of numerous ecological and economic benefits by recycling aluminium it is necessary to improve collecting technics and aluminium recovering from ELV. A literature survey shows that a newly developed technique, such as Laser-induced breakdown spectroscopy (LIBS), provides a good alternative to conventional sorting techniques, as it can lead to significant energy savings and efficient classification of non-ferrous metallic automotive scraps. This paper shows an overview of the available results of improving the recycling technique of aluminium, with the aim of promoting a continuous enhancement of the recycling process as a key component of sustainability.

Key words: Aluminium scrap, Laser-induced breakdown spectroscopy, Recycling, Sorting

1 INTRODUCTION

Development of the modern recycling centres for the End of life vehicle (ELV) treatment imply reducing of the costs of mechanical treatment of auto-residual recycling residues. In the same time, it enables the introduction of innovative technologies that should provide bigger separation level of different materials after crushing.

The aim of sorting the crushed waste is to obtain pure metal fractions from a very complex and different flow input. The input material contains magnetic metals such as steel and iron, and non-magnetic metal fractions such as aluminium, magnesium, copper, zinc and brass, as well as plastics, glass and other composite materials.

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Progressive usage of electronic products and new design concepts of “light“ vehicles have brought huge demand for high-quality secondary raw materials of non-ferrous metals, especially copper and aluminium. Traditional methods of separation such as magnetic separation, indicates a good results for magnetic materials but new technologies for sorting non-ferrous metals are necessary. One of the research challenges is the development of a sorting technology that would generate clean non-ferrous metals from automotive waste.

The development and usage of technologies for sorting based on the sensors and automated sorting systems could overcome weaknesses of conventional methods and could contribute significantly to the development of the recycling process ELV [1, 2]. Some of the research results in this field will be presented and discussed about hereinafter.

2 RECYCLING OF NON-FERROUS METALS

Nowadays, huge part of the total resources which are using in automotive production is obtained by using recycled metal components. The use of waste metal has become an integral part of the modern industry which improves economic industry sustainability and reducing the impact on the environment [3]. Compared to extraction of ore, the use of secondary metals significantly reduces CO_2 emissions, energy and water consumption and air pollution. At the same time, recycling of metals makes more efficient use of natural resources of the country. Because of that, the metal industry strives to replace primary resources with secondary raw materials as much as possible. Figure 1. shows a comparative overview of the amount of new metals obtained using recycled material, as well as the energy savings that are materializing in this process [4, 5].

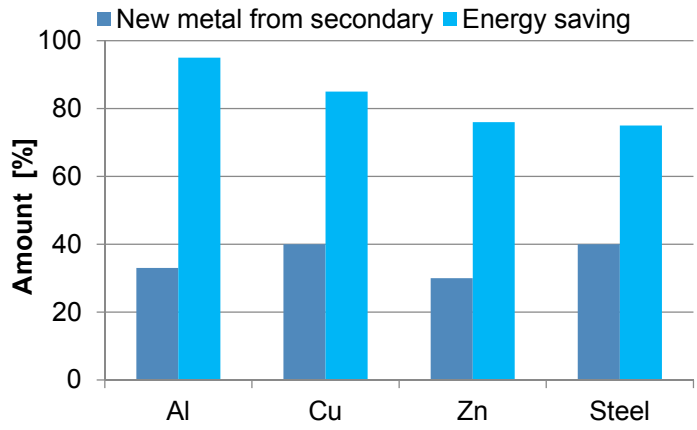


Figure 1. *Effects of production of the different metals using recycled material*

In comparison with other materials such as copper, zinc and steel, aluminium production creates the biggest difference in energy between primary and secondary ways but it is not case with share of secondary production with regard to the total (Figure 1). The recycled aluminium fraction is about 33%, which is close to the value of recycled zinc (> 30%), while copper and steel materials with the highest impact in terms of recycled amounts (> 40%). Beside of that, in comparison with production of primary aluminium, by recycling of aluminium products it is emitting only 5% of gases to the

greenhouse effect, by recycling cooper 35% and steel 42% [5].

Metal recycling industry has a big potential because of great demand for the secondary raw materials. However, without using the contemporary sorting equipment, valuable materials can be lost in the residual waste stream and the quality of the recovered fractions could not generate the actual value [6]. Because of economic reasons it is important to assort the mixtures of waste metals in the different fraction. Separation of copper and brass is technically solved and adequate devices for industrial use are available. Separation of the other metals and alloys is much more difficult because that their characteristics are very similar, like colour and electrical conductivity. For the non-ferrous metal industry, the separation of aluminium and various cast and forged alloys of aluminium is of particular importance.

Production of passenger cars in Germany is increasing from 4.7 in 1997 to predicted 6.9 million units per year in 2040. Besides that, application of advanced concepts in car design implicate much higher demand of aluminium products from 460 thousand tonnes in 1997 to predicted between 2,160 and 3,450 thousand tonnes in 2040. Furthermore, increasing of passenger cars production with simultaneous increasing share of aluminium-intensive vehicles must be followed by improvement in sorting technology. Necessity of improvement in sorting technology of wrought and casting alloys comes from the fact that the absolute amount of old scrap is higher than the casting demand [7].

Usage of high-strength, low weight aluminium for making of elements of car and truck construction will continually increase during the next decade with higher level of increase more than any time till nowadays. It is expected that total aluminium content will grow from around 180 kg per vehicle (397 PPV) in 2015 to around 256 kg (565 PPV) in 2028, that represent about 16 percent of total vehicle abridge weight [8]. Uninterrupted growth of aluminium content in light vehicles during next decade is basic assumption of all present mass reduction scenarios. Strategy for the 7% mass reduction by 2028 involves an average addition of around 6 kg (12-15 pounds) of aluminium content per year starting from 2015 onward as it is presented in Fig. 2 [8].

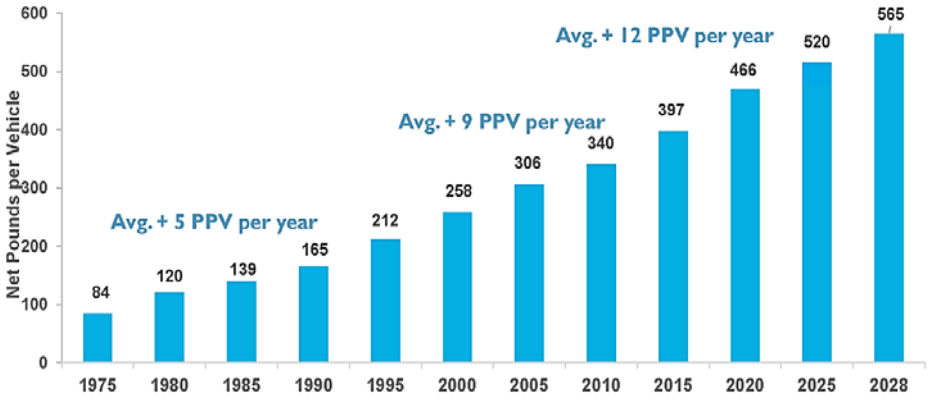


Figure 2. *Accelerating aluminium used in automotive [8]*

Aluminium is material that is the most recycling, after steel and paper. As indicated, recycling of aluminium is not only economically sustainable, but also energy and environmentally efficient. By recycling, aluminium does not lose original physical characteristics and with the help of that it can be recycled unlimitedly into new products. In order to obtain useful aluminium, pure aluminium must be added to the secondary

resource until the concentration meets the specifications. This secondary resource still contains small amounts of other metals that are not sorted and one of the aims is to get small as possible amounts of inclusions in aluminium waste.

Compared to aluminium, aluminium alloys can provide improved performance and because of that they are suitable for engineering applications in various industrial sectors. In the automotive industry, bigger use of cast and forged aluminium alloys is noticeable in the bodywork construction and engine parts, and thanks to the development of new technologies, advanced alloys are becoming more and more used [8].

In the recycling process, aluminium and zorba, which is a waste that containing a mixture of non-ferrous metals (predominantly aluminium and aluminium alloys) from the ELV process [9], are usually sent directly to the foundry after crushing and sorting.

Recycled aluminium alloy ingot is the output of scrap melting. Recycled aluminium alloy ingot can be used interchangeably with ingots made of primary aluminium, means that recycled aluminium alloy substitute primary aluminium. Presented facts implicate that aluminium economy have cyclic character. It can be stated that aluminium is not consumed but rather used in present. Cyclic character means that life cycle of an aluminium product is "cradle-to-cradle" in practise, not “cradle-to-grave" as it is characteristic for linear life cycle. The life cycle of usual aluminium product typically ends when the recycled aluminium is extracted in a form that is usable for making of completely new aluminium product that means that an ingot is used to fabricate and manufacture new products. Characteristic cycle of aluminium product life is presented in Fig. 3 [10].

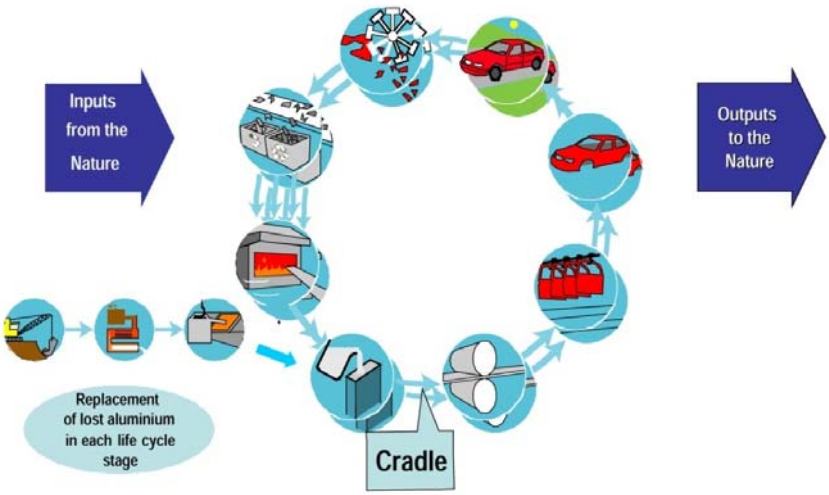


Figure 3. *Closed-loop aluminium material flow [10]*

Compared to many other metals, the challenge is to remove unwanted elements from aluminium and its alloys. There are different solutions dealing with the separation of unwanted elements and each represents a compromise between the cost and the separation efficiency [11]. Depending on the waste composition, several traditional physical separation and sorting technologies can be applied to obtain high-quality fractions of non-ferrous metals.

Method of separation of the non-ferrous and ferrous scrap components by using of magnetic forces is known as magnetic separation. Usually two conveyor belt near

each another with the scrap materials are used. One conveyor belt equipped with NdFeB magnets. When scrap is near to magnet, the ferromagnetic portion of scrap (steel and some iron) is attracted to the magnet and pulled onto the conveyor belt while the non-ferrous portion falls into a collection bin. This sorting method is widely used in the recycled aluminium industry [11].

Using of Eddy currents soon became standard industry practice for further separation of non-ferrous automotive shredder residue. Eddy current separation method is based on advantage of the large range in conductivities of many of the mixed metals present in scraps. Concept of Eddy current separation is a similar to concept of magnetic separation. A rotor is lined with NdFeB magnets with alternating north and south poles Nonmagnetic electrically conductive metals are pulled by external magnetic field produced by rotor. This provokes their removal from the scrap stream, leaving the non-metallic particles. Rotor speed controls the magnetic field [11].

The manual sorting method is still significantly widespread in present sorting. High purity level is characteristic for this sorting method. High labour cost for this process implicate that this sorting method is used only as a final check for quality control purposes. Manual sorting method can differentiate aluminium from other materials such as copper and zinc. It is still a challenge for this separation method differentiation of specific Al alloys. However, the possibility of identifying castings against wrought Al alloys on the basis of their different appearance is not possible [4].

Separation of Al scrap from undesired materials can be based on the difference in density. Sorting method based on the density variation is known as sink float (Dense Media) separation. Separation of non-ferrous materials with a different density is done by using of water-based slurries with known specific gravity [4].

For the sorting of alloys contained in automotive waste of non-ferrous metals, other technologies based on sensors and laser-induced spectroscopy are being developed, which is a present significant contribution to increasing the recycling rate of valuable metal fractions [12,13].

3 INNOVATIVE SORTING METHODS IN ALUMINIUM RECYCLING

In the past few years, researchers are focused on the development of innovative technology for separating high quality fractions from ELV, and some of the most important existing technologies and systems are presented below.

Sorting metals which is based on the atomic density at high capacity without regard to surfaces and material thickness is using with X-Ray Transmission (XRT). After the non-ferrous scrap stream moves through ECS, a conveyor belt system carries the scrap to the XRT equipment's feed mechanism. The x-ray source and ejection method of the individual scrap piece's belt location is alerting by laser, 3D camera and weighing scale. Below and above the conveyor belt are positioned an x-ray source tube and an x-ray detection system. Once the belt location and density are known, the ejection system is alerted to either fire the compressed air or pneumatic hammer system to induce separation or to allow the scrap piece to fall if the material's density does not meet the pre-programmed criteria. Zorba could be converted into furnace ready aluminium by utilizing an XRT based system [14].

Beside the analysis of the elemental composition of metals, X-Ray fluorescence (XRF) has more possibilities than XRT. XRF identify alloying elements and their respective weight percentages by technology of x-ray fluorescence detection from an unknown scrap. Otherwise low energy x-ray radiation is fired at the scrap streams which leads to the excitation of low-energy electrons causing them to eject from orbit. The material is excited by low-energy x-ray radiation and element specific fluorescence is

released. With an energy dispersive x-ray sensor this fluorescence can be measured. Result is processed data and information about the presence of elements and their concentration. For basic stainless sorting and some non-ferrous alloy grade separations, XRF has traditionally been used but determining the difference between types of aluminium has always been a challenge [4].

The overview of upgrading technologies available at both the industrial and lab-scale for improving purity of aluminium scrap and facilitate recycling is known to researchers and practitioners [13]. The wide range in technologies already available highlights the fact that models are necessary in order for producers to properly choose which upgrading technology will have the most benefit.

Three high-value metals that make up most of the non-ferrous fraction - copper, aluminium and brass are sorting by MIS (magnetic induction spectroscopy) which is a new classification method [15]. Metal recycling uses induction sensors that are distinctly applicable: They are low-cost, reliable, practical, and robust. They are resistant to harsh environments and they are unaffected by variable lighting or dirty samples. However, their performance is dependent on a degree of homogeneity in the geometry of the metal fragments; something difficult to achieve in practice [6]. Multi-frequency induction sensors and a simple, straightforward classification algorithm are using for projection of an effective non-ferrous metal sorting system which present main conclusion. Magnetic induction spectra and the selection of frequency components as features, based on the physics of how induced eddy-currents circulate in metal objects are newest aspects. Frequency components that are chosen as features: (1) A high frequency component, where magnetic field penetration is negligible, to model the geometry of the metal fragments, and (2) a low frequency component, where skin-depth is significant, which is a function of both geometry and conductivity of the fragments. If these key criteria are satisfied, good performance rates could be achieved and well-suited to industry needs [15].

Recent advances in physical processes, sensors, and actuators used as well as control and autonomy related issues in automated sorting and recycling of source-separated municipal solid waste are presented in [16].

Laser Induced Breakdown Spectroscopy (LIBS) utilizes a high-power laser pulse [1]. A LIBS system is composed of a solid state (Nd:YAG) Neodymium-doped yttrium aluminium garnet laser, a CCD spectral range spectrometer and a processing unit for fast data analysis (Figure 4). First step is collecting of waste into the inspection area, which is a further task of the laser. This leads to ablation of waste material, which generates plasma plumes. CCD spectrometer capture the radiation from emitted the ablated portion. Optical spectroscopy reads and distinguishes the characteristic atomic emission lines and enables a quick analysis of the bulk waste followed by the detection of constituent materials. Next step is sorting of the detected constituent materials into their respective bins [16].

Comparing LIBS with the eddy current technique shows that the segregation of waste takes place at a relatively higher volume and speed with LIBS. A limitation of LIBS is that the waste sample must be free from lubricants, paints, or oxide layers, which is difficult to achieve in practice [16].

Separating both cast and wrought aluminium into their individual alloys is currently possible only with LIBS. Using the LIBS process, a sensor first detects the presence of a particle which is then bombarded with a pulse. The pulse laser illuminates the surface of the metal, producing an atomic emission, with possibility that the chemical information about the material could be obtained by a spectral detector.

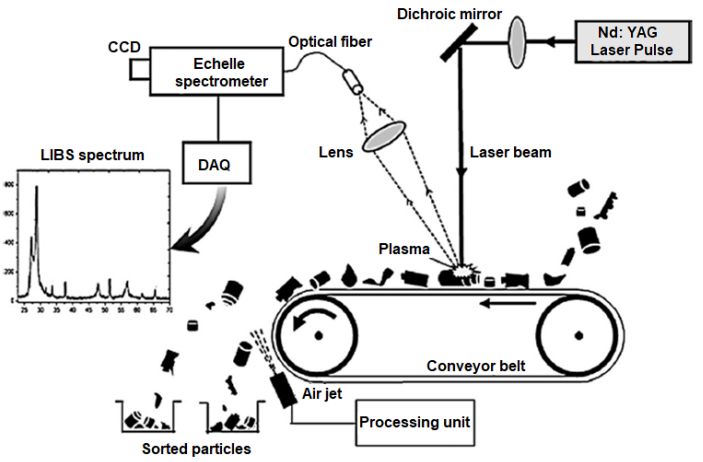


Figure 4. *Components of a LIBS sorting system [16]*

The resulting emission could be transferred to a sorting signal by using of an optical fiber, a polychromator and a photodiode detector which are all connected to a computer system. After that the sorting signal activates a mechanical device which forces the identified piece to be placed in a sorting bin. Separation of the scrap particles into specific alloys is completed by that [13]. Even if the scrap is free from these, the oxide formation on the surface could cause erroneous reading. The new generation of LIBS sensor, like this one, seems to have overcome this problem and has found a good application for special alloys [10].

Because of that, overview about LIBS studies published in the last four years focusing on industrial applications or perspectives therefore is given in [2]. LIBS is the best analytical method which offering such a wide range of measuring distances for chemical analyses [2].

4 CONCLUSION

This research shows currently difficulties of ELV recycling industry and innovative recycling approaches, in the first place using aluminium in cars. Also, paper presents potential of new recycling technology for aluminium and different aluminium alloys.

With concept of „light weight“ in the automobile applications and with the climate changes provides higher aluminium using in the cars. Usage of recycling aluminium instead of primary aluminium metal results with the reducing of the greenhouse effect and energy savings. High value of aluminium waste is the crucial economic effect for the recycling. In practice, recycled aluminium alloys replace primary aluminium alloys for new aluminium products. Also, in practice, ELV process includes selective dismantling with the accent on the dangerous and reusable components. New developed technologies, as LIBS, provide possibilities of using different applications for recycling automobile industry.

Development of new sorting technologies is crucial for recycling aluminium promotion in the high purity alloys which provide better environmental protection and economy and resource savings. Electromagnetic and spectroscopic characteristics of new sorting technology would provide higher contribution to recycling aluminium.

ACKNOWLEDGMENT

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POSTROJENJA ZA PROIZVODNJU SEKUNDARNIH ENERGENATA OD DRVNOG OTPADA – KAPACITETI I MOGUĆNOSTI NA PODRUČJU ZENIČKO – DOBOJSKOG KANTONA

Velid Halilović[1], Srđan Vasković[2], Jusuf Musić[3], Jelena Knežević[4], Besim Balić[5], Jasmin Softić[6]

Sažetak: Utvrđivanje kapaciteta proizvodnje sekundarnih energenata na području Zeničko-dobojskog kantona pruža važno uporište za detaljnije i racionalnije planiranje korištenja drvnog otpada iz različitih izvora, koji nastaje na navedenom području. U ovom radu istražene su i prikazane prednosti korištenja sekundarnih energenata u odnosu na fosilna goriva, i to sa ekonomskog, ekološkog i energetskog aspekta.
U cilju prikupljanja podataka kreiran je anketni upitnik sa konkretnim pitanjima vezanim za proizvodnju sekundarnih energenata na koja su odgovore dali odgovorna lica subjekata koji su obuhvaćeni istraživanjem.
Rezultati rada pokazuju da potencijal proizvodnje sekundarnih energenata na području Zeničko-dobojskog kantona ne koristi se na zadovoljavajućem nivou. Maksimalni kapaciteti proizvodnje se ni približno ne ostvaruju.
Zaključci govore da je proizvodnja cijepanog drveta tek 49% od maksimalnog kapaciteta, peleta i briketa oko 60%.
Ključne riječi: Drvna biomasa, sekundarni energenti, obnovljivi izvori energije

INSTALLATIONS FOR THE PRODUCTION SECONDARY ENERGY SOURCES FROM WOOD WASTE – CAPACITIES AND POSSIBILITIES ON THE AREA OF ZE-DO CANTON

Abstract: Determining the capacity of secondary energy sources in the ZE-DO canton provides important support for the detailed planning and rational use of wood waste from various sources, which is produced on this area.
Every advantage of using the secondary energy resources has been studied and shown in this work, in relation to fossil fuels, from an economic, ecologic and energetic

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standpoint. In the purpose of getting file data a research poll questionary was created and administered by the responsible persons of subject participating in the study.
The study shows that the potential of production of secondary energy sources in the ZE-DO canton is not satisfactory. Maximum capacities of production aren't even nearly fulfilled.
Conclusion indicate that the production of firewood is only 49% of the maximum capacities of production, and pellets and briquettes about 60%.
Key words: wood biomass, secondary energy sources, renewable energy resources.

1 UVOD

Drvo je prva energetska materija koju je čovjek koristio. Čak i sada u vremenu fosilnih goriva, drvo predstavlja značajan izvor energije. S obzirom da je poznato da su rezerve fosilnih goriva ograničene, te da opterećuju atmosferu stakleničkim gasovima, sve se više koriste obnovljivi izvori energije. Prema izvještajima REN-a 21 (2015), u svjetskoj potrošnji energije, fosilna goriva trenutno participiraju sa 78,3%, nuklearna energija zauzima udio od 2,6%, a obnovljivi izvori energije 19,1%, od kojih dominira biomasa sa 9%.

Biomasa podrazumijeva živu tvar čije se rezerve stalno popunjavaju djelovanjem sunčeve energije i može biti različitog porijekla (Đukanović, 2009), a prema Dizdar (1982) energetski sadržaj biomase na Zemlji je dvadeset puta veći od fosilne energije koja se u svijetu potroši.

Prema GEF-u (2009) najbolja zamjena za fosilna goriva je drvna biomasa uz velike ekološke i ekonomske efekte (smanjenje emisije CO_2, novčana ušteda, smanjenje otpada od drveta, stabilna cijena goriva itd.).

Drvna biomasa predstavlja obnovljiv izvor energije koji obuhvata drvnu masu iz šume, sporednu drvnu biomasu, drvne ostatke i isluženo drvo. Može se pojaviti kao: drvni ostatak nakon sječe, čišćenja i drugih aktivnosti u šumarstvu, sirovina energetskih kultura, ostatak primarne i sekundarne prerade drveta u drvnoj industriji, ostatak u voćarstvu i vinogradarstvu, drvni otpad urbanih područja itd. (Jovanović i dr., 2005).

S obzirom da u Bosni i Hercegovini šume i šumska zemljišta zauzimaju oko 2,7 miliona ha ili gotovo 53% površine, drvo kao izvor energije ima veliki značaj. Drvna biomasa je u BiH široko i gotovo ravnomjerno raspoređena sa odličnim potencijalom. Međutim, potrebno je koristiti na mnogo efikasniji i energetski korisniji način nego do sada (GEF, 2009).

Od drvnih energenata u Bosni i Hercegovini se uglavnom koristi ogrjevno drvo, a s obzirom da je potražnja sve veća, to se sve više počinje koristiti i šumski drvni otpad.

U Bosni i Hercegovini šumama gazduju preduzeća koja su odgovorna kantonalnom (Federacija BiH) i entitetskom ministarstvu (Republika Srpska). U Federaciji BiH preduzeća su raspoređena po kantonima.

Prema podacima Zavoda za urbanizam u Zenici, površina Zeničko-dobojskog kantona je 3.326 km^2, od čega na šume i šumska zemljišta otpada oko 65% površine, po čemu možemo zaključiti da je šumarska proizvodnja dobro razvijena, a shodno tome i drvna industrija koja je aktivni izvoznik.

Razvijena šumarska proizvodnja te drvna industrija obezbjeđuje značajne količine drvnog otpada koji bi se mogao koristiti u energetske svrhe. Shodno navedenom u ovom kantonu ima izuzetno velikog potencijala za proizvodnju sekundarnih energenata.

2 METOD RADA

Za potrebe ovog istraživanja korišten je metod analize i sinteze, kao i komparativna analiza na osnovu podataka dobivenih prilikom posjete vlasnicima postrojenja za proizvodnju sekundarnih energenata, drvno-prerađivačkih preduzeća i preduzeća koja gazduju šumama Zeničko-dobojskog kantona, te ostala relevantna dokumentacija.

Istraživanjem su obuhvaćeni svi privredni subjekti koji egzistiraju na području Zeničko-dobojskog kantona a u svom asortimanu proizvoda imaju pelet i/ili briketi/ili cijepano drvo. Istraživanje je bilo anketnog karaktera i u tu svrhu kreiran je upitnik, koji je dat u prilogu, sa listom pitanja na koja su odgovore dala odgovorna lica firmi, prilikom dogovorene posjete.

Na osnovu upita Privrednoj komori Zeničko-dobojskog kantona te na osnovu sudskih registara, utvrđeno je da tačan broj proizvođača sekundarnih energenata nije poznat. Razlog tome je što ova proizvodnja nema jedinstveni sektor, nego je pridružena sektoru prerađivačke industrije u grupi prerađivača i proizvođača proizvoda od drveta, što ne podrazumijeva da sva lica iz ovog sektora vrše proizvodnju sekundarnih energenata koji su predmet našeg interesovanja.

Nakon šturih informacija iz Privredne komore Zeničko-dobojskog kantona, poslan je upit svakoj pojedinoj općini, odakle je proslijeđen službama za gospodarstvo i finansije, od kojih su dobivene informacije da na Zeničko-dobojskom kantonu ima 10 postrojenja za proizvodnju sekundarnih energenata, te da su 2 postrojenja u fazi pripreme.

U tabeli 1. dat je spisak prizvođača sekundarnih energenata koji egzistiraju na području Zeničko-dobojskog kantona.

Tabela 1: *Proizvođači sekundarnih energenata na području ZE-DO kantona.*

Naziv firme	Opština	Vrsta energenta
Kepić d.o.o.	Maglaj	Cijepano drvo
Euroimpex-AN d.o.o.	Zavidovići	Pelet, briket, cijepano drvo
Budo export d.o.o.	Žepče	Briket
Asko komerc d.o.o.[7]	Zenica	Pelet
Secom d.o.o.	Visoko	Briket
Smajić drvo d.o.o.	Visoko	Cijepano drvo
Strong d.o.o.[8]	Breza	Briket
Naha d.o.o.	Vareš	Pelet
Kovan M.I. d.o.o.	Olovo	Pelet
Kraško-promet d.o.o.	Olovo	Cijepano drvo

Postrojenja koja su u fazi pripreme nalaze se na području općina Kakanj i Zavidovići, te ove godine neće početi sa proizvodnjom.

Prilikom kreiranja upitnika vodilo se računa da pitanjima budu obuhvaćeni svi oni parametri koji daju sliku o trenutnoj situaciji u kojoj se nalaze obuhvaćene firme, a to su: uključenost vlasti u smislu pomoći proizvođačima, nabavka sirovine i eventualni problemi koji dolaze sa tim, prosječne cijene nabavke sirovine, tehnička opskrbljenost firmi, maksimalni i ostvareni kapacitet proizvodnje, tržišno stanje te socijalne, ekološke i ekonomske karakteristike proizvodnje.

[7] Odbio ustupiti podatke.
[8] Postrojenje radi samo u toku sezone, i to po narudžbama, gdje se radi o vrlo malim količinama.

Nakon prikupljanja podataka sa terena, izvršena je i procjena potencijala drvnog otpada na području Zeničko-dobojskog kantona. U tu svrhu biće prikazani potencijali drvnog otpada koji nastaju gazdovanjem šumama, te potencijali drvnog otpada nakon prerade drveta. Na taj način utvrdiće se količina drvnog ostatka u regionu, njegova trenutna iskoristivost, te preporuke za povećanje korištenja.

Podaci o količini drvnog ostatka iza sječa su dobiveni iz stvarnih podataka od pet šumsko privrednih područja koja se nalaze u sklopu JP ŠPD ZDK i koji gospodare državnim šumama, pa se tako i podaci odnose samo na državne šume.

Zbog složenosti prikupljanja podataka o tačnoj količini drvnog otpada nakon prerade drveta, uslijed velikog broja subjekata, izvršena je procjena. Procjena je izvršena na osnovu podataka prikupljenih prilikom posjeta drvno-prerađivačkim subjektima, intervjua sa vlasnicima, te na osnovu izvještaja o poslovanju i statističkih biltena.

Svi prikupljeni i grupisani podaci obrađeni su u aplikaciji MS office excell 2013 koji je korišten za kreiranje tabela i grafika predstavljenih u radu.

3 REZULTATI ISTRAŽIVANJA SA DISKUSIJOM

3.1 Analiza postrojenja za proizvodnju cijepanog drveta na području Zeničko-dobojskog Kantona

Na području Zeničko-dobojskog kantona ogrjevno drvo predstavlja najvažniji energent. Drvo za ogrjev izrađivano je u vidu cjepanica ili trupaca, koji su se daljom preradom kratili na potrebne dužine. Velike količine šumskog otpada su ostajale u šumi, jer adekvatnom uspostavnom šumskog reda nisu predstavljale ekološki problem.

Ogrjevno drvo nabavljalo se preko šumarstva u vidu trupaca ili cjepanica, a zatim ručno cijepalo (svako za svoje potrebe), ovlaštenih proizvođača bilo je vrlo malo. Shodno sve većoj potražnji, sve se više napuštao manuelni način cijepanja, a težilo se automatizovanom radu, pa tako su se nabavljali mehanizirani cjepači, kojih danas na Zeničko-dobojskom kantonu ima 5 (tabela 2.).

Tabela 2*: Maksimalni kapaciteti izrade ogrjevnog drveta mehaniziranim cjepačima na području Zeničko-dobojskog kantona*

Proizvođač	Općina	Max. kapacitet m^3/h	Max. godišnji kapacitet (m^3)	Korištena tehnologija	Vrsta pokretača
Smajić drvo d.o.o.	Visoko	1,5	3.240	Hidraulični vertikalni cjepač, 10 t	Elektromotor
Kepić d.o.o.	Maglaj	2,0	4.320	Hidraulični vertikalni cjepač, 15 t	Traktorsko vitlo
Euroimpex-AN d.o.o.	Zavidovići	3,0	6.480	Dva hidraulična vertikalna cjepača , 10t	Elektromotor
Kraško-promet d.o.o.	Olovo	1,5	3.500	Hidraulični vertikalni cjepač, 10 t	Traktorsko vitlo
Ukupno	**-**	**8,0**	**17.540**	**-**	**-**

Kako se vidi iz tabele 2. na Zeničko-dobojskom kantonu, korištenjem samo mehaniziranih cjepača, može se proizvesti oko 17.540 m³ cijepanog drveta. Međutim, većina proizvođača ne vrši proizvodnju isključivo mehaniziranim cjepačima, nego angažuje dodatne radnike koji vrše cijepanje manuelnim putem. U tabeli 3. dati su podaci o ostvarenoj godišnjoj proizvodnji i maksimalnom godišnjem kapacitetu proizvodnje uzimajući u obzir i mehanizirano i ručno (manuelno) cijepanje.

Tabela 3*: Ostvarena godišnja proizvodnja cijepanog drveta na području Zeničko-dobojskog kantona*

Proizvođač	Općina	Godišnji max. kapacitet (m³)	Ostvarena godišnja proizvodnja (m³)	Ostvarena godišnja proizvodnja u PJ
Smajić drvo d.o.o.	Visoko	8.000	4.700	0,050
Kepić d.o.o.	Maglaj	10.000	5.000	0,054
Euroimpex-AN d.o.o.	Zavidovići	6.480	350	0,004
Kraško-promet d.o.o.	Olovo	3.500	3.500	0,038
Ukupno	**-**	**27.980**	**13.550**	**0,146**

Analizom podataka iz tabele 3. zaključuje se da su kapaciteti, ako uzmemo u obzir i ljudsku radnu snagu, znatno veći i iznose cca 28.000 m³ godišnje. Međutim, ostvari se tek 13.550 m³, što je manje od 50%. Ova proizvodnja na godišnjem nivou ima energetsku vrijednost od 0,146 PJ.

Također, vidimo da se maksimalni kapacitet proizvodnje ni približno ne ostvaruje u 3 firme. Svoju vrijednost dostiže u firmi „Kraško-promet“ d.o.o., iz razloga što se u navedenoj firmi, cijepanje vrši isključivo mehaniziranim cjepačem pa se nabavlja onoliko sirovine koliki je kapacitet cjepača (grafik 6.).

U ostalim firmama prisutni su brojni problemi kao što su: snabdijevanje sirovinom, plasman proizvoda van sezone, radna snaga itd.

3.2 Analiza proizvodnje peleta i briketa na području Zeničko-dobojskog kantona

Na području Zeničko-dobojskog kantona drvoprerađivačka industrija preradi ogromne količine drvne mase. Pri tome nastaje velika količina drvnog otpada (okorci, piljevina, blanjevina, itd.).

Sve do posljednjih nekoliko godina taj otpad se uopšte nije koristio, te je odlagan ili spaljivan do te mjere da je nerijetko predstavljao i ekološku prijetnju. Tek u novije vrijeme kada je zaživjela proizvodnja peleta i briketa od drvnog otpada, počeo se iskorištavati i drvni otpad u svim oblicima.

Danas u Zeničko-dobojskom kantonu postoje 3 registrovana proizvođača briketa i 3 registrovana proizvođača peleta. Većinom su to postrojenja instalirana kao tzv. „čistači pogona“ u firmama gdje se vrši primarna ili sekundarna prerada drveta. Izuzetak je firma „Kovan M.I.“ u kojoj je proizvodnja peleta primarna djelatnost i gdje se sirovina striktno nabavlja za proizvodnju peleta.

Trenutni kapacitet postrojenja za proizvodnju peleta i briketa na Zeničko-dobojskom kantonu prema podacima iz tabele 4. iznosi oko 66.528 tona godišnje. Kapacitet proizvodnje briketa i peleta u jednom postrojenju predodređen je kapacitetom prese. Sva ostala oprema u postrojenju mora biti takva da u svakom trenutku obezbijedi snabdijevanje prese sirovinom.

Tabela 4*: Maksimalni kapaciteti i ostvarena godišnja proizvodnja peleta i briketa na području Zeničko-dobojskog kantona*

Naziv proizvođača	Vrsta proizvoda	Tip prese	Max. godišnji kapacitet (t)	Ostvarena godišnja proizvodnja (t)	Ostvarena godišnja proizvodnja u PJ
Secom d.o.o.	Briket	Mehanička	9.072	5.200	0,094
Budo export d.o.o.	Briket	Mehanička	9.072	4.800	0,086
Euroimpex-AN d.o.o.	Briket	Mehanička	6.048	50	0,001
	Pelet	Prstenasta	9.072	5.000	0,092
Naha d.o.o.	Pelet	Prstenasta	12.096	5.000	0,092
Kovan M.I. d.o.o.	Pelet	Prstenasta	21.168	20.000	0,369
Ukupno	**-**	**-**	**66.528**	**35.370**	**0,734**

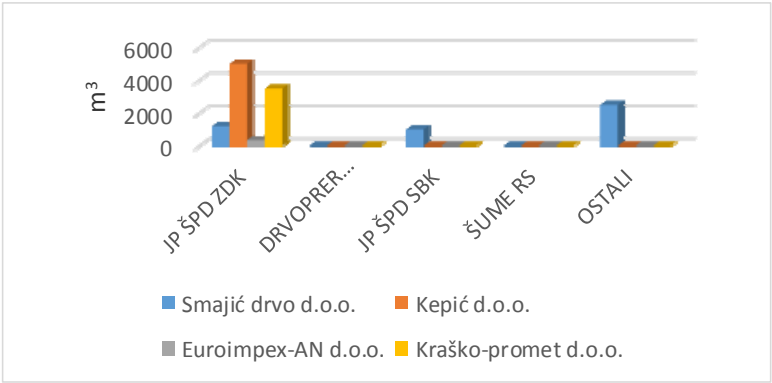
Tabela 4. pokazuje da se maksimalni godišnji kapacitet ne ostvaruje kod navedenih proizvođača, i uočava se jasna razlika između maksimalne moguće i ostvarene proizvodnje briketa i peleta. Najveći razlog tome je što je proizvodnja peleta ili briketa sporedna djelatnost u firmama koje se bave primarnom i/ili sekundarnom preradom drveta, pa je direktno zavisna od količine ulazne sirovine i količine otpada nakon prerade. Što se tiče konkretno proizvodnje briketa maksimalni kapacitet se ne ostvaruje iz još nekoliko razloga, a najznačajniji su nedovoljna potražnja na tržištu i proizvodnja samo u toku sezone. Maksimalni mogući kapacitet proizvodnje briketa na području Zeničko-dobojskog kantona je oko 24.200 tona godišnje od čega se ostvari samo 10.050 tona, odnosno oko 42%, pri čemu je energetska vrijednost ovakve proizvodnje jednaka 0,181 PJ.

Proizvodnja peleta također ne ostvaruje maksimalni kapacitet godišnje proizvodnje izuzev u firmi „Kovan M.I. d.o.o.“, gdje je ostvarena proizvodnja tek neznatno ispod maksimalnog kapaciteta proizvodnje. Na području Zeničko-dobojskog kantona maksimalni kapacitet proizvodnje peleta je oko 42.340 tona godišnje od čega ostvari 30.000 tona, odnosno oko 71%, što bi u jedinici energije iznosilo 0,553 PJ. Dodatni razlozi nedostizanja maksimalnog kapaciteta proizvodnje peleta su čuvanje i održavanje mašina, rad samo u jednoj ili dvije smjene.

3.3 Snabdijevanje sirovinom postrojenja za proizvodnju sekundarnih energenata na području Zeničko-dobojskog kantona

Kako je već ranije navedeno snabdijevanje sirovinom proizvođačima nerijetko predstavlja problem. Razlozi tome su, kako vlasnici firmi tvrde, višestruki, a najčešće je to nepoštivanje ugovora od strane preduzeća koje gospodari šumama. Vlasnici firmi problem vide u tome što se ugovori potpisuju na godinu dana, pa je u nekim mjesecima moguć veći priliv sirovine, dok u nekim mjesecima dolazi do nedostatka, što je najčešće slučaj u mjesecima kada je potražnja velika.

Proizvođači cijepanog drveta najčešće sirovinu otkupljuju u obližnjim šumarijama (grafik 1.), i to ogrjevno drvo u obliku cjepanica ili trupaca. Proizvodnja drveta od drvnih ostataka iza sječe se ne vrši iako je tehničko-tehnološki proces izrade vrlo sličan kao i sa ogrjevnim drvetom.



Grafik 1*: Raspodjela otkupljene sirovine za izradu cijepanog drveta po snabdijevačima*

Iz podataka prikazanih na grafiku 1. vidi se da većina proizvođača cijepanog ogrjevnog drveta na Zeničko-dobojskom kantonu sirovinu otkupljuje iz JP ŠPD ZDK. Na godišnjem nivou ukupna količina ogrjevnog drveta, bilo u trupcu ili cjepanicama, koja se otkupi od JP ŠPD ZDK za potrebe proizvođača cijepanog drveta iznosi oko 10.050 m³. Najviše ogrjevnog drveta godišnje otkupi „Kepić d.o.o.“ oko 5.000 m³, a najmanje „Euroimpex-AN d.o.o.“ oko 350 m³.

Što se tiče proizvodnje peleta i briketa, sirovina koju koriste proizvođači je većinom drvni otpad koji ostaje iza primarne ili sekundarne prerade drveta, koju oni vrše u vlastitim firmama (tabela 4.). Izuzetak je firma „Kovan M.I.“ u kojoj je, kako je već navedeno, proizvodnja peleta primarna djelatnost i koja sirovinu isključivo nabavlja u svrhe proizvodnje peleta.

Tabela 5*: Količina i porijeklo sirovine koja se koristi za proizvodnju peleta i briketa na području Zeničko-dobojskog kantona*

Naziv proizvođača	Vrsta sirovine	Količina prerađene sirovine (m³)
Secom d.o.o.	Okorci, piljevina	20.800
Budo export d.o.o.	Okorci, piljevina	19.200
Euroimpex-AN d.o.o.	Okorci, piljevina	15.200
Naha d.o.o.	Okorci, piljevina	15.000
Kovan M.I. d.o.o.	Celuloza i drvni otpad liščara	42.000
Ukupno	**-**	**112.200**

Prema podacima iz tabele 5. za proizvodnju peleta i briketa na području Zeničko-dobojskog kantona utroši se 112.200 m³ sirovine. Od toga oko 70.200 m³ ima porijeklo od drvoprerađivačke industrije. Preostalih 42.000 m³ sirovine je porijekla iz šumarske proizvodnje. Tu sirovinu otkupljuje firma „Kovan M.I. d.o.o.“ od različitih dobavljača u vidu celuloze četinara i drvnog otpada liščara. Celuloza četinara je zastupljena oko 95%, dok ostatak čini drvni otpad liščara.

3.4 Raspoloživi potencijali drvnog otpada sa područja Zeničko-dobojskog kantona

Raspoloživi potencijali drvnog otpada za proizvodnju sekundarnih energenata se uglavnom nalaze u šumarskoj i drvoprerađivačkoj proizvodnji. Za proizvodnju cijepanog drveta na području Zeničko-dobojskog kantona isključivo se koristi ogrjevno drvo i to od hrasta, bukve i graba. Drvni otpad u ovu svrhu se uopšte ne koristi. Iako ogrjevno drvo ne spada u šumski ostatak, bit će predstavljene količine jer se koristi u svrhu proizovdnje sekundarnih energenata, što je u zoni interesovanja ovog rada.

Za proizvodnju peleta i briketa na Zeničko-dobojskom kantonu koristi se drvni otpad iz drvoprerađivačke industrije ili celuloza četinara i drvni otpad liščara (u vrlo malom procentu) iz šumarske proizvodnje. Iz navedenog proizilazi da se drvni otpad četinara, čije će količine biti prikazane, uopšte ne koristi za proizvodnju sekundarnih energenata bez obzira na veliki potencijal na Zeničko-dobojskom kantonu.

3.4.1 Analiza potencijala šumskog ostatka iz gospodarenja šumama

Prilikom iskorištavanja šuma, u fazi sječe i izrade nastaje drvni ostatak, koji se najčešće smatra drvnim otpadom. Na Zeničko-dobojskom kantonu energija iz biomase ima značajnu ulogu kada se radi o ogrjevnom drvetu, dok šumski otpad predstavlja značajan izvor neiskorištene biomase.

Otpatkom u šumarstvu, smatra se sva drvna biomasa koja ne zadovoljava standarde za preradu u drvnoj industriji. Drvni otpadak u šumarstvu može se podijeliti na krupni i sitni otpad. Sva drvna masa koja je tanja od 7 cm (sa korom) smatra se sitnim otpadom. A otpadak koji nastaje prilikom sječe i izrade sortimenata, a deblji je od 7 cm, predstavlja krupni otpad. Prema podacima iz planova proizvodnje za ŠGP (šumskogospodarska područja) Zeničko-dobojskog kantona udio krupnog otpada, u bruto drvnoj masi iznosi i do 20%. Kada je u pitanju sitni otpad, u šumarstvu Bosne i Hercegovine postoje zakonske regulative koje ograničavaju korištenje sitnog otpada.
Mogućnost korištenja krupnog otpada u energetske svrhe ogleda se u tome, da se može koristiti kroz standardne procese izrade ogrjevnog drveta, tj. izrade cjepanica za loženje i kroz procese usitnjavanja u cilju dobivanja drvne sječke. Korištenje sitnog otpada je moguće jedino kroz proces usitnjavanja, pod uslovom da se dozvoli korištenje zakonskim regulativama i da bude ekološki prihvatljivo.

S obzirom da je cijepano drvo najzastupljeniji drvni energent na Zeničko-dobojskom kantonu i da se izrađuje isključivo od ogrjevnog drveta iz šumarske proizvodnje u tabeli 6. date su količine ogrjevnog drveta koje se godišnje u prosjeku izrade na Zeničko-dobojskom kantonu.

Tabela 6*: Prosječne količine ogrjevnog drveta koje se izrade na području Zeničko-dobojskog kantona godišnje*

ŠGP	Posječena drvna masa liščara (m^3/god)	Drvna masa ogrjevnog drveta (m^3/god)	Procenat
Krivajsko	97.522	49.733	51,00
Gornjebosansko	31.031	19.450	62,68
Kakanjsko	39.822	23.474	58,95
Olovsko	46.872	25.736	54,91
Natron-Usorsko-Ukrinsko	22.563	13.488	59,78
Ukupno za JP ŠPD ZDK	**237.810**	**131.881**	**55,46**

Kako se vidi iz tabele 6. najveće količine ogrjevnog drveta izrade se na ŠGP „Krivajsko“, a najmanje u ŠGP „Natron-usorsko-ukrinsko“, što je i razumljivo s obzirom na površine. Najveći procenat ogrjevnog drveta u ukupno posječenoj masi liščara je u ŠGP „Gornjebosansko“. Na cjelokupnom području Zeničko-dobojskog kantona izradi se oko 132.000 m³ ogrjevnog drveta, odnosno oko 55% od ukupne posječene drvne mase liščara.

Potrebno je, međutim, navesti da cijela ova količina ogrjevnog drveta nije u potpunosti na raspolaganju proizvođačima cijepanog drveta jer JP ŠPD ZDK ima godišnje obaveze prodaje ogrjevnog drveta određene ugovorom prema različitim institucijama i udruženjima, te nakon što se isporuče te količine ogrjevnog drveta, ostatak je na raspolaganju trećim licima. U tabeli 24. date su količine ogrjevnog drveta koje je JP ŠPD ZDK dužno isporučiti različitim institucijama i udruženjima.
Prema podacima iz JP ŠPD ZDK ta količina iznosi cca 16.200 m^3, što znači da oko 115.000 m^3 namijenjeno je za prodaju trećim licima, među koje spadaju i proizvođači cijepanog drveta.

Za proizvodnju peleta i briketa mnogo značajnije su količine drvnog otpada koje ostaju nakon sječa koji se provode planski prilikom gospodarenja šumama. Količina drvne mase iz godine u godinu je različita ali skoro uvijek približna. Plan sječa se kreira prvo u šumskogospodarskim osnovama za period od 10 godina za svako šumskogospodarsko područje. Na osnovu tog plana prave se godišnji planovi sječa na nivou šumskogospodarskih područja i to tako da po isteku važenja šumskogospodarske osnove dostignemo planiranu količinu sječa definisanu u šumskogospodarskim osnovama.

U tabeli 7. prikazane su prosječne godišnje količine otpada koje su na raspologanju proizvođačima sekundarnih energenata.

Tabela 7*: Količina drvnog otpada iz šumarske proizvodnje na području Zeničko-dobojskog kantona*

GP	Posječena bruto drvna masa (m³)	Posječena neto drvna masa (m³)	Količina drvnog otpada (m³)
Krivajsko	132.844	113.169	19.675
Gornjebosansko	75.974	63.078	12.896
Kakanjsko	57.327	45.439	11.888
Olovsko	130.159	108.866	21.293
Natron-Usorsko-Ukrinsko	27.958	24.312	3.646
Ukupno za JP ŠPD ZDK	**424.262**	**354.864**	**69.398**

Na području Zeničko-dobojskog kantona, kako se vidi u tabeli 7., postoje značajne količine drvnog otpada. Najveće količine drvnog otpada su na ŠGP „Olovsko“ a najmane na ŠGP „Natron-usorsko-ukrinskom“. Nažalost, iako se od ove količine može proizvesti 23.132 tone peleta, ova sirovina se skoro uopšte ne koristi. Firma „Kovan M.I. d.o.o.“ otkupi oko 2.000 m³ drvnog otpada liščara, i to je sve od drvnog otpada iz šumarske proizvodnje što se otkupi u svrhu proizvodnje sekundarnih energenata na području Zeničko-dobojskog kantona. Postoje i određene količine otpada koje nakon sječe skupljaju treća lica i koriste ga za ogrjev ili prodaju proizvođačima sekundarnih energenta, ali su te količine vrlo male.

3.4.2 Analiza potencijala iz drvoprerađivačke industrije

Zeničko-dobojski kanton karakteriše razvijena i primarna i sekundarna prerada drveta. Najzastupljeniji vid primarne prerade drveta je pilanska obrada. Pilanska obrada podrazumijeva: rezanje, uzdužno glodanje, sječenje, guljenje i blanjanje drvnih sortimenata. Prerada primarno obrađenog drveta i proizvodnja finalnih proizvoda od drveta, podrazumijeva sekunadarnu preradu drveta. Osim ovih industrija postoje još mnoge djelatnosti usko vezane za drvo koje na određen način stvaraju drvni otpad.

Za proizvodnju peleta i briketa drvni otpad iz industrije u vidu piljevine, blanjevine i bruševine je naročito pogodan iz razloga što je prethodno usitnjen kroz preradu drveta. Drvni otpad u vidu okoraka, krupnijih ostataka, proizvoda sa greškom, itd., također se koristi u proizvodnji peleta i briketa ali ga je potrebno usitniti u drobilicama.

Drvni otpad iz industrije je moguće koristiti u energetske svrhe i u izvornom obliku bez dalje dorade. Takav primjer korištenja je sagorijevanje piljevine i ivera, kojeg je potrebno prethodno samo osušiti. Ovakav način se rijetko koristi i na Zeničko-dobojskom kantonu nema ovakvih primjera.

Na području Zeničko-dobojskog kantona skoro svaka općina ima razvijenu drvoprerađivačku industriju bilo da se radi o proizvodnji rezane građe i furnira ili stolarije, namještaja, podova i drugih proizvoda od drveta.

Potencijale drvnog otpada na području Zeničko-dobojskog kantona nastale iz drvoprerađivačke industrije vrlo je teško tačno utvrditi. Razlog tome je što se nijednoj nadležnoj instituciji ne podnose izvještaji o količini ulazne sirovine u m^3 od strane drvoprerađivača. Zbog toga će u tabeli 8. biti prikazana količina drvnog otpada iz drvoprerađivačke industrije dobijena na osnovu procjene. Podaci koji su služili kao uporište procjeni dobiveni su iz raznih statističkih biltena i informacija iz 2015. godine, koji su preuzeti iz Privredne komore Zeničko-dobojskog kantona, te direktnih razgovora sa vlasnicima firmi.

Tabela 8*: Količina drvnog otpada iz različitih drvoprerađivačkih djelatnosti na području Zeničko-dobojskog kantona*

Djelatnost	Količina prerađenog drveta (m^3/god)	Vrsta prerade	Procentualna količina ostatka	Količina drvnog ostatka (m^3/god)
Proizvodnja rezane građe	274.829	primarna	30%	82.448,7
Proizvodnja furnira i ploča od drveta	5.171	primarna	20%	1.034,2
Proizvodnja podova	14.560	sekundarna	10%	1.456,0
Proizvodnja stolarije i elemenata od drveta	52.160	sekundarna	12%	6.259,2
Proizvodnja namještaja	85.150	sekundarna	10%	8.515,0
Proizvodnja ostalih proizvoda od drveta	96.180	sekundarna	15%	14.427,0
Ukupno	**528.050**			**114.140,1**

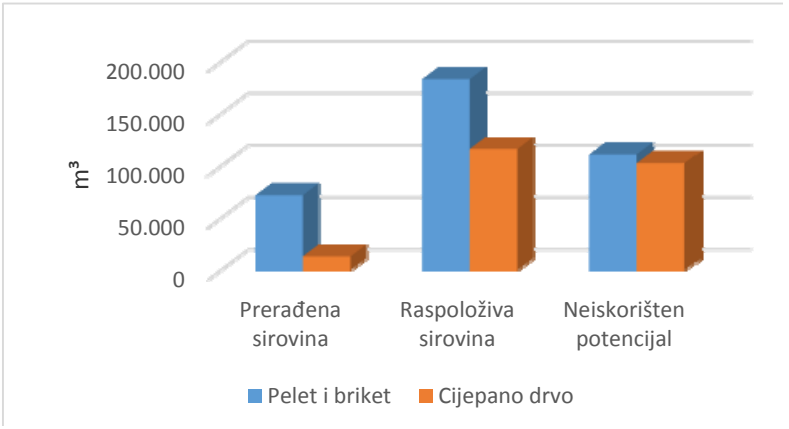
Analizom podataka iz tabele 8. može se primijetiti da se kroz primarnu preradu drveta obradi oko 280.000 m^3 drveta godišnje na području Zeničko-dobojskog kantona. Prema „Analizi postojećeg stanja i prijedloga mjera za poboljšanje rada u drvnoj

industriji FBiH“, koju je uradilo Federalno ministarstvo energije, rudarstva i industrije 2010. godine, na Zeničko-dobojskom kantonu ukupni kapacitet pilanske proizvodnje iznosi 618.000 m³, što znači da se ostvari samo oko 45%.

U tabeli 8. također je predstavljena i količina drvnog ostatka iz primarne i sekundarne prerade drveta koja iznosi oko 114.140 m³ godišnje. Ranije je navedeno da se u proizvodnji peleta i briketa na Zeničko-dobojskom kantonu upotrebljava oko 70.200 m³ drvnog otpada iz drvoprerađivačke industrije, što znači oko 62% od ukupnog potencijala. Međutim, treba navesti da su ovi podaci dobiveni procjenom i predstavljaju samo okvirno stanje. Za dobijanje konkretnih podataka o ovom izvoru sirovine, za čiju obradu je potrebno mnogo više vremena i veći angažman na terenu, predlaže se izrada posebne, detaljne studije.

3.5 Usporedba iskorištenih i raspoloživih potencijala drvnog otpada za proizvodnju sekundarnih energenata na području Zeničko-dobojskog kantona

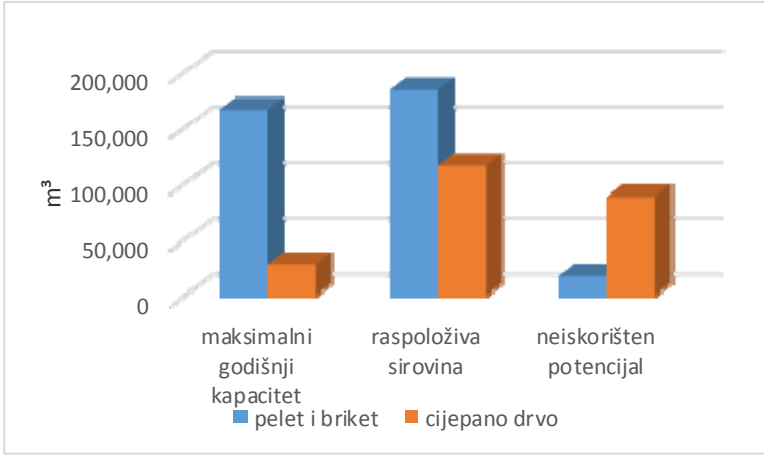
Na području Zeničko-dobojskog kantona ukupno raspoloživa količina drvnog otpada, koji je naročito povoljan za proizvodnju peleta i briketa, iz šumarske i drvoprerađivačke proizvodnje iznosi oko 183.538 m³ godišnje. Količina ogrjevnog drveta koja je na raspolaganju trećim licima iznosi oko 117.000 m³ godišnje. Količina drvnog otpada koja se godišnje utroši na proizvodnju briketa i peleta na Zeničko-dobojskom kantonu iznosi 72.200 m³. Na proizvodnju cijepanog drveta na području Zeničko-dobojskog kantona utroši se oko 13.600 m³. Iz ovih podataka može se zaključiti da su potencijali višestruko veći od same proizvodnje (grafik 2.).
Treba naglasiti da se za ogrjevno drvo ne može reći da potencijali nisu iskorišteni, nego da nisu otkupljeni i prerađeni od strane zvaničnih proizvođača cijepanog ogrjevnog drveta.



Grafik 2: *Usporedba prerađene sirovine i neiskorištenih potencijala za proizvodnju sekundarnih energenata na području Zeničko-dobojskog kantona*

Ako se još uzme u obzir da maksimalni godišnji kapaciteti proizvodnje sekundarnih energenata nisu ni približno ostvareni, onda će sigurno u budućnosti porasti i potražnja drvnog otpada kao sirovine za proizvodnju istih.

Na grafiku 3. prikazano je kolika bi količina neiskorištenog potencijala bila da proizvođači ostvaruju maksimalne godišnje kapacitete.



Grafik 3*: Usporedba maksimalno moguće prerade i neiskorištenih potencijala drvnog otpada za proizvodnju sekundarnih energenata na području Zeničko-dobojskog kantona*

Na grafiku 3. vidi se da i ukoliko bi bili ostvareni maksimalni godišnji kapaciteti proizvodnje u postrojenjima za proizvodnju sekundarnih energenata na području Zeničko-dobojskog kantona, još uvijek bi bilo neiskorištenih potencijala, što je veoma važna informacija za proizvođače koji žele proširiti proizvodnju ili za nove potencijalne ulagače u ovu proizvodnju.

4 ZAKLJUČCI

Na osnovu svega navedenog u ovom radu mogu se izvesti sljedeći bitni zaključci.

Zeničko-dobojski kanton ima površinu od 3.326 km², od čega na šume i šumska zemljišta otpada oko 65%, te je šumarska proizvodnja izuzetno razvijena, a shodno tome i drvoprerađivačka industrija.

Razvijena šumarska proizvodnja te drvna industrija obezbjeđuje značajne količine sirovine za proizvodnju sekundarnih energenata na području Zeničko-dobojskog kantona.

Na području Zeničko-dobojskog kantona postoji 10 postrojenja za proizvodnju sekundarnih energenata. Od toga 4 proizvođača cijepanog drveta, 3 proizvođača peleta i 3 proizvođača briketa.

Maksimalni tehnički kapaciteti proizvodnje cijepanog drveta od strane zvaničnih proizvođača na području Zeničko-dobojskog kantona iznose 28.000 m³/godišnje, a peleta i briketa 66.500 t/godišnje.

Ostvarena godišnja proizvodnja cijepanog drveta od strane zvaničnih proizvođača na području Zeničko-dobojskog kantona je 13.600 m³, odnosno oko 49% od maksimalnog tehničkog kapaciteta. Proizvodnja peleta i briketa je 40.050 t/godišnje, odnosno oko 60% od maksimalnog tehničkog kapaciteta proizvodnje.

Za proizvodnju cijepanog drveta na području Zeničko-dobojskog kantona koristi se isključivo ogrjevno drvo iz sektora šumarstva, dok za proizvodnju peleta i briketa najčešće drvni otpad iz drvne industrije, te celuloza iz šumarske proizvodnje. Postrojenja za proizvodnju peleta i briketa većinom su instalirana kao tzv. “čistači” pogona u firmama kojima je primarna djelatnost prerada drveta.

Na području Zeničko-dobojskog kantona količina ogrjevnog drveta koja je u prosjeku godišnje raspoloživa trećim licima iznosi oko 115.000 m³, što znači da zvanični proizvođači otkupe samo oko 12%, međutim, ne može se reći da preostala količina nije iskorištena, nego samo da nije otkupljena i prerađena od strane zvaničnih proizvođača. Razlog ovome je što postoje brojni kupci ogrjevnog drveta koji ga samostalno cijepaju, među kojima su značajna ruralna domaćinstva koja otkupljuju onoliko koliko im je potrebno za jednu sezonu grijanja.

Raspoložive količine drvnog otpada na području Zeničko-dobojskog kantona su 183.538 m³/godišnje, od čega se na trenutnu godišnju proizvodnju peleta i briketa utroši 72.200 m³, odnosno oko 39%. Neiskorištenog potencijala drvnog otpada na godišnjem nivou ostane 111.338 m³, od čega se može proizvesti 44.535 t peleta i briketa. Ovo je veoma značajna informacija za proizvođače koji žele proširiti proizvodnju ili za nove zainteresovane ulagače.

Sagledavši cjelokupnu situaciju, kako na lokalnom tako i na regionalnom i globalnom planu, obnovljivi izvori energije dobivaju sve veći značaj, a među njima naročito drvna biomasa. Stoga se u budućnosti očekuje povećanje potražnje, a samim tim i proizvodnje, što će omogućiti da se drvni otpad i iz sektora drvne industrije i iz sektora šumarstva racionalnije i potpunije koristi.

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THE POSSIBILITY OF USING LIQUID WASTE BIOGAS PLANT AS FERTILIZER FOR CORN

Natalia Nikitskaya[1]

Mankind has long known the technology of processing organic waste into high-quality fertilizer by anaerobic digestion. It is successfully used in a number of countries, can dramatically improve the economic, environmental and social conditions in agriculture. The use of fermented residue as fertilizer promises a real breakthrough in increasing yields, and biogas plants show a record for the process equipment payback and reduce the class of waste hazard. Object of research – a liquid biofertilizer «Samorodovo». It is a product of biotechnological processing of quail droppings. Research was conducted on the territory of the agricultural enterprise «Agrofirma «Trud» Kungur district of Perm region for corn.

Key words: biogas plant, catalase activity, cellulolytic activity, corn, fertilizing fertilizers, liquid organic fertilizer.

1. INTRODUCTION

With the increasing anthropogenic impact on the soil, there is a growing interest in non-traditional organic fertilizers, which are derived from the utilization of animal wastes. Organic fertilizers have a positive impact on crop productivity. A large accumulation of raw manure pose a threat of contamination of livestock farming and can spread to large areas. A modern alternative and environmentally friendly way is the use of biotechnology, in which the processing of organic matter in anaerobic conditions (methanogenesis) using biogas plants. This ensures the disinfection of raw materials, the duration of its storage with maximum preservation of nutrients in it, the elimination of wastes, polluting the environment [1].

2. THE AIM AND OBJECT OF THE STUDY

The aim of the study - study of the possibility of using organic fertilizer «Samorodovo» for corn in the field experiment. The research was conducted on the basis of the agricultural enterprise «Agrofirma «Trud» of the Kungur district of Perm region. The objects of study are the liquid organic fertilizer, sod - podzol heavy-loamy soil and the maize varieties ROSS 140 SV – early maturing (FAO 150) 3-linear hybrid.

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*The object of study.To examine the liquid organic fertilizer «*Samorodovo*» at various concentrations. The organic* fertilizer «Samorodovo» is produced to bio-energy installation mounted at the Peasant farm V. Rashina. This is located in the village of Katishi in Krasnokamsky district of the Perm region. The farm contains about 60000 heads of quail. Biofertilizer «Samorodovo» is a product of biotechnological processing of the bird litter (the quail).

Options experience, methods of research and design experiments. The experiments were conducted in the chemical laboratory of the Department of ecology of the Perm State Agro-Technological University. Experimental parameters: control (wet); ammophos (5 kg/ha N); «Samorodovo» 1:30 (0.94 kg/ha N); «Samorodovo» 1:20 (1.88 kg/ha N); «Samorodovo» 1:10 (3.75 kg/ha N). The experience is a one-factor, where the factor is the dose of fertilizer. Accommodation plots are systematic, repeated the experience three times. The total area of the plot is 46.7 m^2, the accounting area is 25.2 m^2. The inter-rowspacingis 60 cm.

For the field experiment the equal site of a field with sowing of corn of the ROSS 140 SV grade is chosen. The seeding was 70000 plants per hectare. The soil of the experimental plot is typical for the study area and is homogeneous over the entire area of the plot. The maize grow in the recommended sowing time of the maize silage in the Perm Krai for the seeder Amazone Green Drill 200. The predecessor of corn in the crop rotation scheme was winter rye. For economy reasons prior sowing the corn the mineral fertilizer (azofoska) was introduced. For control the case without fertilizer with watering water was taken. In the phase of 3-4 leaves was carried out fertilizing with organic fertilizer «Samorodovo» in different doses. Preparation of fertilizer solutions was carried out taking into account the studied concentrations of the active substance (N). In the phase of milk-wax ripeness of corn the morphometric description of plants was carried out. The silage mass and the mass of ears were measured by weight method. Spot samples of soil were treated the with a spade to a depth of 15-20 cm. Soil samples for chemical analysis were dried to air-dry state (GOST 174301-83). Agrochemical studies and studies of soil enzymatic activity were carried out according to generally accepted methods [2].

3. THE RESEARCH RESULTS

The research results. Agrochemical soil survey allows to determine the need for soil fertilizers and chemical meliorants that affect soil fertility. To conduct the study the soil in «Agrofirm «Trud» in village Troelga Kungur district Perm region was selected.

Humus contributes to the formation of stable soil structure, provides a favorable water-air regime, gives the soil buffering in relation to nutrients, especially nitrogen. High level of microbiological activity of soils is also supported by the high level of humus. Thus, the humus is an important indicator of soil fertility. The humus content in the studied soil was 3.8±0.4%, typical sod-podzolic heavy loamy soils (3...6%) [2].

Actual acidity is due to the content of free hydrogen ions in the soil solution and is measured on the pH value of the aqueous extract from the soil. In the studied soil reaction is medium sized environment (4.9±0.2). The sum of exchangeable bases (S) – total amount of alkali and alkaline earth cations absorbed by the soil and is able to exchange, depends on soil texture and humus content. In the studied soil, the amount of exchangeable bases – 21, which exceeds typical of sod-podzolic soils a value of 15...20 mEq/100 g of soil. The cation exchange capacity (PC) – the sum of all the cations absorbed by the soil. Depends on granulometric composition and content of humus. The heavier the soil, the higher PC. In the analyzed soil the cation exchange capacity elevated. The degree of saturation of soil base (V) shows the percentage of

exchangeable bases in the total absorption capacity. It is used to evaluate soils in relation to the saturation of bases. In the analyzed soil it is of low saturation.

The total content of phosphorus depends on the mechanical composition of the soil and humus. The heavier the texture, the higher the phosphorus content. The content of phosphorus, according to the classification Kirsanov is medium (72.1±4.1 mg/kg). The effect of different doses of organic fertilizers «Samorodovo» to the biometrics corn varieties 140 ROSS SV. Biometric indicators or the structure of the yield are the main parameters characterizing the growth and development of culture, and also productivity. In this paper, the following biometric parameters were measured: plant height, number of leaves, number of ears of corn, the height of the first cob.

The height of the corn plant is characterized by the increase in the linear size of the vegetative and generative parts of the stem. The height of corn plants indirectly characterizes the potential yield of green mass. The measurements have shown that the tallest plants were obtained in variants with the use of ammophos (193.8 cm) and organic fertilizer «Samorodovo» with a concentration of 1:20 (191.7 cm). In other embodiments, the height ranges from 184.2 to 184.9 cm. The fertilizer «Samorodovo» was also found to affect the number of leaves on the plant. The maximum number obtained in the variant with application of organic fertilizers «Samorodovo» with the concentration 1:20 (7.4 units) compared to control, the minimum number - in making organic fertilizer «Samorodovo» with the concentration 1:10. Corn cob (modified lateral shoots) - located in the axils of the leaves at the top of the lateral shoots with shortened internodes and modified leaves, forming a wrapper. The number of full ears on the plant may be different. The greatest number of corn cob can be observed in variant with application of organic fertilizers «*Samorodovo*» with the concentration 1:30, equal to 2.6 units, the minimum number of cobs when making organic fertilizers «Samorodovo» with the concentration 1:20 and 1:10, it is equal to 2.4 units.

The quality of feed from corn for silage significantly depends on the number of product organs (corn cob). When mechanical cleaning agricultural machines can not always fully remove the cob due to the small height of the cob. Therefore, the height of the first cob is very important for mechanized harvesting of corn. The organic fertilizer «Samorodovo» affects the height of the first cob, at a concentration of 1: 20, the height of the first cob was the highest 47.1 cm, and the minimum indicator-control (watering) - 35.5 cm. Therefore, the best concentration of organic fertilizer solution «Samorodovo» to increase the height of the plant, the number of leaves and the height of the first cob is the concentration of 1:20, as recommended by the manufacturer.

The effect of different doses of organic fertilizers «Samorodovo» on the corn yield of the ROSS 140 SV corn variety. In order to plan a given yield, it is necessary to determine the optimal performance of the main elements of the structure of the corn crop, the formation of which should be provided by a set of agrotechnical measures. The main elements of the structure of the crop are formed in the process of growth and development of plants and are largely regulated by the biological characteristics of the variety, the weather conditions that develop during their cultivation, and the provision of plants with elements of mineral nutrition, primarily nitrogen.

The highest yield of green mass of corn received in the variants with application of mineral fertilizers monoammonium phosphate and organic fertilizers «Samorodovo» with the concentration 1:10 and amounted to 63.3 and 63.7 t/ha, respectively as compared to control is above 2 %. The noted difference in the formation of the crop is due to the structure of the yield of green mass. The contents of leaf-stem mass of the total harvest was the highest in the variants with application of organic fertilizers «Samorodovo» with the concentration 1:10 and amounted to 43.4 in the control 39.9 t/ha. For other options, one can see a tendency to reduce the leaf

mass comparedto the control from 7 to 21 %. The mass of cobs at harvest varied from 18.2 t/ha in the variant with application of organic fertilizers «Samorodovo» with the concentration 1:30 to 26.2 t/ha in the variant with application of monoammonium phosphate.

The effect of different doses of fertilizer «Samorodovo» on cellulolytic, catalase and urease activity of the soil. The biological activity of the soil can be determined not only by the number of individual groups of microorganisms, but also by the intensity of some processes caused by them [2].

The enzymatic activity of the soil can be used as a diagnostic indicator of the fertility of different soils, because the activity of enzymes reflects not only the biological properties of the soil, but also their changes under the influence of agroecological factors. There are various biological activities of the soil: cellulolytic, urease, catalase and other species. *Cellulolytic activity.* The rate of decomposition of fiber in the soil depends on the availability of readily available nitrogen in it, so this method allows one to evaluate the energy of mobilization of soil processes in general. The rate of decomposition of cellulose affects the rate of decomposition of organic matter in the soil. Organic fertilizer has a different effect on the cellulolytic activity of sod - podzolic heavy loamy soil. The best organic fertilizer «Samorodovo» was at concentration of 1:20 (43.7%) which is the average intensity of the destruction of the fiber. The lowest cellulolytic activity was observed with the introduction of mineral fertilizer ammophos (7.2%), which is a very weak indicator. According to other variants, the weak cellulolytic activity was revealed.

Catalase activity. The investigated soil is characterized by poor 1 cm^3 O_2 per 1 g/min. and very poor security by the enzyme catalase 0.1-0.9 cm^3 O_2 per 1 g/min. the Activity of catalase in the soil largely depends on air regime, soil texture, redox potential. *Urease activity*. Depending on the humus content, pH values, the urease activity increases from sod-podzolic and gray forest soils to chernozems. Urease in the soil can play a negative role. High levels of urease activity in soils with neutral and especially alkaline pH values can lead to significant gaseous losses of nitrogen introduced into the soil of urea, both in the form of ammonia and nitrogenous oxides – products of denitrification. Urease catalyzes the hydrolysis of urea. Urea enters the soil in the composition of plant residues, manure and as nitrogen fertilizer, it is also formed in the soil itself as an intermediate product in the process of transformation of nitrogenous organic compounds [2]. A high amount of organic matter in the soil affects urease activity. Thus, studies have shown that the soil according to the degree of enrichment of the enzyme urease, is medium enriched in variants with application of monoammonium phosphate (14.89 mg $N\text{-}NH_4$ at 10g/day) and organic fertilizers «Samorodovo» in a concentration of 1:30 (17.45 mg $N\text{-}NH_4$ at 10g/day), and rich for the rest of the options after application of fertilizers, including control variant (43.77-49.36 mg $N\text{-}NH_4$ at 10 g/day).

4. CONCLUSIONS

The addition of various doses of fertilizers «Samorodovo» on biometrics corn showed the greatest effect on the length of the aerial part, number of leaves and height of laying the first cob from the fertilizer «Samorodovo» with the concentration 1:20.

The highest yield of green mass of corn received in the «Samorodovo» with the concentration 1:10 and 63.7 t/ha, compared to the control above 2%.The contents of leaf-stem mass of the total harvest was highest in the variants with application of organic fertilizers «Samorodovo» with the concentration 1:10 and in control. For other options, one can see a tendency to reduce the leaf mass compared to the control from 7 to 21 %.

The most intensive decomposition of cellulose in the studied soil was observed when applying organic fertilizer «Samorodovo» with a concentration of 1: 20. Lowest cellulolytic activity was observed when making a map. The greatest catalase activity in the soil was observed in the version with the introduction of organic fertilizer «Samorodovo» with a concentration of 1: 30. The lowest activity of catalase in the soil was observed in the version with the introduction of fertilizer «Samorodovo» with a concentration of 1: 20, as well as with the introduction of ammophos.

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ENERGETSKA UČINKOVITOST I MEĐUNARODNE NORME

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Sažetak. Radi sve većih globalnih izazova - neočišćenog okoliša, globalnog zagrijavanja, lošije kvalitete zraka i smanjenja kapaciteta konvencionalnih energetskih resursa (nafta) - javlja se potreba za primjenom energetske učinkovitosti u svim područjima koja koriste energiju. Prisutna je i težnja za zamjenom uobičajenih energenata za obnovljive izvore energije.
Rad nastoji objasniti kakve pogodnosti može donijeti politika energetske učinkovitosti. Ulaskom u Europsku uniju Republika Hrvatska je bila obvezna u svoj zakonodavni sustav implementirati europske smjernice odnosno urediti energetsku politiku. Utvrđena je obveza energetske certifikacije i klasifikacije energetske učinkovitosti.
Međunarodna norma ISO 50001 jamči djelovanje poslovnog subjekta prema načelu energetske učinkovitosti. Natječajima za raznolike projekte osiguravaju se financijski poticaji radi smanjenja potrošnje energije i unaprjeđenja kvalitete života građana u Republici Hrvatskoj.

Ključne riječi: energetska učinkovitost, europske direktive, međunarodna norma ISO 50001.

ENERGY EFICIENCY AND INTERNATIONAL STANDARDS

Abstract: In response to ever-increasing global challenges - the untreated environment, global warming, poorer air quality and capacity reduction of conventional energy resources (oil) - there is a need for energy efficiency in all areas that use energy. There is also a tendency to replace conventional energy sources for renewable energy sources. The paper tries to explain the benefits of energy efficiency policy. By joining the European Union, the Republic of Croatia was obliged to implement European guidelines in its legislative system or to regulate energy policy. The obligation of energy certification and energy efficiency classification has been established.
The international standard ISO 50001 guarantees the business's performance according to the principle of energy efficiency. Contests for a variety of projects provide financial incentives to reduce energy consumption and improve the quality of life of citizens in the Republic of Croatia.

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1. POJAM I VAŽNOST ENERGETSKE UČINKOVITOSTI

Energetska učinkovitost suma je isplaniranih i provedenih mjera čiji je cilj korištenje minimalno moguće količine energije tako da razina udobnosti i stopa proizvodnje ostanu sačuvane. Pojednostavljeno, energetska učinkovitost znači uporabiti manju količinu energije (energenata) za obavljanje istog posla – funkcije (grijanje ili hlađenje prostora, rasvjetu, proizvodnju raznih proizvoda, pogon vozila i drugo). Pod pojmom energetska učinkovitost podrazumijevamo učinkovitu uporabu energije u svim sektorima krajnje potrošnje energije: industriji, prometu, uslužnim djelatnostima, poljoprivredi i u kućanstvima.

Energetska učinkovitost se ne promatra kao štednja energije. Naime, štednja uvijek podrazumijeva određena odricanja, dok učinkovita uporaba energije nikada ne narušava uvjete rada i življenja. Nadalje, poboljšanje učinkovitosti potrošnje energije ne podrazumijeva samo primjenu tehničkih rješenja. Štoviše, svaka tehnologija i tehnička oprema, bez obzira koliko učinkovita bila, gubi to svoje svojstvo ukoliko ne postoje obrazovani ljudi koji će se njom služiti na najučinkovitiji mogući način. Energetska učinkovitost prvenstveno je stvar svijesti ljudi i njihovoj volji za promjenom ustaljenih navika prema energetski učinkovitijim rješenjima, negoli je to stvar kompleksnih tehničkih rješenja. (Bukarica et al., 2008:8)

Ponajprije, energetska učinkovitost služi zaštiti okoliša. Nepobitna je činjenica da je pristup energiji po prihvatljivim cijenama ključan preduvjet gospodarskog i socijalnog razvoja svakog društva. No, proizvodnja energije i njezina uporaba značajno utječu na okoliš, uzrokujući zagađenja lokalnog i regionalnog karaktera (primjerice, smog i kisele kiše), ali i globalne probleme poput globalnog zagrijavanja i rezultirajućih klimatskih promjena. Naime, energija se još uvijek proizvodi iz fosilnih goriva: ugljena, nafte i naftnih derivata i prirodnog plina. Njihovim sagorijevanjem u atmosferu se ispuštaju razni polutanti poput sumpornog dioksida, dušičnih oksida, čestica te ugljičnog dioksida.

Sumporni dioksid i dušični oksidi, osim njihovog potencijalno štetnog djelovanja na zdravlje, poznati su i kao „kiseli“ plinovi jer njihovom transformacijom prilikom daljinskog transporta nastaju kiseli sastojci koji se talože iz atmosfere u obliku mokrog (kisele kiše) i suhog taloženja. Osim zakiseljavanja, dušični oksid sudjeluje u eutrofikaciji i stvaranju štetnog prizemnog ozona; ugljični dioksid je najznačajniji uzročnik globalnog zagrijavanja. Valja imati na umu da se energija uvijek proizvodi kako bi zadovoljila potrošnju – proizvodnja je uzrokovana potrošnjom, pa nepažljiva, neučinkovita potrošnja uzrokuje nepotrebno veliku proizvodnju, a time i nepotrebno veliki negativni utjecaj na okoliš. Poboljšana učinkovitost uporabe energije rezultirat će njezinom smanjenom potrošnjom, što vodi i smanjenju proizvodnje energije. Može se reći da svaki kwh energije koji se ne potroši znači određenu količinu onečišćujućih plinova koji nisu ispušteni u atmosferu. Prema tome, učinkovitom uporabom energije podiže se kvaliteta okoliša te se pridonosi globalnoj borbi za suzbijanje klimatskih promjena.

Energetska učinkovitost pridonosi i makroekonomskom razvoju. Provedba energetske učinkovitosti može doprinijeti mnogim područjima ekonomije, s direktnim i indirektnim učincima na ekonomske aktivnosti (bruto domaći proizvod, nezaposlenost, omjer uvoza i izvoza, cijene energije i drugo). Primjerice, analize provedene u kretanju

bruto domaćeg proizvoda u državama s razvijenom politikom energetske učinkovitosti, pokazuju pozitivne rezultate sa rastom BDP-a od 0.25% - 1.1.% na godinu. Naravno, ima li energetska učinkovitost pozitivni ili negativan učinak, ovisi o ekonomskoj strukturi pojedine države te o njezinim temeljnim politikama. (IEA, 2014:45).

Važno je naglasiti pozitivne utjecaje na ljudsko zdravlje i kvalitetu života općenito. Primjerice, smanjenim korištenjem neobnovljivih izvora energije (nafta, ugljen i drugi), instalacijom sustava za održavanje kvalitete zraka, reduciraju se i razni simptomi dišnih i kardiovaskularnih stanja, reume, artritisa, alergije te raznih upalnih procesa.

2. ENERGETSKA UČINKOVITOST U REPUBLICI HRVATSKOJ

Zakonom o energetskoj učinkovitosti (Narodne novine, 127/2014) Republika Hrvatska uređuje područje učinkovitog korištenja energije, donošenje planova na lokalnoj, područnoj (regionalnoj) i nacionalnoj razini za poboljšanje energetske učinkovitosti. U Zakonu su također određenje mjere energetske učinkovitosti, njihovo provođenje, obveze energetske učinkovitosti, obveze regulatornog tijela za energetiku, operatora prijenosnog i distribucijskog sustava te tržišta energije u vezi s transportom i distribucijom energije, obveze distributera energije, opskrbljivača energije i/ili vode, a posebice djelatnost energetske usluge, utvrđivanje ušteda na energiji te prava potrošača u primjeni mjera energetske učinkovitosti. Svrha je Zakona ostvarivanje ciljeva održivog energetskog razvoj. Točnije, svrha jest smanjenje negativnih utjecaja na okoliš iz energetskog sektora, poboljšanje sigurnosti opskrbe energijom, zadovoljavanje potreba potrošača energije i ispunjavanje međunarodnih obveza Republike Hrvatske u području smanjenja emisije stakleničkih plinova i to poticanjem mjera energetske učinkovitosti u svim područjima potrošnje energije.

Jedan od ciljeva energetske učinkovitosti jest povećanje korištenja obnovljivih izvora energije te smanjenje korištenja neobnovljivih izvora energije, kao što su nafta, ugljen te nuklearna goriva.

Obnovljivi izvori energije u hrvatskom se Zakonu o energiji definiraju kao izvori energije koji su sačuvani u prirodi i obnavljaju se u cijelosti ili djelomično, posebno energija vodotoka, vjetra, neakumulirana sunčeva energije, biodizel, biomasa, bioplin, geotermalna energija i tako dalje (Zakon o energiji, Narodne novine, 120/2012, 14/2014, 95/2015, 102/2015, 68/2018).

Obnovljivi izvori energije su kinetička energija (energija vjetra), sunčeva energija, biomasa, toplinska energija zemljine unutrašnjosti i vrući izvori (geotermalna energija), potencijalna energija vodotoka (vodne snage), potencijalna energija plime i oseke i morskih valova te toplinska energija mora. Republika Hrvatska se, kao članica Europske unije, obvezala na prihvaćanje europskog energetskog paketa koji podrazumijeva i Direktivu 2009/28/EZ (https://www.mingo.hr, pristupano 10.9. 2018.) o poticanju uporabe energije iz obnovljivih izvora.

Prihvaćanjem direktive, Republika Hrvatska je preuzela obvezu povećanje uporabe energije iz obnovljivih izvora, pri čemu bi u 2020. godini udio energije iz obnovljivih izvora u bruto neposrednoj potrošnji trebao iznositi najmanje 20%, promatrano na razini Europske unije. U svrhu poticanja razvoja i korištenja obnovljivih izvora energije u Republici Hrvatskoj, izrađeni su programi sufinanciranja nabave sustava za korištenje obnovljivih izvora energije od strane Fonda za zaštitu okoliša i energetsku učinkovitost te sustav poticanja proizvodnje električne energije putem povlaštenih otkupnih

cijena.(http://www.fzoeu.hr/hr/energetska_ucinkovitost/obnovljivi_izvori_energije/, datum pristupanja: 10.9. 2018).

3. MEĐUNARODNA NORMA ISO 50001

Sustav upravljanja energijom pomaže organizacijama kako bi bolje upravljali korištenjem energije. Sustav uključuje razvoj i provođenje energetske politike, postavljanje ciljeva za racionalno korištenje energije te planiranje akcijskih planova kako bi se postavljeni ciljevi mogli ostvariti. To može uključivati primjenu novih energetski učinkovitih tehnologija, smanjivanje energetskog otpada ili poboljšanje već postojećih procesa u svrhu smanjenja troškova energije.

ISO 50001 je dobrovoljna međunarodna norma koja postavlja zahtjeve za uspostavljanje sustava upravljanja energijom. Primjenjuje se širom svijeta u velikim i malim, privatnim i javnim, uslužnim i proizvodnim organizacijama. Procjenjuje se da će ISO 50001 utjecati na oko 60% svjetske uporabe energije. Potreba za energijom je u intenzivnom rastu te se procjenjuje da će u sljedećih dvadesetak godina potrošnja energije porasti za 50%. Također, raste i cijena energije. Očekuje se poskupljenje energije u Europskoj uniji za minimalno 20% u narednih nekoliko godina. Klimatske promjene su sve učestalije i snažnije. Kao izazovi navode se i zakonski propisi i ciljevi. Slijedom europske Direktive o energetskoj učinkovitosti (EE direktiva) te hrvatskog Zakona o energetskoj učinkovitosti, javni sektor, poduzeća i distributeri energije koji rade u Europskoj uniji moraju neprestano unaprjeđivati energetsku učinkovitost i smanjivati emisije stakleničkih plinova. Pri tome, velika poduzeća, osim onih koji već imaju uspostavljen sustav upravljanja energijom, dužna su svake četiri godine provesti energetski pregled.

Norma ISO 50001 postavlja skup zahtjeva koji omogućavaju organizaciji razvijanje politike za učinkovitije korištenje energije, prepravljanje već postojećih ciljeva i utvrđivanje novih koji vode ka realizaciji politike, prikupljanje podataka za bolje razumijevanje i donošenje odluka o potrošnji energije i troškovima, mjerenje dobivenih rezultata, pregled učinkovitosti politike te kontinuirano poboljšavanje upravljanja energijom. ISO 50001 je osmišljen kako bi pomogao organizaciji poboljšati energetske performanse. Poboljšana energetska učinkovitost može organizaciji pružiti korist maksimiziranjem korištenja energetskih izvora i energetske imovine, smanjujući ujedno i troškove i potrošnju. Koristi ove norme su širokog spektra, od smanjenja negativnih učinaka na okoliš i poboljšanju reputacije organizacije, do smanjenja troškova. (ISO 50001, 2016).

Sve ove koristi poboljšavaju se uslijed standardizirane metodologije za identificiranje i implementiranje poboljšanja uporabe energije, bolje iskoristivosti postojećih potrošača energije, transparentne i olakšane komunikacije i upravljanju energetskim resursima, promoviranja najbolje prakse upravljanja energijom, podrške za organizacijske promjene i promjene ponašanja te strukturirane procjene novih energetski učinkovitijih tehnologija. ISO 50001 se temelji na istom modelu upravljanja koji milijuni organizacija koriste kroz ISO 9001 (kvaliteta), ISO 14001 (okoliš), ISO 22000 (sigurnost hrane) i ISO/IEC 27001 (informacijska sigurnost).

U svijetu je u 2016. godini izdano 18976 ISO 50001 certifikata (The ISO Survey of Management System Standard Certifications 2016, https://www.iso.org/the-iso-survey.html, datum pristupanja 10.09.2017.), a u Republici Hrvatskoj, u razdoblju od 2011. do 2016., 55 certifikata (http://isotc.iso.org/livelink/livelink?func=ll&objId=18808772&objAction=browse&viewType=1, datum pristupanja: 10.9.2018.).

4. EUROPSKE DIREKTIVE U PODRUČJU ENERGETSKE UČINKOVITOSTI

Direktiva 2012/27/EU - EUR - Lex - Europa EU (https://eur-lex.europa.eu/legal-content/hr/TXT/?uri=celex%3A32012L0027, pristupano 11.9. 2018) je direktiva Europske unije, odnosno europskog parlamenta i vijeća, o energetskoj učinkovitosti. Tom se Direktivom uspostavlja zajednički okvir mjera za postizanje energetske učinkovitosti u državama članicama Europske unije, a koja za cilj ima poboljšanje energetske učinkovitosti za 20% do kraja 2020.godine. U njoj se utvrđuju pravila čija je namjena otklanjanje prepreka na tržištu energije i prevladavanje neefikasnosti tržišta koje ograničavaju učinkovitost u opskrbi energijom i njezinoj uporabi te osigurava utvrđivanje okvirnih nacionalnih ciljeva povećanja energetske učinkovitosti do 2020. godine.

Svaka država članica Unije određuje okvirni nacionalni cilj povećanja energetske učinkovitosti na temelju potrošnje primarne energije ili krajnje potrošnje energije (cjelokupna energija kojom se opskrbljuju industrija, promet, kućanstva, usluge i poljoprivreda), uštede primarne ili krajnje energije ili energetskog intenziteta. Komisija Europske unije mora biti obaviještena od strane država članica o njihovim okvirnim ciljevima. Pri određivanju ciljeva države članice mogu uzeti u obzir nacionalne okolnosti koje utječu na potrošnju energije, kao što su razvoj i predviđanja u vezi s BDP-om ili promjene u izvozu i uvozu energije.

Direktiva 2010/31/EU o energetskoj učinkovitosti zgrada - EUR-Lex (https://eur-lex.europa.eu/legal-content/HR/TXT/?uri=celex%3A32010L0031, pristupano 11.9. 2018) je direktiva Europske unije, odnosno europskog parlamenta i vijeća, o energetskoj učinkovitosti zgrada. Direktiva 2010/31/EU promiče poboljšavanje energetske učinkovitosti zgrada u Uniji, uzimajući u obzir vanjske klimatske i lokalne uvjete te zahtjeve unutarnje klime i troškovnu učinkovitost. Direktiva sadrži zahtjeve u pogledu zajedničke opće metodologije za izračunavanje integrirane energetske učinkovitosti zgrada i građevinskih cjelina, primjene minimalnih zahtjeva energetske učinkovitosti za nove i već postojeće zgrade, nacionalnih planova za povećanje broja zgrada približno nulte energije, energetskog certificiranja zgrada ili građevinskih cjelina, redovotih pregleda sustava grijanja i klimatizacije u zgradama i neovisnih sustava kontrole energetskih certifikata i izvješća o pregledu.

Zgrade su odgovorne za 40% ukupne potrošnje energije u Uniji. Stoga su smanjenje potrošnje energije i korištenje energije iz obnovljivih izvora u zgradarstvu važne mjere koje su potrebne da bi se smanjila energetska ovisnost Europske unije i emisije stakleničkih plinova. Mjere za smanjenje potrošnje energije u Uniji, u kombinaciji s povećanim korištenjem energije iz obnovljivih izvora omogućavaju Europskoj uniji da ispoštuje Kyotski protokol. Kao i u Direktivi 2010/31/EU, određivanje minimalnih zahtjeva energetske učinkovitosti zgrada i građevinskih elemenata isključiva je odgovornost država članica.

Energetska učinkovitost zgrada izračunava se na temelju metodologije koja se razlikuje na nacionalnoj, ali i na regionalnoj razini. To uz toplinske značajke uključuje i druge čimbenike kojima pripada sve važnija uloga.Neki od čimbenika jesu postrojenja za grijanje i klimatizaciju, primjena energije iz obnovljivih izvora, elementi pasivnog hlađenja i grijanja, zaštita od sunca, kakvoća zraka i drugi. Metodologija izračuna se ne temelji samo na podacima uzetima samo u sezoni u kojoj se koristi grijanje, već obuhvaća godišnju energetsku učinkovitost zgrade.

Kako bi zahtjevi iz Direktive 2010/31/EU bili zadovoljeni, Europska unija nudi financijske poticaje za njihovo ostvarenje. Države članice sastavljaju popis postojećih i,

prema potrebi, predloženih mjera i instrumenata uključujući i one financijske prirode koje promiču ciljeve Direktive, te taj plan ažuriraju svake tri godine. Komisija ispituje učinkovitost predloženih mjera i na temelju tog ispitivanja daje savjete i preporuke u pogledu nacionalnih programa i koordinacije s Unijom i međunarodnim financijskim institucijama, vodeći računa o načelu supsidijarnosti. Također, Komisija Europske unije prema potrebi na zahtjev država članica pomaže kod određivanja nacionalnih i regionalnih programa financijske potpore, s ciljem povećanja učinkovitosti zgrada, posebice onih već postojećih. Države članice kod osiguravanja poticaja za izgradnju ili obnovu zgrada vode računa o troškovno optimalnim razinama energetske učinkovitosti, ali ih ne priječe da osiguraju poticaje koji prelaze te razine. Poticaji se financiraju iz Europske investicijske banke.

Direktiva 2014/94/EU - EUR-Lex - Europa EU (https://eur-lex.europa.eu/legal-content/hr/TXT/?uri=CELEX:32014L0094, pristupano 11.9. 2018) je direktiva europskog parlamenta i vijeća o uspostavi infrastrukture za alternativna goriva. Potreba za njom se javila iz „Europa 2020: Strategije za pametan, održiv i uključiv rast“, u kojem Komisija za cilj ima jačanje konkurentnosti i sigurnosti opskrbe energijom putem učinkovitije uporabe resursa i energije, te prema Bijeloj knjizi - Planu za jedinstveni europski prometni prostor, u kojem se poziva na smanjenje ovisnosti prometnog sustava o nafti.

Predmet Direktive jest utvrđivanje zajedničkog okvira za postavljanje infrastrukture za alternativna goriva u Europskoj uniji kako bi se na najmanju moguću mjeru smanjila ovisnost o nafti i ublažio negativan utjecaj prometa na okoliš. Utvrđuju se minimalni zahtjevi za izgradnju infrastrukture za alternativna goriva, uključujući mjesta za punjenje električnih vozila i mjesta za opskrbu prirodnim plinom i vodikom, koji se provode putem nacionalnih okvira politika država članica, kao i zajedničke tehničke specifikacije za taka mjesta za opskrbu te zahtjeve za informiranje korisnika. Kao alternativni izvori se navode svi izvori energije koji se ne moraju oslobađati izgaranjem ili oksidacijom bez izgaranja, kao što su primjerice vodik i električna energija. Također, kao alternativna goriva navode se i sintetička goriva (proizvedena iz različitih sirovina, pretvaranjem biomase, plina, ugljena ili plastike u tekuća goriva) te autoplin (gorivo dobiveno preradom prirodnog plina i rafiniranjem nafte), koja su manje štetnija za zdravlje i okoliš nego konvencionalna goriva.

Direktiva promovira elektromobilnost i električnu energiju koja bi mogla povećati učinkovitost cestovnih vozila i doprinijeti smanjenju ugljičnog dioksida u prometa. Sukladno tome, države članice bi trebale osigurati da se izgradnjom javno dostupnih mjesta za punjenje osigura odgovarajuća pokrivenost kako bi se omogućilo da električna vozila prometuju barem u gradskim i prigradskim sredinama. Broj takvih mjesta za punjenje trebalo bi odrediti uzimajući u obziru procjenu broja registriranih električnih vozila u svakoj državi članici do kraja 2020.godine (okvirno jedno mjesto za punjenje na 10 automobila). Uz to, elektromobilnost se priželjkuje i u vodnom prometu.

5. ZAKLJUČAK

Iz godine u godinu sve je veća potreba za energijom. Kako bi se potrošnja energije racionalizirala, potrebno je uvesti mjere i načela energetske učinkovitosti u zgradarstvo, industriju, promet, javnu rasvjetu i ostala područja. Energetska učinkovitost predstavlja uporabu manje količine energije za obavljanje istog posla ili funkcije. Kako bi se energetska učinkovitost primijenila, potrebna su ne samo tehnička rješenja već i ljudi obrazovani za njezinu primjenu.

Glavna svrha primjene energetske učinkovitosti jest služba zaštiti okoliša. Svijet je pred izazovima sve većeg onečišćenja voda, zraka i tla, klimatskih promjena te velikih emisija ugljičnog dioksida, koji je glavni uzročnik globalnog zagrijavanja.

Naime, ispostavlja se da je glavni krivac za drastične promjene u okolišu upravo čovjek. Čovjek bi implementiranjem načela učinkovitog korištenja energije uvelike pridonio održivom razvoju te smanjio ovisnost o korištenju neobnovljivih izvora energije. Također, energetska učinkovitosti pridonosi makroekonomskom razvoju, s raznim učincima na ekonomske aktivnosti, kao što su nezaposlenost, omjer uvoza i izvoza, cijene energije i slično, te pozitivno utječe na ljudsko zdravlje i kvalitetu života općenito.

U zgradarstvu energetska učinkovitost se predstavlja kao uporaba manje količine energije za određene funkcije, kao što su hlađenje i grijanje, ventilacija, rasvjeta i priprema tople vode, na način da razina komfora ostane ista. Kako bi bilo moguće utvrditi mjere za poboljšanje tih funkcija, potrebno je napraviti energetski pregled zgrade. To je postupak kojim se analiziraju postojeća potrošnja i energetska svojstva zgrade, ali i određuje isplativost mogućnosti za uštedu energije. Nakon obavljenog pregleda, ovlašteni energetski certifikator izdaje energetski certifikat, dokument koji predočuje energetska svojstva zgrade. Važeći je 10 godina, a izdaje se elektroničkim putem. Što se tiče kućanstava, važno je napomenuti i uporabu energetski učinkovitih kućanskih uređaja. Uređaji u današnje doba su standardizirani, čime su kupcima vidljiva njihova svojstva. Na taj način kupac prije same uporabe uređaja može procijeniti kolike uštede energije i novca može očekivati.

Industrija je odgovorna za 17% potrošnje energije te je od velike važnosti racionalno upravljati energijom. Trend smanjenja energetske potrošnje pada, ali je upitno je li to rezultat primjene energetske učinkovitost ili ekonomske situacije u državi i svijetu. Uz zgradastvo i industriju, promet i javna rasvjeta čine bitan udio sveukupne potrošnje energije. Primjenom europskih i nacionalnih normi te raznim projektima postupno raste trend provedbe racionalnog korištenja energije i na tim područjima.

Međunarodna organizacija za normizaciju ISO osmislila je normu koja postavlja zahtjeva za uspostavljanje sustava upravljanja energijom, ISO 50001. Norma omogućava organizacijama razvijanje politike za učinkovito korištenje energije, utvrđivanje ciljeva za realizaciju politike te doprinosi boljem donošenju odluka po pitanju energije. Pretpostavlja se da će, zahvaljujući normi ISO 50001, 60% svjetske energije biti učinkovito korišteno.

Kao članica Europske unije, Republika Hrvatska je implementirala europske direktive u svoje zakonodavstvo i uređuje sustave energije prema zahtjevima Europske unije. Za energetsku učinkovitost, najznačajniji je Zakon o energetskoj učinkovitosti.

Može se zaključiti kako je trend energetske učinkovitosti u Republici Hrvatskoj u porastu. Zahvaljujući financijskim poticajima Europske unije, ali i onim na nacionalnoj razini (primjerice, Fonda za zaštitu okoliša i energetsku učinkovitost) te provedenim projektima, ostvarene su brojne uštede. Međutim, na nekim područjima je načela energetske učinkovitosti lakše provoditi nego na drugima. Primjerice, na području rasvjete se zakonom zabranila proizvodnja ekološki neprihvatljivih žarulja te samim time one više ne postoje na tržištu i potrošači nemaju izbora kupovanja istih. Također, kućanski uređaji su proizvodi kraćeg roka trajanja (otprilike 10 godina) te ih je lakše zamijeniti onim učinkovitijima što nije slučaj kod, primjerice, zamjene stolarije ili termoizolacije. Za takve se aktivnosti nude poticaji. Ključni element za napredak jeste obrazovanje pojedinaca i buđenje svijesti o samoj energetskoj učinkovitosti i njezinim pogodnostima.

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EKONOMSKA OPRAVDANOST PRIMENE SOLARNE ENERGIJE U ZLATIBORSKOM OKRUGU

Dragan Vujović[1] , Pavle Popovic[2], Dragan Protić[3]

Rezime: Potreba za energijom uslovila je da su svetske rezerve fosilnih goriva na minimumu i da se čovečanstvo mora „okrenuti“ ka obnovljivim izvorima energije, bilo da je reč o sunčevoj energiji, energiji vetra, hidro energiji i energiji bio mase. Pored toga energija dobijena iz obnovljivih izvora je "čista" što je u potpunoj saglasnosti sa apelima za očuvanje i onako narušene životne sredine. U ovom radu je prikazana primena solarne energije i njena ekonomska opravdanost korišćenja u Zlatiborskom ogrugu.

Ključne reči: Sunčeva energija, kolektor, toplotna energija.

ECONOMIC JUSTIFICATION OF THE USE OF SOLAR ENERGY IN THE ZLATIBOR REGION

Abstract: The need for energy has made it necessary that the notebooks of the reserve of fossil fuels are at a minimum and that mankind must "turn" to irrelevant sources of energy, whether it is solar energy, wind energy, hydro energy and energy of bio mass. In addition, the energy obtained from renewable sources is "pure", which is in full compliance with the appeals for the conservation of such a disrupted environment.By opening this topic, you may not have to ask the question of the justification of the investment, but the issue of subsidies for something that is completely profitable.

Key words: Solar energy, collector, heat energy

1. UVOD

Energija je glavni pokretač tehnološkog napretka u poslednjih stotinjak godina. Zahvaljujući industrijalizaciji i porastu broja stanovnika, potreba za energijom iz godine u godinu se eksplicitno povećava. Svetska energetska kriza početkom sedamdesetih godina prošlog veka, pa sve do danas, suočila je čovečanstvo sa sve većom nestašicom energije. To je rezultiralo donošenjem programa energetske politike i očuvanja energije. Razvijaju se i uvode nove tehnologije koje po istoj jedinici proizvoda troše manje energije.

Prema scenariju svetskih istraživanja obnovljivi izvori energije bi do 2050. godine u potpunosti mogli da obezbede potrebnu energiju koja se danas proizvodi iz konvencionalnih izvora uključujući i nuklearnu energiju, a stoje u saglasnosti za očuvanje prirode. Uzimajući sve to u obzir svetska asocijacija za solarnu energiju je održala prvi solarni samit septembra 1996. u Harareu (Zimbabve) na kome su usvojena dva dokumenta od velikog značaja:

- Solarna deklaracija
- Svetski solarni plan akcije za period od 1996 do 2005 godine.

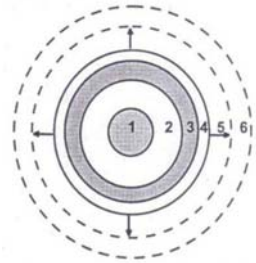
2. ENERGIJA SUNCA

Sunce, jedna od 400 milijardi zvezda u našoj galaksiji, nalazi se na polovini svog životnog veka i procenjuje se da će Sunce na postojeći način sijati jos pet milijardi godina. Po svom obliku Sunce je gasovita sfera prečnika $1{,}319 \times 10^6$ kilometara. Temperatura na površini Sunca je oko 5500^0C. Ukupna količina energije koju sunce izrači u okolinu iznosi Ls=3,83x1026 J/s. Poreklo sunčeve energije je otkrio Hane Bete 1938. godine. On je dokazao da se energija na suncu stvara u termonuklearnom procesu fuzije vodonika u helijuma u takozvanom protonskom lancu. Hemijski sastav Sunca je dat u sledećoj tabeli:

Tabela 1. *Hemijski sastav sunca*

Element			Procenat od ukupnog broja atoma	Procenat od ukupne mase sunca
Vodonik			92	73,4
Helijum			7,8	25
C	N	O	0,2	1,6
Ne	Mg	Si		
S	Fe			

Struktura sunca (sl.1) se sastoji iz jezgara (1), radijacione zone (2), konventivne zone (3), i fotosfere (4), dok se atmosfera Sunca sastoji od hromosfere (5) i korone(6).



Slika 1. *Struktura sunca*

Interesantno je da je temperature u fotosferi 5527^0C koja u hromosferi opada,a na 1000 kilometara iznad fotosfere dostiže svoj minimum od približno 3727^0C. Posle toga temperatura naglo raste da bi u koroni dostigla10^6 ^{0}C. Iz fotosfere sunčevo zračenje dospeva na Zemlju prolazeći kroz hromosferu i koronu gde se delimično apsorbuje. [2] Na Zemlju pada oko 97% sunčevog zračenja u oblasti talasnih dužina 0,3/2,5μm, a oko 3% sa talasnim dužinama većim od 2,5 μm.Od dozračnih talasa 3% se nalazi u ultraljubičastoj, oko 42% u vidljivoj i oko 55% u infracrvenoj oblasti spectra elektro magnetnog zračenja.

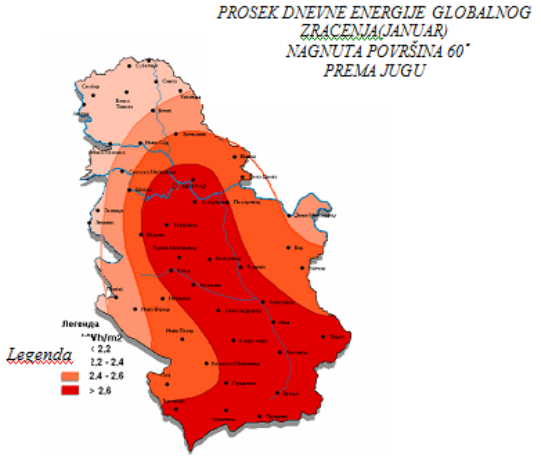
Međutim ako sagledamo činjenicu da na Zemlju dospe “svega” polovina milijarditog dela zračenja sunčeve energije što odgovara snazi 175×10^9 MW koja je oko 10^5puta veća od snage svih elektrana na svetu kada su u punoj snazi.

3. MOGUĆNOSTI KORIŠĆENJA SUNČEVE ENERGIJE U ZLATIBORSKOM OKRUGU

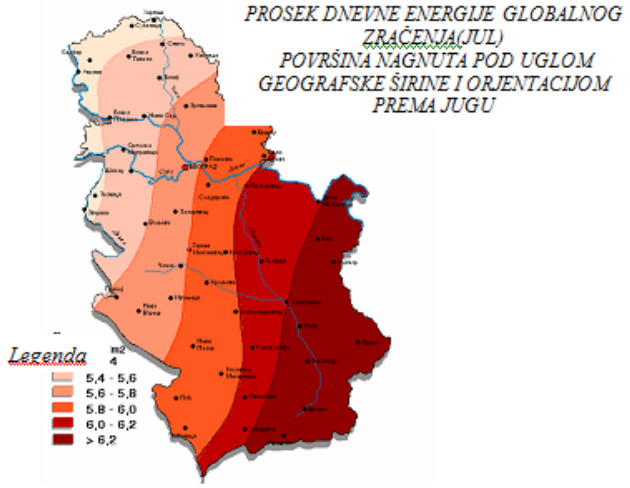
Da bi se utvrdila isplativost primene solarne energije za dogrevanje sanitarne vode u Zlatiborskom okrugu, neophodno je najpre indentifikovati raspoloživi potencijal energije sunca.

3.1 Mape energije globalnog Sunčevog zračenja u Srbiji

S obzirom na to da priliv Sunčeve energije određenoj površini zavisi od njenog nagiba i orijentacije u odnosu na Sunčeve zrake, to će u ovom radu biti prikazani podaci o energiji Sunčevog zračenja za nagnute površine i orijentisane prema jugu. Na *slici 2.* prikazana je prosečna dnevna energija globalnog zračenja na površinu sa nagibom 60^0 i orijentacijom prema jugu u januaru za teritoriju Srbije. Zlatiborski okrug prima energiju od 2,2 kWh/m^2 do 2,6 kWh/m^2. Na *slici 3.* prikazana je prosečna dnevna energija globalnog zračenja na površinu sa nagibom jednakim geografskoj širini i orijentacijom prema jugu u julu za teritoriju Srbije. Zlatiborski okrug prima energiju od 5,6 kWh/m^2 до 5,8 kWh/m^2.[2]

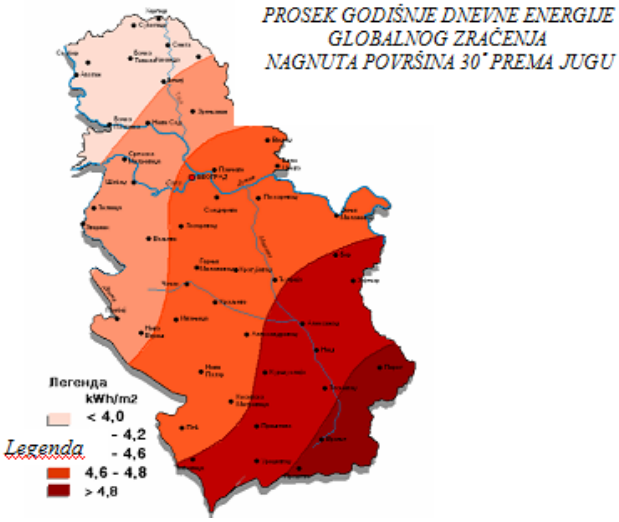


Slika 2. *Prosečna dnevna energija globalnog zračenja na površinu sa nagibom 60^0 i orijentacijom prema jugu u januaru (kWh/m^2)* .



Slika 3. *Prosečna dnevna energija globalnog zračenja na površinu sa nagibom jednakim geografskoj širini i orijentacijom prema jugu u julu (kWh/m^2)* .

Na *slici 4.* [2] prikazan je godišnji prosek dnevne energije globalnog zračenja na površinu sa nagibom 30^0 i orijentacijom prema jugu. Vrednosti za Zlatiborski okrug se kreću od 4 kWh/m^2, do 4,6 kWh/m^2.



Slika 4. *Godišnji prosek dnevne energije globalnog zračenja na površinu sa nagibom 30^0 i orijentacijom prema jugu (kWh/m^2)*

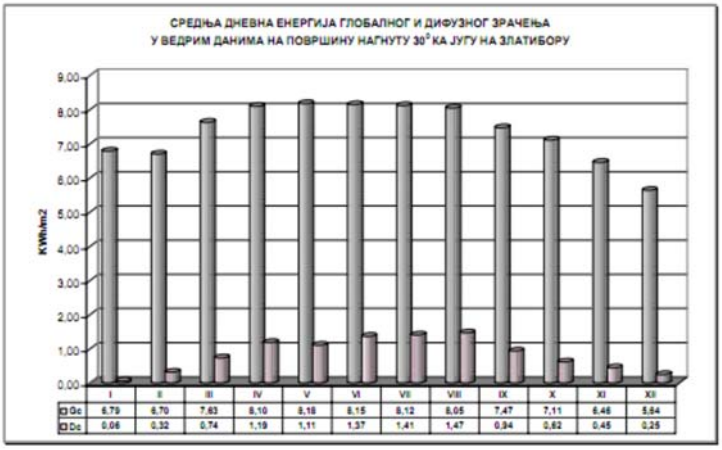
3.2. Statistička analiza podataka Sunčevog zračenja za meteorološku stanicu Zlatibor

Na *slici 5.* prikazano je srednje dnevno trajanje sijanja Sunca za Zlatiboru. Na *slikama 6 i 7.* [2] je data srednja dnevna energija globalnog i difuznog zračenja na različito nagnutim i orijentisanim površinama na Zlatiboru. [2] Simboli imaju sledeća značenja:

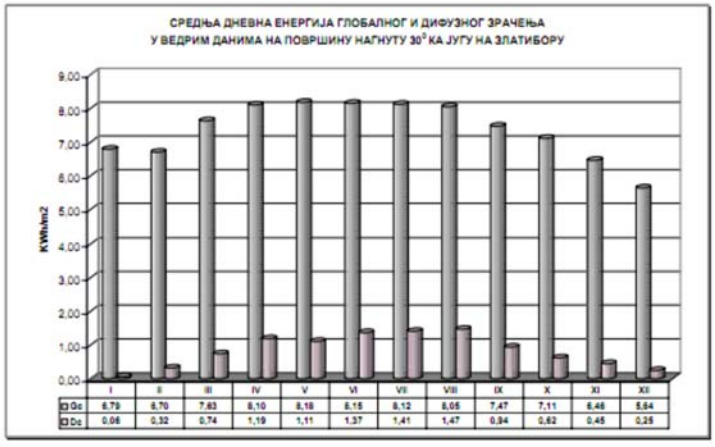
Gm Srednja dnevna energija globalnog zračenja
Dm Srednja dnevna energija difuznog zračenja
Gc Srednja dnevna energija globalnog zračenja u vedrim danima
Dc Srednja dnevna energija difuznog zračenja u vedrim danim



Slika 5. *Srednje dnevno trajanje sijanja Sunca, Zlatibor*.



Slika 6. *Srednja dnevna energija globalnog i difuznog zračenja na površinu nagnutu 30^0 ka jugu na Zlatiboru.*



Slika 7. *Srednja dnevna energija globalnog i difuznog zračenja u vedrim danima na površinu nagnutu 30^0 ka jugu na Zlatibor*.

Iz prikazanih podataka je očigledno da u Zlatiborskom okrugu postoje prirodni uslovi za korišćenje solarne energije.

4. PARAMETRI PRORAČUNA POTREBA ZA TOPLOM SANITARNOM VODOM DOMAĆINSTAVA NA BAZI BROJA ČLANOVA

Najvažniji papametar koji služi za dimenzionisanje solarnih sistema za zagrevanje sanitarne vode jeste potrebna količina toplote za pripremu tople sanitarne vode. Potrebna količina tople sanitarne vode u postojećem objektu najlakše se može odrediti pomoću vodomera koji bi bio ugrađen ispred uređaja za zagrevanje vode. Pošto je takvo merenje prezahtevno (iziskuje troškove nabavke i ugradnje vodomera) primenjuje se procena na temelju iskustvenih vrednosti prema broju osoba i ostalih potrošača. Prema iskustvenim podacima [3] potrošnja tople sanitarne vode, zagrejane na 45^{0}C kreće se u rasponu od 20 do 70 litara po osobi dnevno. U ovom radu potrebni proračuni će se vršiti na bazi projektovane potrošnje od 50 litara tople sanitarne vode po jednoj osobi dnevno. Potrošnja tople sanitarne vode za ostale potrošače kao što su

mašina za pranje veša i mašina za pranje sudova (podrazumeva se da ovi uređaji moraju imati priključak za toplu vodu) najtačije se mogu odrediti prema podacima proizvođača. U ovom radu prema podacima [3] uzeto je da ovi uređaji troše 20 litara tople vode dnevno. Kada se utvrde dnevne potrebe tople sanitarne vode, potrebno je utvrditi dnevnu potrebnu količinu energije za pripremu tople sanitarne vode. Dnevna količina energije za pripremu sanitarne vode određuje se:

$$Q = (m \cdot c \cdot \Delta T) \quad (1)$$

Gde je:
Q – količina toplote u *Wh*
m – masa u *kg* (za vodu *1kg* ≈ 1l)
c – kapacitet toplote u *Wh/kgK* (za vodu *c* ≈ 1.*16Wh*/*kgK*)
ΔT – temperaturna razlika između tople i hladne vode u *K*

U *tabeli 2. [3]* dati su podaci o prosečnim dnevnim potrebama količina tople sanitarne vode za tri nivoa potrošnje kao i potrebne energije za pripremu tople sanitarne vode određene pomoću obrasca (1)

Tabela1. *Prosečna dnevna potrošnja sanitarne vode i potrebna energija*

	Potrošnja po osobi i danu	Dnevna potrošnja energije
Niska potrošnja	20-30 tople sanitarne vode (45^0)	0,8-1,2 kWh/d
Tipična potrošnja	30-5o l tople sanitarne vode (45^0)	1,2-2 kWh/d
Visoka potrošnja	50-7o l tople sanitarne vode (45^0)	2-2,8 kWh/d
Mašina za prenje veša ili mašina za pranje sudova sa priključkom za toplu vodu	20 l tople sanitarne vode (45^0)	0,8-kWh/d

Za odgovarajuće proračune u ovom radu dat je primer dnevne i godišnje potrošnje tople sanitarne vode i potrebne energije za njenu pripremu.

Primer:
Četvoročlana porodica koja poseduje mašinu za pranje veša sa priknjučkom za toplu vodu, čija je dnevna potrošnja tople vode 20 l/d.
Dnevna potrošnja tople sanitarne vode:

$$m = 4 \cdot 50 + 1 \cdot 20 = 220 l / dan$$

Dnevna potreba energije za pripremu tople sanitarne vode:[3]

$$Q = (m \cdot c \cdot \Delta T) = 220 \cdot 1{,}16 \cdot 35 = 8932 Wh / d \approx 8{,}93 kWh / d$$

Godišnja potrošnja tople sanitarne vode:

$$m = (4 \cdot 50 + 1 \cdot 20) \cdot 365 = 80300 l / g$$

Godišnja potreba energije za pripremu tople sanitarne vode:

$$Q = 365 \cdot 8{,}93 \approx 3260 kWh / g$$

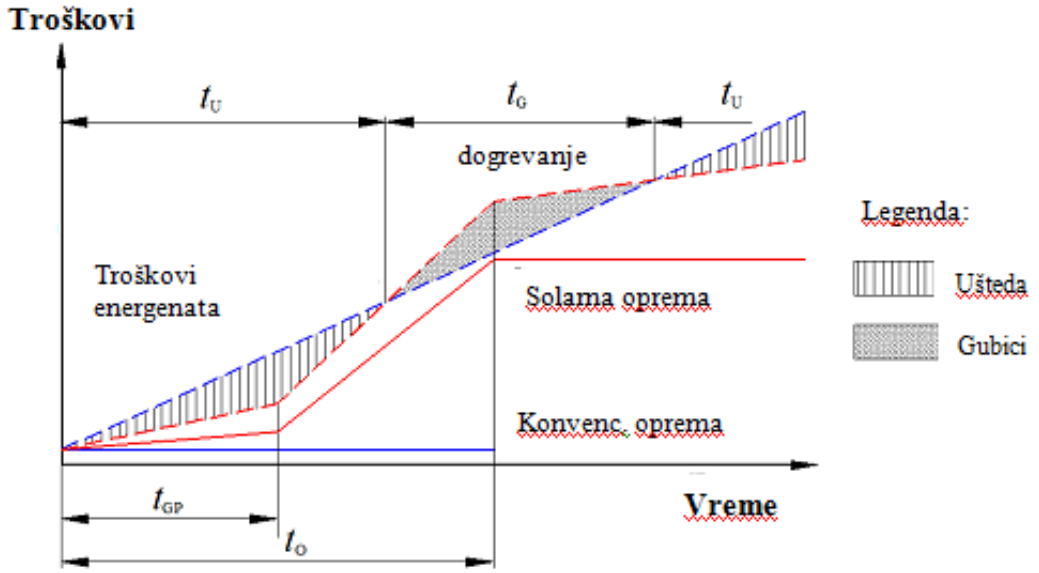
Na osnovu ovih količina u nastavku rade će biti izvršeno ispitivanje ekonomske i tehničke opravdanosti primene solarne energije za dogrevanje sanitarne vode u domaćinstvima.

5. EKONOMSKA OPRAVDANOST PRIMENE SOLARNE ENERGIJE ZA DOGREVANJE SANITARNE VODE

Kada je u pitanju korišćenje solarnih sistema za pripremu potrošne sanitarne vode, postoji niz prednosti koje mogu opredeliti njegovu primenu. Međutim, samo ekonomska isplativost može dovesti do veće primene ovih sistema.
Očekivanja su da će cena solarne opreme u budućnosti opadati, dok će se cena energenata (posebno ekološki čistih energenata) povećavati. Vek trajanja opreme kod oba sistema ne zavisi od količine potrošene vode. Ova konstatacija ne važi za mnoge tehničke sistema kao što je na primer automobil gde vek trajanja uveliko zavisi od inteziteta korišćenja (broja pređenih kilometara, prosečne brzine kretanja). Količina potrošene tople sanitarne vode po članu domaćinstva može značajno varirati od porodice do porodice.
Pre bilo kakve analize može se sa gotovo stopostotnom sigurnošću izreći sledeća tvrdnja: Ako se za bilo koju vrstu sistema, nabavlja oprema pod istim uslovima (za gotovinu ili na kredit), na početku korišćenja će ukupna ulaganja biti veća kod solarnih sistema, dok će zbog besplatne solarne energije u jednom momentu doći do izjednačavanja ukupnih troškova nakon čega će solarni sistem dovesti do određenih ušteda.

5.1. Optimalni uslovi za nabavku solarne opreme

Na *slici 8.,* prikazan je pregled troškova kada se konvencionalna oprema nabavlja za gotovinu a solarna oprema pod optimalnim uslovima kreditiranja.



Slika 8. *Pregled troškova kada se konvencionalna oprema nabavlja za gotovinu a solarna oprema pod optimalnim uslovima kreditiranja.*

Pod optimalnim uslovima kreditiranja u ovom primeru je uzeto sledeće:

- Investitor u solarnu opremu obezbeđuje učešće koje nije veće od cene konvencionalne opreme.
- Uz državnu subvenciju, banka obezbeđuje grejs period (t_{GP}), u kojem korisnik kredita plaća samo kamatu i
- Rok vraćanja kredita treba da je što duži kako bi se izbeglo veliko opterećenje korisnika.

Na *slici 8.* može se uočiti da je ovo izuzetno povoljna opcija za primenu solarne energije. Već u periodu u kome još nije otplaćena solarna oprema, dolazimo do toga da su izdvajanja za solarni sistem manja od računa za utrošenu električnu energiju (t_U). Zbog vraćanja kredita nastupiće i vremenski period u kome su veći troškovi kod solarne energije (t_G), ali ovo neće poništiti uštede koji ovako nabavljen solarni sistem donosi.

5. ZAKLJUČAK

Racionalno korišćenje energije i zamena konvencionalnih energenata obnovljivim izvorima energije je u interesu vlasnika porodičnih kuća i to iz energetskih i ekoloških razloga. Energetski razlozi su uštede koje nastaju smanjenjem korišćenja konvencionalnih energenata prirodnog gasa, lož ulja, električne struje, a ekološki razlozi su povezani sa smanjenjem emisije štetnih gasova.

U domaćinstvima Zlatiborskog okruga 80% do 85% energije troši se na zagrevanje stanova, i to u periodu kada je najmanje dostupne solarne energije. Sa sadašnjim cenama solarne opreme i uslovima za njenu nabavku, praktično se ne razmišlja o primeni solarne energije za grejanje već uglavnom za pripremu potrošne tople vode.

Malo je verovatno, masovnije korišćenje solarnih sistema od strane malih korisnika, domaćinstva sa jednim do dva stana, bez odgovarajućih posticajnih mera od strane države.

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THE USE OF PV/T SOLAR COLLECTORS FOR DOMESTIC HOT WATER PREPARATION WITHIN A RESIDENTIAL HOUSE IN THE CITY OF KRAGUJEVAC (SERBIA)

Novak Nikolić[1], Nebojša Lukić[2], Miloš Proković[3], Aleksandar Nešović[4]

Abstract: In this paper the possibility of using PV/T solar collectors for DHW preparation within a residential house in the city of Kragujevac (Serbia) was investigated. Based on the consumption profile of domestic hot water of a single family the PV/T solar system is sized to meet the demand for electricity consumed for the DHW heating during the summer season (15th of April-15th of October). The thermal behavior of the PV/T system was simulated only for the summer season, since the working medium is water. The electrical behavior of the analyzed PV/T solar system was simulated for the entire year. All simulations were performed in the EnergyPlus simulation soft-ware. Four scenarios of payback period of using PV/T solar system were investigated. All of them are defined according to the price of electricity that is saved and/or sold to the utility company: the average electricity selling price for residential houses (5.089 c€/kWh) and the electricity selling price for privileged electricity producers (20.66 c€/kWh). The first two scenarios are related to the system without solar batteries and the other two to the system with solar batteries. The most favorable scenario is scenario for which the total produced electricity is sold to the utility company for the selling price for privileged electricity producers. The payback period for this scenario is 13.7 years.

Key words: PV/T solar collector, domestic hot water, simulation, EnergyPlus.

1 INTRODUCTION

The increasing need for renewable energy sources, specifically solar energy, requires more complex research to be conducted to improve the efficiency of systems that transform solar energy. The most common solar systems are flat-plate (water) solar collectors. The men-tioned collectors transform solar energy into heat energy through

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an absorber plate with high thermal conductivity (copper, aluminum) placed in an insulated box with a flat glass cover. The main carrier of heat energy is a working fluid (water or antifreeze liquid) that passes through the absorber or absorber tubes integrated or attached to the same. Conventional flat-plate solar collectors receive a rela-tively low solar flux and have an average efficiency, especially at lower level of solar radiation. Many investigations have been carried out to improve a performance of flat-plate solar collectors by concentrating solar radiation using reflective surface [1, 2]. Also, one of the ways to increase the overall solar energy conversion efficiency is usage of a hybrid solar collectors (PV/T solar collectors). A PV/T solar collectors generate both electricity and thermal energy from a single aperture area. Many research has been conducted to model and improve the design of hybrid solar collectors [3-7]. Most residential water heating systems are equipped with conventional gas or elec-tric heaters that generate heat by consuming fossil fuels or electricity. These systems are undesirable in terms of energy utilization effi-ciency because the overall conversion efficiency into thermal energy is relatively low [8]. In relation to this, the goal of this paper is related to the investigation of the possibility of using hybrid water solar collectors for domestic hot water preparation within a single family residential house.

2 MODEL DESCRIPTION

2.1 Description of the analyzed residential building

Isometric view of the analyzed residential building is shown in Fig. 1. The total heated floor area of the building is 118.1 m^2.

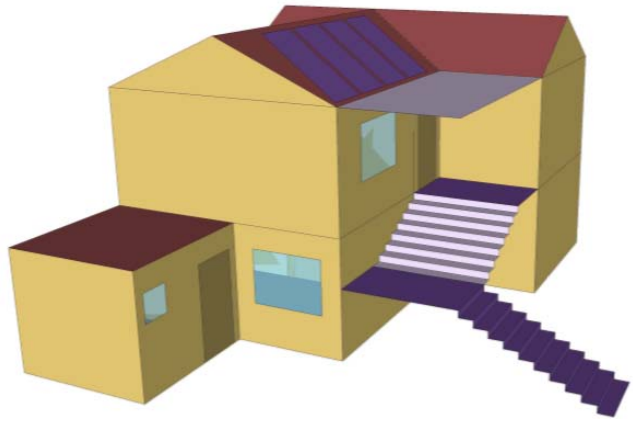


Figure 1. *Isometric view of the analyzed residential building*

The building has a total of 10 heated zones (rooms) distributed on 2 levels. It is assumed that the building located in the city of Kragujevac (Serbia) is not surrounded with any object. Total number of people that accommodates this building is four.

2.2 Description of the analyzed system for heating of domestic hot water

In this paper the possibility of using hybrid solar collectors for heating of domestic hot water was analyzed. Consumption profile of domestic hot water within the analyzed

house is given in Table 1.

Table 1. *Domestic hot water consumption*

Bathroom and kitchen	Time period [h]	Water consumption [l]
Washing, dish washing (40˚C)	06:00-06:03	12
Washing, dish washing (40˚C)	07:00-07:03	12
Meal preparation (40˚C)	08:00-08:05	7
Meal preparation (40˚C)	11:00-11:05	5
Dish washing (40˚C)	16:00-16:05	30
Showering (40˚C)	19:00-19:06	50
Showering (40˚C)	19:30-19:36	50
Showering (40˚C)	19:54-20:00	50
Face washing, brushing teeth (40˚C)	22:00-22:06	6
Laundry (50˚C)	21:00-23:27	49

The main components of the system for domestic hot water heating (Fig. 2) are: hybrid solar collectors (1), heat storage tank (3) and water heater (7). There are two water circulation loops. The first loop includes the solar collectors and heat storage tank, while the sec-ond circulation loop connects the storage tank, water heater and water consumers. The hot water from the heat storage tank circulates into the water electric heater which, if necessary, heats the water to the desired temperature.

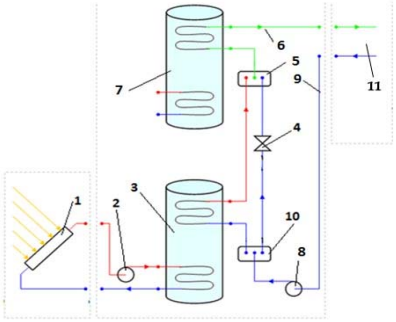


Figure 2. *Scheme of the system for domestic hot water heating*: *1-hybrid solar collectors, 2-pump, 3-heat storage tank, 4-regulating valve, 5-mixer, 6-water consumer inlet, 7-water heater, 8-pump, 9-water consumer outlet, 10-splitter, 11-water consumers*

Table 2. *The sizing parameters of the water electric heater*

Parameter	Unit	Value
Maximum flow rate of the DHW during one hour	[l/s]	0.04166
Minimum allowed temperature for water in water heater	[˚C]	10
Mean water temperature at the points of consumption	[˚C]	45
Heat loss coefficient of the water heater	-	1.1
Thermal efficiency of the electric heater	-	0.9
Number of hours for water heating	[h]	1
Number of hours for water heater operation	[h]	1
Maximum temperature for water in water heater	[˚C]	60
Factor due to unused space under the heating surface of the water heater	-	1.1
Heat capacity of the water heater (electric heater)	[W]	4000
Volume of the water heater tank	[l]	80

The heat capacity and volume of the water electric heater are determined according to the procedure described in [9]. The adopted values of the parameters needed for sizing of the water heater are given in Table 2.

The thermal and electrical power of the analyzed hybrid solar collector is determined according to the following equations:

$$Q_{TH} = A_S \cdot f_A \cdot G_T \cdot \eta_{TH} \quad (1)$$

$$P_E = A_S \cdot f_A \cdot G_T \cdot \eta_{EL} \cdot \eta_{INVERT} \quad (2)$$

It was assumed that the electric efficiency of the hybrid solar collector (η_{EL} = 0.15) is fixed throughout the year as well as the thermal efficiency (η_{TH} = 0.3). For the volume of the heat storage tank the value of 250 l was adopted. The water flow rate through the solar collector amounts 0.015 kg/sm^2. The PV/T solar collectors are sized to meet the demand for electricity consumed for the DHW prepara-tion during the summer season (15th of April-15th of October). During the winter season the PV/T solar collectors produce only electric energy since the working medium within the solar collector is water. This was the limitation of the simulation software. The total surface area of the PV/T solar collectors is 6.32 m^2. The collector tilt angle is 37.5˚ and the orientation is 180˚. This is the yearly optimal collec-tor position for the city of Kragujevac, Serbia. The technical characteristics for the investigated PV/T solar collectors are summarized in Table 3 [10].

Table 3. *The technical characteristics of the single PV/T solar collector module [10]*

Electrical characteristics	
Number of cells per module	60
Cell type (dimensions)	Monocrystalline (156 mm x 156 mm)
Nominal power	250 W_p
Module efficiency	15.4%
Rated voltage	30.7 V
Rated current	8.15 A
Open circuit voltage	38.5 V
Short circuit current	8.55 A
Maximum system voltage	1000 V DC
NOCT	49˚C
Thermal characteristics	
Gross area	1.66 m^2
Aperture area	1.58 m^2
Maximum temperature	74.7˚C
Maximum operating pressure	1.2 bar
Average thermal efficiency	30%

2.3 EnergyPlus software

In order to simulate the thermal and electrical behavior of the investigated system for domestic hot water heating, software EnergyPlus (version 8.4.0) was used. This program is very useful tool for modeling of energy and environmental behavior of buildings and HVAC systems [11]. The EnergyPlus software takes into account all factors that influence thermal loads in the building, such as electricity devices, lighting, people occupancy, solar radiation, wind, infiltration, and shading [12]. The simulations

were conducted for real weath-er data for the city of Kragujevac (latitude of 44.02˚N, longitude of 20.92˚E, the average height of the above sea level of 209 m).

2.4 Simulation scenarios

The main goal of this investigation is analysis of application of the PV/T solar collectors for DHW preparation within a single family residential house in the city of Kragujevac. This analysis is related to the payback period of using PV/T solar collectors. The payback period is determined by the value of the investment and operating costs of the DHW heating system and by energy (money) savings achieved by using the same system. Four scenarios were investigated (Table 4). All of them are defined according to the price of elec-tricity that is saved and/or sold to the state company for electricity generation and distribution. The first two scenarios are related to the system without solar batteries and the other two to the system with solar batteries.

Table 4. *Investigated scenarios for payback period of using PV/T solar system*

Scenario	PV/T solar system	Electricity selling price [c€/kWh]
1	PV/T solar system without batteries	5.089 (average electricity selling price for residential houses)
2	PV/T solar system without batteries	20.66 (electricity selling price for privileged electricity producers)
3	PV/T solar system with batteries	5.089 (average electricity selling price for residential houses)
4	PV/T solar system with batteries	20.66 (electricity selling price for privileged electricity producers)

3 RESULTS AND DISCUSSION

The electrical behavior of the analyzed PV/T solar system was simulated for the entire year, while the thermal behavior was simulated only for the summer season (15th of April-15th of October), since the working medium is water. The values of the produced electric energy of the hybrid solar collectors, consumed electric energy of the water heater with and without PV/T solar system are shown in Fig. 3.

As it was mentioned, the hybrid solar collectors are sized to meet the demand for electricity consumed for the DHW heating during the summer season. For this period the amount of produced electricity is higher than the consumed electricity of the DHW system that includes PV/T solar collectors. The highest and lowest value for the produced electricity is recorded in July and December, respectively. For these months the intensity of solar radiation on a tilted solar collector surfaces was the highest and lowest. The electricity consump-tion of the water heater without PV/T system is more than three times higher than the electricity consumption of the water heater with PV/T system. For both systems, the monthly electricity consumption is approximately the same. This is explained by the fact that it was assumed that the consumption profile of domestic hot water is the same for every day during the simulated period.

In order to determine the payback period of the investigated system for DHW preparation it is necessary to know the value of invest-ment costs. The investment costs for every component of the PV/T system are given in Table 5. In Table 6 the comparison of four ana-lyzed scenarios of payback period is shown.

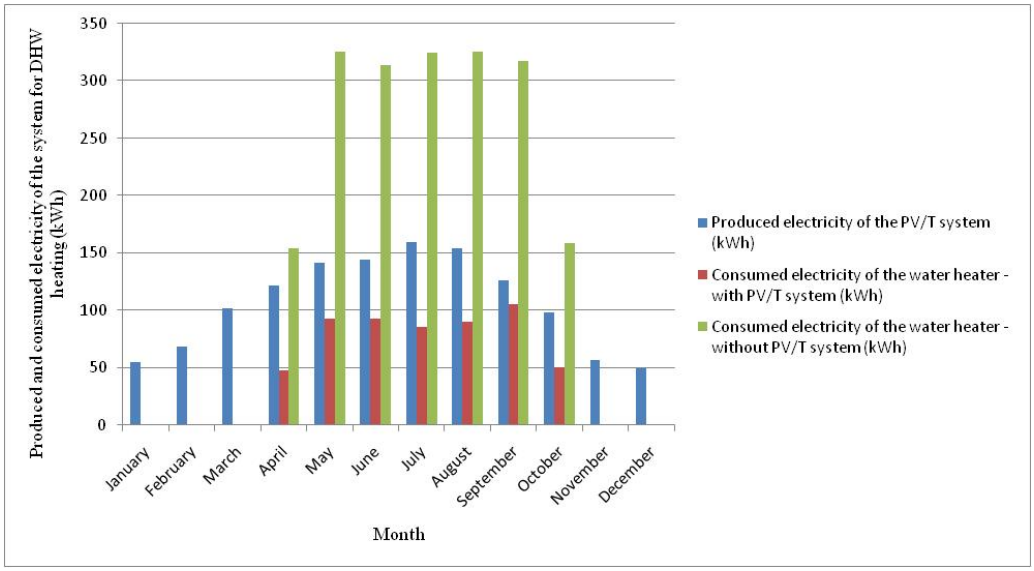


Figure 3. *Monthly values of the produced electricity of the PV/T system and consumed electricity of the water heater with and without PV/T sys-tem*

Table 5. *Investment costs for analyzed system for DHW heating*

Component	Investment costs [€]
Inverter	100 [13]
Heat storage tank	657 [14]
PV/T solar collectors	2440 [10]
Voltage controller	190 [13]
Pumps	321 [15]
Solar batteries	1360 [13]
Installation	850 [13]
Total costs for system without batteries	4558
Total costs for system with batteries	5918

Table 6. *Payback period of analyzed system for DHW heating for four investigated scenarios*

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total investment costs (€)	4558	4558	5918	5918
Electricity savings (kWh)	1356.14	1356.14	1921.15	1921.15
Electricity savings (€)	69.02	69.02	97.78	97.78
Produced electricity (kWh)	1277.25	1277.25	712.24	712.24
Produced electricity (€)	65	263.88	36.25	147.15
Money savings (€)	134.02	332.9	134.03	244.93
Payback period (years)	34	13.7	44.2	24.16

It should be noted that for the first two scenarios there are costs of consumed electricity. For the scenario 1 and 2 all produced electricity is sold to the state company for electricity generation and distribution. On the other side, for the other two cases due

to solar batteries there are no costs of consumed electricity. In other words, for the scenario 3 and 4 part of the produced electricity is used for DHW heating while the excess electricity is sold to the utility company.

According to the economic analysis it can be concluded that the most favorable scenario is scenario 2, for which the total electricity produced by the PV/T solar collectors is sold to the utility company for the selling price for privileged electricity producers. The payback period for this scenario is 13.7 years. For the city of Kragujevac (Serbia), the electricity selling price for privileged electricity producers is approximately four times higher than the average electricity selling price for residential houses. The payback period for the scenario when total produced electricity is sold for the average electricity selling price for residential houses (scenario 1) amounts 34 years. If the system for DHW heating included batteries for electricity storage the payback period would amount 44.2 years for the scenario 3 and 24.2 years for the scenario 4. The values for the payback period would be certainly lower in the case of higher electricity consumption (more expensive tariff rates), higher electricity selling price, lower investment costs as well as higher values of the thermal and electrical efficiency of a PV/T solar collectors.

4 CONCLUSIONS

In this paper the possibility of using PV/T solar collectors for heating of domestic hot water within a residential house in the city of Kragujevac (Serbia) was investigated. Based on the consumption profile of domestic hot water of a single family the PV/T solar system is sized to meet the demand for electricity consumed for the DHW heating during the summer season (15th of April-15th of October). The thermal behavior of the PV/T system was simulated only for the summer season, since the working medium is water. The electrical behavior of the analyzed PV/T solar system was simulated for the entire year. All simulations were performed in the EnergyPlus simula-tion software. Four scenarios of payback period of using PV/T solar system were investigated. All of them are defined according to the price of electricity that is saved and/or sold to the utility company. The first two scenarios are related to the system without solar batteries and the other two to the system with solar batteries. The most favorable scenario is scenario for which the total produced electricity is sold to the utility company for the selling price for privileged electricity producers (20.66 c€/kWh). The payback period for this scenario is 13.7 years. The most unfavorable scenario (44.2 years) is the scenario 3. This scenario relates to the PV/T system that consists of solar batteries and for which the excess produced electricity is sold for the average electricity selling price for residential houses (5.089 c€/kWh). The higher values of the electricity selling price, lower values of the investment costs and higher values of the thermal and electrical efficiency of a PV/T solar collectors. would certainly reduce the value of the payback period.

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NOMENCLATURE (10 PT BOLD, UPPERCASE, Spacing Before 18 pt, After 6 pt)

Q_{TH} thermal power of the hybrid solar collector, W

A_S gross area of the hybrid solar collector, m^2

f_A fraction of the surface with active PV/T solar collector

G_T intensity of the instantaneous solar radiation on a tilted solar collector surface, W/m^2

η_{TH} thermal efficiency of the hybrid solar collector;

η_{EL} electrical efficiency of the hybrid solar collector;

η_{INVERT} conversion efficiency from direct to alternating current (ηinvert = 1).

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THE INFLUENCE OF THERMAL PARAMETERS OF DIFFERENT TYPES OF SOIL ON THE CONSUMPTION OF FINAL ENERGY FOR HEATING THE LOW-ENERGY RESIDENTIAL BUILDING AND THE INVESTMENT COST OF PLACING GEOTHERMAL VERTICAL PROBES

Aleksandar Nešović[1] , Nebojša Lukić[2] , Novak Nikolić[3] , Marko Radaković[4]

Abstract: Low-energy residential buildings, from active heating systems, most often use heat pump systems in combination with geothermal vertical probes on primary and panel heaters on the secondary side. The number and depth of the wells is usually determined in practice only on the basis of the specific withdrawal rate of the soil, while parameters such as thermal conductivity and specific volume thermal capacity of the soil are neglected. The aim of this paper is to show that the thermal parameters of different types of soil characteristic for Serbia affect the consumption of final energy for heating the low-energy residential building and the investment costs of placing geothermal probes. The research was conducted by simulations in software EnergyPlus. The investment costs of installing geothermal probes are the lowest when the building is built on alluvial soil (near the river).

Key words: low-energy residential building, specific withdrawal rate of the soil, temperature conductivity of the soil, GHEV, GSHP.

1 INTRODUCTION

The global definition of a low-energy building does not exist. Because national standards vary considerably, low energy developments in one country may not meet normal practice in another. In Germany a low-energy building has an energy consumption limit of 50 kWh/m² per year for space heating. In Switzerland the term is used in connection with the MINERGIE standard – no more than 42 kWh/m² per year should be used for space heating. Right now, it is generally considered that low-energy building uses around half of energy mentioned in those standards for space heating, typically in the range from 30 kWh/m² per year to 20 kWh/m² per year [1].

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Low-energy buildings typically use high levels of insulation, energy efficient windows, low levels of air infiltration and heat recovery ventilation to lower heating and cooling energy. They may also use passive solar building design techniques or active solar technologies. These homes may use hot water heat recycling technologies to recover heat from showers and dishwashers [1]. Low-energy buildings often use GSHP in combination with a panel heating system in order to reduce operating costs and emission CO_2 [2]. Also, systems with a heat pump are often combined with other energy systems, in order to minimize the consumption of final energy [3, 4]. The operation of the heat pump is influenced by the thermal characteristics of the soil, which depend on the type of soil, which in practice is often neglected in the design phase of the system. The consequences are: oversimination of equipment, higher investment and exploitation costs, higher energy consumption for starting compressors, lower system efficiency, shorter service life. In order to avoid all this, there are works in the literature on thermal characteristics of the soil, vertical geothermal probes and their influence on the operation of the heat pump [5-7].

The aim of this paper is to show that the thermal parameters of different types of soil characteristic for Serbia affect the consumption of final energy for heating the low-energy residential building and the investment costs of placing geothermal probes.

2 DESCRIPTION OF THE BUILDING

The investigated building is a residential house of the total useful area of 198.4 m2. The house consists of two levels, two identical apartments (each of 99.2 m2). The classification number of this building is 112111 [8]. The model of the house is shown in Figure 1. Figure 2 shows the arrangement of rooms with appropriate floor area, identical for both levels.

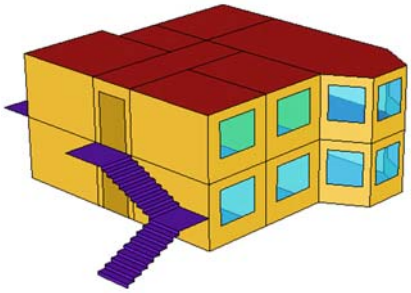


Figure 1. *Low-energy building*

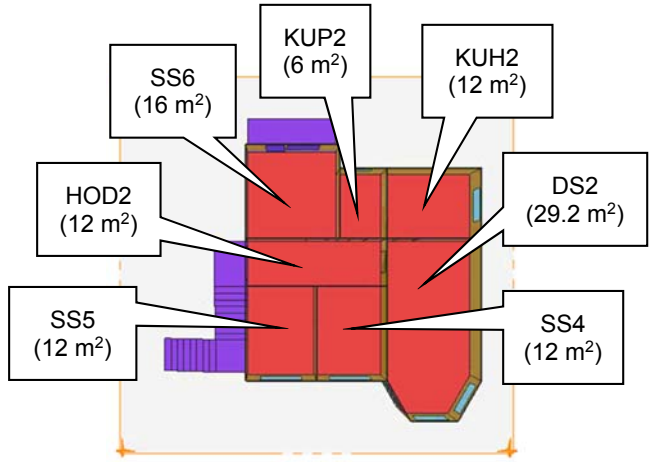


Figure 2. *The base of the second floor*

Thermal characteristics of the building constructions shown in Table 1.

Table 1. *Thermal characteristics of the building constructions* [9]

Construction	Exterior wall	Ground floor	Roof	Exterior door	Window	Interior ceiling	Interior wall
U [W/m²K]	0.172	0.203	0.312	4	1.574	0.226	1.47
U_{DOZ} [W/m²K]	0.3	0.3	0.15	1.6	1.5	0.9	0.9

3 LOCATION OF BUILDING

To simulate weather conditions, in the standard heating season (from 15th of October to 15th of April), of the city of Kragujevac (latitude of 44.02˚N, longitude of 20.92˚E, the average height of the above sea level of 209 m) the EnergyPlus weather file was used. The value of heating degree days determined for indoor temperature of 20˚C and heating threshold temperature of 12˚C, for the observed heating period is 2894. The monthly average values of the weather parameters for the city of Kragujevac are given in Table 2.

Table 2. *The monthly average values of the weather parameters for the city of Kragujevac* [10]

Month	t_{ST} [°C]	t_{VT} [°C]	I_{DIF} [W/m^2]	I_{DIR} [W/m^2]	φ [%]	α [deg]	w [m/s]
January	-0.24	-1.44	33.30	63.63	79.92	213.17	2.01
February	0.88	-0.46	49.39	86.66	79.82	210.60	2.02
March	5.57	3.29	77.08	106.12	72.06	207.98	2.35
April	10.87	7.74	92.65	149.02	67.92	209.06	2.27
May	16.06	12.18	113.30	176.45	66.57	210.08	1.77
June	18.85	14.99	109.50	208.94	69.42	209.51	1.69
July	20.78	16.04	110.60	228.12	64.49	198.04	1.62
August	20.38	15.69	96.25	215.40	64.05	211.45	1.51
September	16.68	13.30	75.54	166.92	71.21	203.79	1.68
October	11.18	8.83	57.34	119.43	76.40	222.28	1.69
November	6.08	4.45	39.83	64.51	79.80	210.38	2.06
December	1.13	0.09	28.66	58.86	83.51	208.33	1.87

4 GSHP

The functional scheme of the analyzed heating system is shown in the Figure 3.

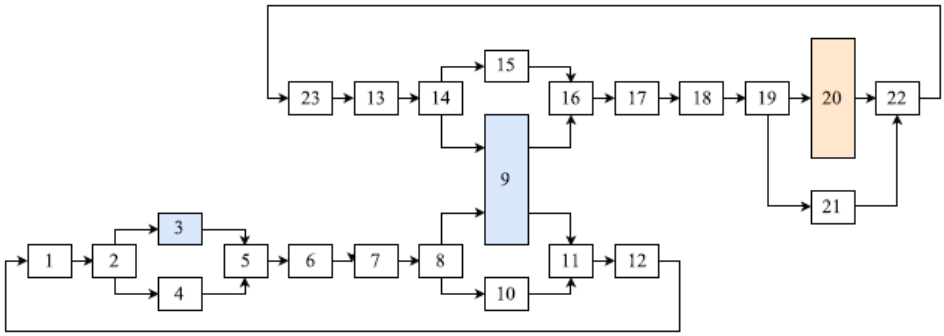


Figure 3. *Analyzed heating system*
1, 13 – circulation pump; 2, 8, 14, 19 – splitter; 3 – ground heat exchanger; 4, 10, 15, 21 – bypass branch; 5, 11, 16, 22 – mixer; 6, 12, 17, 23 – outlet pipe; 7, 18 – inlet pipe; 9 – heat pump; 20 – conditioned zones;

Based on the calculation of the thermal losses of the analyzed building, a heat pump REHAU GEO 7 was adopted. The technical characteristics of this GSHP are given in Table 3.

Table 3. *GSHP REHAU GEO 7* [11]

Parameter	$\dot{Q}_{KON}$ [W]	COP [-]	$\dot{Q}_{KOM}$ [W]	t_{S-MAS} [°C]	t_{S-I} [°C]	p_{S-MAX} [bar]	Δp_{S-MAX} [Pa]	$\dot{V}_{S-MIN}$ [l/h]	$\dot{m}_{P-MIN}$ [kg/h]
Value	7300	4.1	1600	55	37	3	15000	1100	1300

In the Energy Plus program package, a mathematical model of geothermal vertical probes developed by Yavuzturk and Spitler [12] has been implemented. They developed a model that has the ability to evaluate the probe characteristics at low time intervals. Parameters of geothermal probes are shown in Table 4, while the thermal characteristics of the working fluid on the primary side are given in Table 5.

Table 4. *Parameters of the vertical geothermal probe* [11, 12]

Parameter	R_B [m]	d_C [m]	δ_C [m]	l_C [m]	λ_I [W/mK]	λ_C [W/mK]	t_Z [°C]
Value	0.0889	0.04	0.0037	0.03	1.47	0.39	13.37

Table 5. *Operating fluid parameters on the primary side (water and antifreeze)*

Parameter	$\dot{V}_{P-MAX}$ [m^3/s]	c_P [J/kgK]	λ_P [W/mK]	ρ_P [kg/m^3]
Value	0.00036	4066	0.513	1016

5 RESULTS

According to the German standard VDI 4640 [13], which defines the orientation values of specific withdrawal rate for some types of soil (Table 6) and the thermal properties of the soil available in [14, 15], Table 7 shows the consumption of heat final energy and investment costs of installing geothermal vertical probes for 6 characteristic soil types for the Republic of Serbia.

Table 6. *Specific withdrawal rate of the soil (German standard VDI 4640)* [13]

Soil types	$\dot{q}_Z$ [W/m]	
	For 1800 h	For 2400 h
Gravel, sand, dry	< 25	< 20
Gravel, sand, water conducting	65 – 80	55 – 85
For high groundwater flow in gravel and sand	80 - 100	
Clay, loam, moist	35 – 50	30 – 40
Limestone, massive	55 – 70	45 – 60
Sandstone	65 – 80	55 – 65
Sour magnets	65 – 80	55 – 70
Base magnets	40 – 65	35 – 55
Gneiss	70 – 85	60 – 70

The investment costs for all examined cases (Table 7), including the transport of drilling equipment, drilling of the exploratory well, expansion of the exploration well, procurement, preparation and installation of the necessary equipment and trial work were determined by the company GEOING SYSTEM D.O.O [16] from Kragujevac.

Table 7. *Specific withdrawal rate of the soil (German standard VDI 4640)* [13]

Scenario	Soil types	$\dot{q}_Z$ [W/m]	n [-]	H [m]	λ_Z [W/mK]	$c_Z \cdot 10^6$ [J/m^{3}K]	Q_{KON} [kWh/y]	Investment costs [€]
S1	Dry clay	15	3	127	1.4	2.75	5065.59	18507.18
S2			4	95	1.4	2.75	5065.54	18462.95
S3			5	76	1.4	2.75	5065.41	18462.95
S4			6	64	1.4	2.75	5065.27	18639.88
S5	Sandy gravel		3	127	1.1	1.7	5064.51	18507.18
S6			4	95	1.1	1.7	5064.4	18462.95
S7			5	76	1.1	1.7	5064.19	18462.95
S8			6	64	1.1	1.7	5064.16	18639.88
S9	Clay	30	2	95	1.52	4.086	5060.65	10058.73
S10			3	64	1.52	4.086	5060.47	10147.19
S11	Limestone	45	1	127	2.54	2.16	5055.4	7272.06
S12			2	64	2.54	2.16	5053.04	7316.30
S13	Very soft and fine sandy clay	70	1	82	3.57	3.373	5048.65	5281.6
S14	Dark gray clay, sand and silt	80	1	72	4.2	4.366	5046.91	4839.26

The thermal characteristics of the soil (thermal conductivity, specific volume thermal capacity, specific withdrawal rate of the soil) significantly affect the investment costs of placing geothermal probes. For example, for the building that is built for limestone soil (eastern Serbia), the investment costs of installing geothermal probes would be 7272.06 € (1 bore hole 127 m, for house S11) or 7316.3 € (2 bore holes of 64 m, for house S12). The best option is to have a residential building built on an alluvial soil (near the river), because the investment costs of the works would amount to 4839.26 €.

6 CONCLUSION

The global definition of a low-energy building does not exist. Because national standards vary considerably, low energy developments in one country may not meet normal practice in another. Right now, it is generally considered that low-energy building uses around half of energy mentioned in those standards for space heating, typically in the range from 30 kWh/m² per year to 20 kWh/m² per year. This paper examined how the thermal properties of the soil affect the investment costs of placing geothermal probes and the consumption of final energy for heating the low-energy building during the heating season. The results showed that the investment costs of installing geothermal probes are the highest for building S1 (dry clay, 3 bore holes, 127 m) and amount to 18507.18 €. In that case the final energy consumption is 5056.59 kWh. The best case is S14 (dark gray clay, sand and silt, 1 bore hole, 72 m) because the investment costs are 4839.26 €.

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sources. We would like to thank to the Ministry of Education and Science of Republic of Serbia for their financial support during these investigations.

NOMENCLATURE

GSHP	ground source heat pump
GHEV	ground heat exchanger vertical
U	heat transfer coefficient, W/(m^2 K)
U_{DOZ}	permitted heat transfer coefficient for new buildings according to the Rulebook, W/(m^2 K)
t_{ST}	outdoor air temperature measured with a dry thermometer, °C
t_{VT}	outdoor air temperature measured with a wet thermometer, °C
I_{DIF}	diffuse solar radiation, W/m^2
I_{DIR}	direct solar radiation, W/m^2
φ	relative humid outdoor air %
α	wind direction, deg
w	wind speed, m/s
$\dot{Q}_{KON}$	heat power $GSHP$, W
COP	coefficient of performance $GSHP$
t_{S-MAS}	maximum water temperature at the entrance to the floor panel, °C
t_{S-I}	water temperature at the entrance to the floor panel, °C
p_{S-MAX}	maximum operating pressure on the secondary side, bar
Δp_{S-MAX}	maximum pressure drop on the secondary side, Pa
$\dot{V}_{S-MIN}$	minimum volume flow of the working fluid on the secondary side, l/h
$\dot{m}_{P-MIN}$	minimum mass flow of the working fluid on the primary side, kg/h
R_B	bore hole radius, m
d_C	pipe out diameter, m
δ_C	pipe thickness, m
l_C	u-tube distance, m
λ_I	grout thermal conductivity, W/(m K)
λ_C	pipe thermal conductivity, W/(m K)
t_Z	ground temperature, °C
$\dot{V}_{P-MAX}$	maximum volume flow on the primary side, m^3/s
c_P	specific heat of the working fluid on the primary side, J/(kg K)
λ_P	thermal conductivity of the working fluid on the primary side, W/(m K)

ρ_P density of the working fluid on the primary side, kg/m^3

$\dot{q}_Z$ specific withdrawal rate of the soil, W/m

n number of bore holes

H bore hole lenght, m

λ_Z thermal conductivity of the soil, W/(m K)

c_Z specific volume thermal capacity of the soil, J/(m^3 K)

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DEFINISANJE OPTIMALNOG GRADSKOG I REGIONALNOG SISTEMA UPRAVLJANJA KOMUNALNIM ČVRSTIM OTPADOM PRIMENOM METODE VIŠEKRITERIJUMSKOG ODLUČIVANJA

Saša Jovanović[1], Slobodan Savić[2], Zorica Đordjević[3], Danijela Nikolić[4], Goran Bošković[5]

Rezime: Definisanje optimalnog i održivog sistema upravljanja komunalnim čvrstim otpadom na lokalnom i posebno, regionalnom nivou, predstavlja veoma složen zadatak tokom čijeg se rešavanja donosioci odluka suočavaju sa nizom različitih problema. Definisanje osnovnih ulaznih parametara, odnosno sastava i generisanih količina komunalnog otpada predstavlja, praktično, početnu fazu rešavanja postavljenog zadatka. Izbor optimalne tehnologije podrazumeva sagledavanje uticaja velikog broja faktora, kao i specifičnosti okruženja. U ovom radu, kao deo odgovora na kompleksan zadatak ukupne kvantifikacije i rangiranja predloženih rešenja za gradski i regionalni sistem upravljanja otpadom, izabran je metod višekriterijumskog odlučivanja (MCDM). Fazi valorizacije alternativnih opcija i samom izboru optimalne varijante za oba sistema, prethodilo je definisanje i izbor relevantnih kriterijuma. Pritom se posebno vodilo računa o definisanju i izboru kriterijuma, kao i određivanju njihovih težinskih koeficijenata. Softverski alat za podršku metodi višekriterijumskog odlučivanja, DSS (Decision Support Software), je upotrebljen za ocenu i rangiranje četrdeset osam scenarija za budući gradski i regionalni sistem upravljanja komunalnim otpadom.

Ključne reči: Komunalni čvrsti otpad, upravljanje otpadom, višekriterijumsko odlučivanje, MCDM

DEFINING AN OPTIMAL CITY AND REGIONAL MUNICIPAL SOLID WASTE MANAGEMENT SYSTEM BY USING MULTI-CRITERIA DECISION MAKING METHOD

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Abstract: Defining an optimal and sustainable municipal solid waste management system at a local and regional level is a very complex task. In order to solve this task, decision-makers have to face different problems. Defining basic input parameters, i.e. the content and generated amount of the municipal waste practically presents the initial phase of the solution. The choice of the optimal technology involves taking into account a large number of factors, as well as the specific characteristics of the given area. In this paper, the method of multi-criteria decision making (MCDM) has been chosen to quantify and rank the proposed solutions for the city and regional waste management system. Prior to valorisation of the alternatives and the choice of the optimal variant, relevant criteria had to be defined. A special attention was paid to the choice and definition of the criteria and determination of their weight coefficients. Decision Support Software (DSS) was used to assess and rank forty-eight scenarios for future city and regional municipal waste management system.

Key words: Municipal solid waste, waste management, multi-criteria decision making, MCDM

1 UVOD

Izbor optimalnog i održivog sistema upravljanja komunalnim čvrstim otpadom na lokalnom i regionalnom nivou, predstavlja kompleksan proces u okviru koga se donosioci odluka suočavaju sa brojnim izazovima i usaglašavanjem niza protivurečnosti. Imajući u vidu da postojeće stanje u našoj zemlji značajno odstupa od prakse razvijenih zemalja, otvara se relativno veliki prostor za njegovo unapređenje.

Definisanje sistema i njegovih osnovnih ulaznih parametara predstavlja praktično početnu fazu postupka. Koncepcije budućih sistema upravljanja otpadom treba da se, u najvećoj mogućoj meri, oslanjaju na savremena rešenja i primere dobre prakse. Stanje u sektoru upravljanja komunalnim otpadom u Republici Srbiji, karakteristike postojećeg lokalnog sistema, kao i procena postojeće i potrebne infrastrukture, takođe, predstavljaju neke od polaznih tačaka u procesu.

Sveobuhvatna analiza prethodno navedenih segmenata treba da rezultira predlogom određenog broja alternativnih rešenja koja, kao takva, ulaze u proces ocenjivanja njihovih relevantnih performansi. Alternativna rešenja se definišu u skladu sa primerima dobre prakse, kao i stanjem postojeće lokalne infrastrukture u sektoru upravljanja otpadom. U okviru takvih varijantnih rešenja, mora se predvideti maksimalno efikasan i održiv tretman svih frakcija komunalnog čvrstog otpada. Ulazni parametri, kao što su količina i sastav generisanog otpada, predstavljaju značajan uticajni faktor u početnom koncipiranju sistema upravljanja otpadom.

U okviru postupka višekriterijumskog odlučivanja [1], primenjenog u radu, uključen je širok spektar kriterijuma, koji se mogu grupisati u nekoliko glavnih kategorija:

1. ekološki kriterijumi,
2. energetski kriterijumi,
3. ekonomski kriterijumi,
4. sociološki kriterijumi i
5. kriterijumi iz oblasti zakonske regulative.

Neophodno je da svaki od kriterijuma dobije odgovarajući težinski koeficijent, na osnovu koga će vršiti svoj relativni uticaj u fazi vrednovanja (ocenjivanja) alternativnih rešenja. Za potrebe modeliranja, simulacije i vrednovanja određenog broja mogućih varijantnih rešenja u radu je korišćen softverski alat DSS [2].

2 DEFINISANJE SISTEMA I OSNOVNI ULAZNI PARAMETRI

Za potrebe istraživanja u ovom radu, definisana su dva različita sistema upravljanja komunalnim čvrstim otpadom. U okviru prvog, modeliran je sistem upravljanja komunalnim otpadom, koji bi se odnosio na grad Kragujevac. Drugi sistem je koncipiran na bazi teritorijalnih smernica navedenih u Nacionalnoj strategiji upravljanja otpadom 2010. – 2019. [3]. S tim u vezi, razmatrane su opcije upravljanja otpadom za teritorijalnu oblast (u daljem tekstu Region), koja, pored Kragujevca kao regionalnog centra za upravljanje komunalnim otpadom, obuhvata i opštine Aranđelovac, Gornji Milanovac, Topolu i Knić. U tabeli 1 predstavljeni su osnovni podaci, za grad Kragujevac i Region [4].

Tabela 1. *Osnovni podaci za grad Kragujevac i Region*

	GRAD KRAGUJEVAC	**REGION**
Broj stanovnika	179.417	320.000*
Proračunski period (vremenski horizont)	2014 – 2034	2014 – 2034
Produkcija otpada po stanovniku (kg/dnevno)	0,75	1,25
Godišnja stopa rasta produkcije otpada	1,5	1,5

U tabeli 1, broj stanovnika za grad Kragujevac u skladu je sa rezultatima popisa stanovništva u Republici Srbiji iz 2011. godine. Vrednost generisane količine otpada predstavlja rezultat obrade i sistematizacije podataka višegodišnjeg evidentiranja i merenja masenih tokova otpada koja su sprovedena u okviru postojećeg sistema upravljanja komunalnim otpadom na teritoriji grada Kragujevca [5]. Jedinična produkcija otpada na nivou Regiona, uvećana je u odnosu na odgovarajuću vrednost za grad Kragujevac. Treba istaći da ovaj nivo produkcije može da se prihvati u kontekstu očekivanih trendova u bliskoj budućnosti, vezanih za promene u načinu života i standardu stanovništva. Sa druge strane, u svrhu istraživanja, hipotetičkim povećanjem jedinične produkcije komunalnog čvrstog otpada, na teritoriji sa 320.000 stanovnika, stiču se uslovi da se u razmatranje uključe i opcije termičkog tretmana otpada. Naime, izvodljivost, odnosno ekonomska opravdanost izgradnje postrojenja za insineraciju otpada, uslovljena je odgovarajućom količinom otpada koja je neophodna da bi investiciona ulaganja bila u zoni isplativosti.

Neki od osnovnih ciljeva koje svaki od predloženih i odabranih alternativnih scenarija mora da ispuni, a u kontekstu obima deponovanog otpada i nivoa reciklaže (izdvajanja materijala iz otpada), definisani su u skladu sa zakonskom regulativom Evropske unije, budući da je Republika Srbija u statusu kandidata za članstvo u EU od januara 2014. godine. Usklađenost je izvršena prema odredbama Okvirne direktive o otpadu (Waste Framework Directive, 2008/98/EC), Direktive o deponijama (Landfill Directive, 1999/31/EC), kao i Direktive o ambalažnom otpadu (Packaging Directive, 94/62/EC).

Ukupan obim reciklaže za komunalni otpad predviđen je na nivou od 54,39%, a samo za ambalažni otpad 79,35% (tabela 2). Ove vrednosti su dobijene kao suma proizvoda masenog udela pojedinačne frakcije u celokupnom otpadu [5] i usvojenog procenta planiranog izdvajanja određenog materijala (tabela 2). Istovremeno, na

osnovu odredbi Direktive o deponijama (1999/31/EC), kao i Uredbe o odlaganju otpada na deponije (Službeni glasnik Republike Srbije 92/2010), obim deponovanog biorazgradivog i ukupnog komunalnog čvrstog otpada, do 2020. godine potrebno je svesti na nivo od 35% količina iz 1995. godine. Treba istaći da za grad Kragujevac i analizirani Region nisu evidentirani pouzdani podaci o komunalnom čvrstom otpadu za 1995. godinu. Otuda, ove vrednosti su dobijene ekstrapolacijom raspoloživih aktuelnih podataka i usvojene stope rasta produkcije komunalnog otpada.

Tabela 2. *Količine otpada i procenat reciklaže za referentnu 2020. godinu*

DIREKTIVA O DEPONIJAMA				
Komunalni otpad	Odloženo na deponiju (u tonama)		Preusmereno sa deponije (u tonama)	
	Kragujevac	Region	Kragujevac	Region
Biorazgradivi	8.873	26.376	27.911	82.967
Ukupno	13.547	40.268	42.611	126.667

DIREKTIVA O AMBALAŽNOM OTPADU						
Materijal	Papir	Staklo	Metal	Plastika	Drvo	Ukupno (>60%)
Procenat izdvajanja	80	80	80	80	60	**79,35**

OKVIRNA DIREKTIVA O OTPADU							
Frakcija otpada	Organski	Baštenski	Papir i karton (amb.) >60%	Papir (ostalo)	Drvo (amb.) >15%	Drvo (ostalo)	Staklo (amb.) >60%)
Procenat izdvajanja	50	50	80	30	60	30	80
Frakcija otpada	Staklo (ostalo)	Metal (amb.) >50%	Metal (ostalo)	Plastika (amb.) >22,5%	Plastika (ostalo)	Ostali otpad	Ukupno (>50%)
Procenat izdvajanja	30	80	30	80	30	30	**54,39**

U tabeli 3 prikazani su potrebni kapaciteti predviđenih postrojenja za tretman komunalnog otpada za oba razmatrana sistema.

Tabela 3. *Potrebni kapaciteti postrojenja za tretman komunalnog otpada*

Potrebni kapaciteti postrojenja (u tonama, KG- Kragujevac, R- Region)										
God.	**Ukupna količina otpada**		**Ambalažni otpad (izdvojen na izvoru)**		**Biorazgradivi otpad (izdvojen na izvoru)**		**Mešani otpad**		**Ostali otpad**	
	KG	R	KG	R	KG	R	KG	R	KG	R
1995	38.704*	115.053*	-	-	-	-	-	-	-	-
2014	51.359	152.669	15.466	45.975	10.970	32.610	23.425	69.632	1.498	4.452
2020	56.158	166.935	16.912	50.271	11.995	35.657	25.614	76.139	1.638	4.868
2034	69.173	205.623	20.831	61.922	14.775	43.921	31.550	93.784	2.017	5.996

*ne postoje podaci, ekstrapolirana vrednost

U skladu sa iskustvom i savremenim rešenjima u razvijenim zemljama, uzimajući u obzir trenutno stanje u oblasti upravljanja otpadom u Republici Srbiji, na

lokalnom i regionalnom nivou, kao i odgovarajuće karakteristike otpada, u svrhu analize, odabrane su sledeće tehnologije tretmana:

1) Kompostiranje,
2) Anaerobna digestija (AD),
3) Postrojenja za izdvajanje materijala (separacija i reciklaža) (MRF),
4) Mehaničko - biološki tretman (sa opcijom kompostiranja dela mešanog otpada) (MBT),
5) Mehaničko - biološki tretman (sa opcijom anaerobne digestije dela mešanog otpada) (MBT),
6) Biološko sušenje mešanog otpada,
7) Spaljivanje – insineracija mešanog otpada.

Kroz formiranje relativno velikog broja scenarija, svaka od navedenih tehnologija (postrojenja) za tretman mešanog dela otpada je uključena u bar neko od varijantnih rešenja. Na taj način je sprovedena i odgovarajuća valorizacija primene tih tehnologija, i ocenjen stepen kompatibilnosti sa tehnologijama tretmana ostalih frakcija komunalnog otpada. Treba napomenuti da je, iz razloga kapacitativnih ograničenja, postrojenje za insineraciju uključivano samo u predložena rešenja za regionalni sistem upravljanja otpadom.
Predviđena mogućnost instalacije dva postrojenja za tretman mešane komponente otpada je iskorišćena u gotovo polovini kreiranih scenarija.

U okviru dvadeset četiri scenarija za Kragujevac, u trinaest je za tretman biološkog otpada korišćen proces kompostiranja, a u jedanaest proces anaerobne digestije, Potpuno isti odnos zastupljenosti ove dve vrste tretmana je i kod scenarija upravljanja otpadom formiranih i za Region. Ambalažni otpad je u svim scenarijima usmeravan u postrojenja za sekundarnu separaciju. Što se tiče mešanog otpada, dominantna je tehnologija mehaničko – biološkog tretmana. Ovaj vid tretmana je primenjen u jednom od dva predviđena postrojenja i to u dvadeset tri scenarija za grad i dvadeset jedan za Region. Biološko sušenje mešanog otpada je predviđeno u četrnaest scenarija za grad i u pet za Region. Insineracija kompletnog dela mešanog otpada je primenjena samo u jednom scenariju za upravljanje otpadom na nivou Regiona. Spalionica, kao primarno postrojenje za tretman mešane komponente komunalnog otpada, predviđena je u još jednom scenariju (4R), gde se određeni deo ovog tipa otpada tretira kroz proces biološkog sušenja. Proces spaljivanja preostalog mešanog otpada u okviru eventualnog sekundarnog postrojenja čini sastavni deo četiri predložena alternativna rešenja za regionalni sistem.

Dva postrojenja za tretman mešanog otpada, predviđena su u ukupno trinaest scenarija za grad i deset za Region.

RDF i SRF (gorivo iz otpada i čvrsta goriva masa iz otpada) su, u predloženim rešenjima gradskog sistema upravljanja komunalnim čvrstim otpadom, šesnaest puta iskorišćeni za dobijanje energije iz otpada dok je, u preostalih osam varijanti, planirano njihovo deponovanje. U slučaju regionalnog sistema, ovi produkti su sedam puta transportovani na deponiju a devet puta su predstavljali energetsko gorivo. U šest scenarija, koji uključuju opciju spaljivanja preostalog mešovitog otpada, ove komponente se i ne pojavljuju u procesu.

U tabelama 4 i 5 korišćene su sledeće skraćenice: TBO (tretman biološkog otpada), TAO (tretman ambalažnog otpada), TMOT1 (tehnologija za postrojenje 1 za tretman mešanog otpada), TMOT2 (tehnologija za postrojenje 2 za tretman mešanog otpada), komp. (kompostiranje), rec. (reciklaža), %1 (procenat mešanog otpada koji se tretira u postrojenju 1) i %2 (procenat mešanog otpada koji se tretira u postrojenju 2).

Tabela 4. *Alternativni scenariji upravljanja otpadom za grad Kragujevac*

GRAD KRAGUJEVAC (Ukupna količina otpada: 56 158 t)							
Scenario	Tehnologija tretmana otpada za:						
	Biološki otpad (11 995 t)	**Ambalažni otpad** (16 912 t)	**Preostali, mešani rezidualni otpad** (25 614 t)				**Ostali otpad** (1 638 t)
	TBO	TAO	TMOT1	% 1	TMOT2	% 2	RDF/SRF tretman
1G	Kompostiranje	MRF postrojenje	MBT (komp., rec.)	100	-	0	Deponovanje
2G	Kompostiranje	MRF postrojenje	MBT (komp. RDF)	100	-	0	Deponovanje
3G	Kompostiranje	MRF postrojenje	MBT (AD, rec.)	100	-	0	Deponovanje
4G	Kompostiranje	MRF postrojenje	MBT (AD, RDF)	100	-	0	Deponovanje
5G	AD	MRF postrojenje	MBT (komp., rec.)	100	-	0	Otpad u energiju
6G	AD	MRF postrojenje	MBT (AD, RDF)	100	-	0	Otpad u energiju
7G	Kompostiranje	MRF postrojenje	MBT (komp., rec.)	80	Biološko sušenje	20	Otpad u energiju
8G	AD	MRF postrojenje	MBT (AD, rec.)	80	Biološko sušenje	20	Otpad u energiju
9G	Kompostiranje	MRF postrojenje	Biološko sušenje	100	-	0	Deponovanje
10G	Kompostiranje	MRF postrojenje	MBT (komp. RDF)	75	Biološko sušenje	25	Otpad u energiju
11G	Kompostiranje	MRF postrojenje	MBT (komp., rec.)	50	Biološko sušenje	50	Deponovanje
12G	AD	MRF postrojenje	Biološko sušenje	51	MBT (AD, rec.)	49	Otpad u energiju
13G	AD	MRF postrojenje	Biološko sušenje	60	MBT (komp., rec.)	40	Deponovanje
14G	AD	MRF postrojenje	Biološko sušenje	60	MBT (komp., RDF)	40	Otpad u energiju
15G	Kompostiranje	MRF postrojenje	MBT (AD, RDF)	60	Biološko sušenje	40	Otpad u energiju
16G	AD	MRF postrojenje	MBT (komp., RDF)	80	Biološko sušenje	20	Otpad u energiju
17G	Kompostiranje	MRF postrojenje	MBT (komp., rec.)	100	-	0	Otpad u energiju
18G	Kompostiranje	MRF postrojenje	MBT (AD, rec.)	100	-	0	Otpad u energiju
19G	Kompostiranje	MRF postrojenje	MBT (komp., rec.)	50	Biološko sušenje	50	Otpad u energiju
20G	AD	MRF postrojenje	Biološko sušenje	60	MBT (komp., rec.)	40	Otpad u energiju
21G	AD	MRF postrojenje	MBT (komp., rec.)	100	-	0	Deponovanje
22G	AD	MRF postrojenje	MBT (komp., rec.)	80	Biološko sušenje	20	Otpad u energiju
23G	AD	MRF postrojenje	MBT (komp., rec.)	50	Biološko sušenje	50	Otpad u energiju
24G	Kompostiranje	MRF postrojenje	MBT (komp., RDF)	100	-	0	Otpad u energiju

Tabela 5. *Alternativni scenariji upravljanja otpadom za Region*

REGION (Ukupna količina otpada: 166 935 t)							
Scenario	Tehnologija tretmana otpada za:						
	Biološki otpad (35 657 t)	**Ambalažni otpad** (50 271 t)	**Preostali, mešani rezidualni otpad** (76 139 t)				**Ostali otpad** (4 868 t)
	TBO	TAO	TMOT1	% 1	TMOT2	% 2	RDF/SRF tretman
1R	Kompostiranje	MRF postrojenje	MBT (komp., rec.)	100	-	0	Deponovanje
2R	Kompostiranje	MRF postrojenje	MBT (komp. RDF)	100	-	0	Deponovanje
3R	Kompostiranje	MRF postrojenje	MBT (AD, RDF)	100	-	0	Otpad u energiju
4R	Kompostiranje	MRF postrojenje	Insineracija	60	Biološko sušenje	40	-
5R	AD	MRF postrojenje	MBT (komp., rec.)	100	-	0	Otpad u energiju
6R	Kompostiranje	MRF postrojenje	Insineracija	100	-	0	-
7R	Kompostiranje	MRF postrojenje	MBT (komp., rec.)	40	Insineracija	60	-
8R	AD	MRF postrojenje	MBT (komp., rec.)	40	Insineracija	60	-
9R	Kompostiranje	MRF postrojenje	Biološko sušenje	100	-	0	Deponovanje
10R	AD	MRF postrojenje	MBT (komp., rec.)	40	Insineracija	60	-
11R	Kompostiranje	MRF postrojenje	MBT (komp. RDF)	75	Biološko sušenje	25	Otpad u energiju
12R	Kompostiranje	MRF postrojenje	MBT (AD, RDF)	40	Insineracija	60	-
13R	Kompostiranje	MRF postrojenje	MBT (komp., rec.)	50	Biološko sušenje	50	Deponovanje
14R	AD	MRF postrojenje	Biološko sušenje	75	MBT (AD, rec.)	25	Otpad u energiju
15R	Kompostiranje	MRF postrojenje	MBT (komp. RDF)	40	Insineracija	60	-
16R	AD	MRF postrojenje	MBT (AD, RDF)	40	Insineracija	60	-
17R	Kompostiranje	MRF postrojenje	MBT (komp., rec.)	100	-	0	Otpad u energiju
18R	Kompostiranje	MRF postrojenje	MBT (komp. RDF)	100	-	0	Otpad u energiju
19R	AD	MRF postrojenje	MBT (komp., rec.)	100	-	0	Deponovanje
20R	AD	MRF postrojenje	MBT (komp. RDF)	100	-	0	Deponovanje
21R	AD	MRF postrojenje	MBT (komp. RDF)	100	-	0	Otpad u energiju
22R	AD	MRF postrojenje	MBT (AD, rec.)	100	-	0	Deponovanje
23R	AD	MRF postrojenje	MBT (AD, rec.)	100	-	0	Otpad u energiju
24R	AD	MRF postrojenje	MBT (AD, RDF)	100	-	0	Otpad u energiju

3 MULTIPARAMETARSKA ANALIZA I VIŠEKRITERIJUMSKO ODLUČIVANJE

U skladu sa navedenim projektovanim ciljevima, definisani su i odgovarajući kriterijumi u okviru procesa simulacije i vrednovanja alternativnih tehnologija upravljanja komunalnim čvrstim otpadom. Ovi kriterijumi se mogu svrstati u sledećih pet kategorija [6]:

1) *Ekološki kriterijumi* (emisije gasova staklene bašte, emisije sumpor-dioksida, ušteda konvencionalnih goriva, generisanje otpadnih voda, potrošnja vode, produkcija neopasnog otpada, produkcija opasnog otpada, zagađenje bukom),
2) *Tehničko – energetski kriterijumi* (postojeće iskustvo – pouzdanost, prilagodljivost lokalnim uslovima, fleksibilnost, energetska potrošnja, energetska produkcija, sekundarni proizvodi, povezanost sa reciklažnim aktivnostima),
3) *Ekonomski kriterijumi* (kapitalni troškovi, troškovi funkcionisanja i održavanja, prihodi od proizvoda, potrebna površina zemljišta, tržišno stanje proizvoda, eksterni troškovi i dobiti),
4) *Sociološki kriterijumi* (društvena prihvatljivost, vizuelni uticaj, prihvatanje rizika, kvalitet zapošljavanja, stvaranje novih radnih mesta) i
5) *Zakonsko – regulativni kriterijumi* (usklađivanje sa prioritetima domaćeg i zakonodavstva EU, doprinos dostizanju ciljeva Direktive o deponijama).

Da bi se sprovela efikasna i pouzdana simulacija izabranih scenarija upravljanja otpadom, potrebno je definisati rejtinge i težinske koeficijente za svaki od pojedinačnih kriterijuma. Vrednost rejtinga može da varira od 0 (potpuno nevažno) do 100 (maksimalno važno). Težinski koeficijenti, zavisno od odgovarajuće vrednosti rejtinga i ukupnog broja kriterijuma, predstavljaju relativnu vrednost uticaja pojedinačnog kriterijuma. U preliminarnoj fazi simulacija, korišćene su preporučene vrednosti, nastale kao rezultat analiza i istraživanja sprovedenih za susedne zemlje članice Evropske unije [6]. Tokom glavne faze procesa simulacije, izvršeno je specifično variranje rejtinga i težinskih koeficijenata, sa ciljem utvrđivanja uticaja važnosti pojedinih vrsta kriterijuma. Tokom postupka koncipiranja jednog složenog sistema upravljanja komunalnim otpadom, realno je očekivati izvestan sukob interesa različitih učesnika u procesu. Otuda, varijacijom vrednosti rejtinga i težinskih koeficijenata može se uporediti veličina uticaja tih promena što će, u krajnjoj instanci, svakako pružiti dodatne korisne informacije donosiocima konačnih odluka.

U okviru analize i ocenjivanja predloženih scenarija definisano je ukupno 26 različitih kriterujuma kroz simuliranje 5 varijanti različitih vrednosti rejtinga i težinskih koeficijenata. Svaka od varijanti je predviđala dodeljivanje prioriteta (odnosno povećanja vrednosti rejtinga i težinskih koeficijenata) pojedinim grupama kriterijuma (ekološkim, tehničko energetskim itd.) [4].

Treba istaći da je, zbog ograničenog broja scenarija koji u okviru jedne analize mogu da se uporede, u preliminarnoj fazi simulacija uvek vršena zatvorena analiza za po osam alternativnih rešenja (razmatranje relativno malog broja alternativa je karakteristično za sve metode višeatributskog odlučivanja u koje spada i PROMETHEE metoda, na bazi koje je koncipiran softverski paket DSS). U cilju poređenja scenarija koji, u preliminarnoj fazi nisu pripadali istoj grupi, ova algoritamska specifičnost je prevaziđena naknadnim, parcijalnim, poređenjima varijantnih rešenja sa bliskim vrednostima ocena. Konačno, poređenjem ocena svih četrdeset osam scenarija (u okviru dve podgrupe, 24 + 24), izvršen je izbor od po devet najbolje ocenjenih scenarija za grad Kragujevac i Region. Na kraju, u okviru tih grupa, konačno su rangirani scenariji.

Tehnologije tretmana i količine otpada za pojedine vrste otpada, za najbolje ocenjene scenarije za oba sistema (17G i 17R), predstavljene su u tabeli 6. U tabeli 7, prikazani su maseni bilansi za ta dva scenarija.

Tabela 6. *Tehnologije i količine tretiranog otpada za najbolje rangirane scenarije*

Scenario	**Vrsta otpada**				
	Biološki otpad	**Ambalažni otpad**	**Preostali mešani otpad**	**Mešani otpad Postrojenje 1**	**RDF/SRF**
17G	Kompostiranje (11.995 t)	MRF postrojenje (16.912 t)	MBT (kompostiranje i reciklaža) (25.614 t)	100 %	Otpad u energiju
17R	Kompostiranje (35.657 t)	MRF postrojenje (50.271 t)	MBT (kompostiranje i reciklaža) (76.139 t)	100 %	Otpad u energiju

Tabela 7. *Maseni bilansi kod najbolje ocenjenih scenarija*

M A S E N I B I L A N S (za dva najbolja scenarija)		
(u tonama)	Scenario 17G	Scenario 17R
Ukupno reciklirano	18.643	55.417
Fe	1.207	3.587
Al	234	696
Plastika	7.081	21.048
Papir	8.351	24.825
Staklo	1.358	4.036
Drvo	412	1.226
RDF	3.785	11.250
SRF	0	0
Kompost (nizak kvalitet)	3.838	11.410
Kompost (visok kvalitet)	4.198	12.480
Biogas	0	0
Gubici	12.715	37.796
Rezidue, ostaci	11.341	33.713

4 ZAKLJUČAK

Stanje u sektoru upravljanja otpadom, prepoznato je kao jedan od ključnih problema zaštite životne sredine. Izbor optimalne tehnologije podrazumeva

sagledavanje uticaja velikog broja faktora, kao i specifičnosti okruženja [7]. Veliki broj i raznovrsnost kriterijuma za vrednovanje performansi sistema upravljanja otpadom, nameće potrebu za primenom složenih metoda i alata koji treba da pomognu donosiocima odluka prilikom procedure izbora optimalnih rešenja. Za sistem upravljanja komunalnim otpadom na teritoriji grada Kragujevca, najpovoljniju alternativu predstavlja scenario sa oznakom 17G. U okviru ovog sistema, za tretman biološkog otpada predviđen je proces kompostiranja, za tretman ambalažnog otpada MRF postrojenje, dok je za tretman mešanog otpada planirana izgradnja samo jednog postrojenja, koje uključuje mehaničko–biološki tretman sa kompostiranjem organske komponente otpada, kao i reciklažu reciklabilnih materijala. RDF i SRF komponente se, prema ovom scenariju, usmeravaju u postrojenja za dobijanje energije. Na nivou Regiona, najbolje ocenjeni scenario je 17R. Proces kompostiranja biološkog otpada pokazao se kao relativno superioran u pogledu uticaja na opšte performanse sistema. Pod odgovarajućim okolnostima i u skladu sa određenim interesima, i postupak anaerobne digestije daje visoko rangirane rezultate.

ZAHVALNOST

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INOVATIVNI BIONIČKI SISTEMI U KONTEKSTU ODRŽIVOG RAZVOJA I KVALITETA ŽIVOTNE SREDINE

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Rezime: U ovom referatu su obrađeni bionički inovativni sistemi kroz najsavremenije principe, stilove, matematičke modele projektovanja i ekostabilno korišćenje energije. Bionička gradnja je suprotnost „tradicionalnoj“ kompoziciji pravougaonih zapremina. Novi fokus se istražuje kroz estetske i ekonomske aspekte i principe održivosti u skladu sa životnom sredinom. Bionička gradnja je eko-filozofska sinergija načela životne sredine i inženjerstva, koji se zajednički primenjuju u stvaranju novih formi i novih objekata, u ravnoteži i skladu sa održivim razvojem. Bionika otvara široke mogućnosti razvoja multidisciplinarnih, interdisciplinarnih i intradisciplinarnih nauka, kao što su konstrukcijska bionika, transformacijska i informacijska bionika. Jačaju se korelacione veze formi iz životne sredine i graditeljstva. Istraženi su prenos “prirodnih izuma” u konstrukcije, podele i primeri, kao i matematički i metodološki aspekti bionike, prikriveni matematički principi, metode u bioničkom dizajniranju, Aalborg metod, biomimikrijski metod, spirala dizajna, bio-inspirisan metod dizajniranja i inverzni metod. Bioničke inovacije su date kroz niz modelskih primera iz savremene svetske prakse novoprojektovanih i najnovijih izvedenih objekata.

Ključne reči: bionika, inovacije, konstrukcije, projektovanje, životna sredina.

INNOVATIVE BIONIC SYSTEMS IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT AND ENVIRONMENTAL QUALITY

Abstract: Bionic innovative systems are processed in this paper, through the most up-to-date principles, styles, mathematical models of design, and ecostable use of energy. Bionic construction is the opposite of the "traditional" composition of rectangular shapes. New focus is explored through aesthetic and economic aspects and sustainability principles in a harmony with the environment. Bionic construction is an

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eco-philosophical synergy of the principles of environment and engineering, which are commonly applied in the creation of new forms and new facilities, in balance and in accordance with sustainable development. Bionic opens wide possibilities for development of multidisciplinary, interdisciplinary and intradisciplinary sciences, such as structural bionics, transformation and information bionics. Correlation ties between forms from the environment and construction are strengthened. The transfer of "natural inventions" into constructions, divisions and examples, as well as the mathematical and methodological aspects of bionics, hidden mathematical principles, methods in bionic design, Aalborg method, biomimicry method, spiral design, bio-inspired design method and inverse method were investigated. Bionic innovations are given through a series of model examples from the modern world practice of cutting age designed and newly constructed structures.

Key words: bionics, innovation, construction, design, environment.

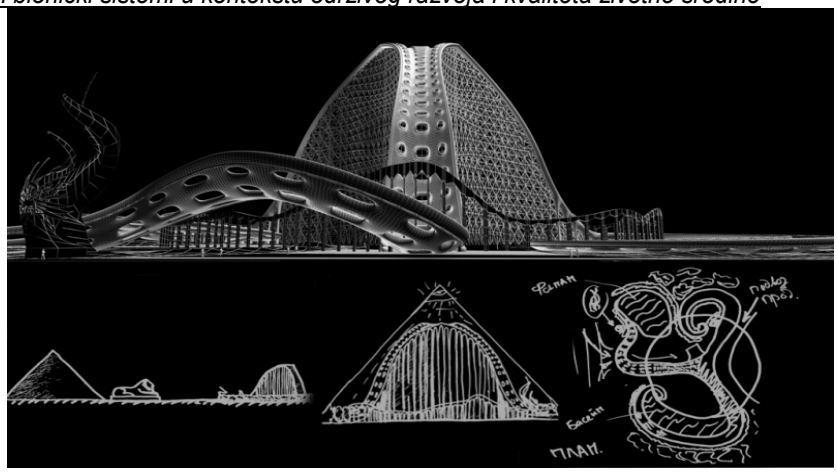
1. UVOD

Bionika je nova grana nauke, koja svojim inovativnim formama sve više potiskuje tradicionalne forme projektovanja. Reč bionika je relativno nov pojam u srpskom jeziku, a nastala je od grčke reči „bion“, što znači osnovni elemenat života, živeći. Pojam bionika je najčešće usvojen naziv za novu primenjenu nauku o tehničkim rešenjima, zasnovanim na osnovnim principima organizacije, osobina, funkcija i struktura žive prirode. Bionika, biometrika ili kreativni biološki inženjering je skup metoda i sistema koji postoje i javljaju se u prirodi, a koriste u inženjerstvu i novim tehnologijama, [1]. Biomimikrija je jedan od termina koji najbolje opisuje nauku sistema baziranih na živim bićima, a stvorio ga je Otto Schmitt 1950-ih, radeći kao naučnik na vazduhoplovnim programima američke vlade, [2]. U suštini mogu se razdvojiti tri biološka nivoa, na kojima mogu biti bazirane nove tehnologije.

- Imitacija prirodnih načina proizvodnje
- Imitacija mehanizama koji postoje u prirodi
- Istraživanje organizovanih principa baziranih na socijalnom ponašanju organizama.

Čovek je tokom istorije često pokušavao da, pomoću razumevanja prirode i repliciranja dođe do određenih otkrića kako bi svoj život učinio lakšim i praktičnijim, [3]. Najpoznatiji među pionirima koji su pokušavali da spoje mehanizme prirode i inženjerstvo svakako je bio Leonardo Da Vinči u svojim nastojanjima da stvori leteću mašinu posmatrajući let ptica, [4]. Njegovo istraživanje smatra se jednom od prvih biometrijskih studija u istoriji. Bioničko projektovanje, uz poštovanje formi životne sredine, kao novi estetski, funkcionalni i konstruktivni pristup inženjerskom projektovanju pomera granice kreativnosti i uvodi u oblast najsavremenije metode 21. veka u konstrukcije i graditeljstvo.

Bionika – bionički stil dodaje odnosu između dinamičkog, razigranog, karaktera forme i funkcije, razmeštajući konstruktivne elemente kao ključne detalje. Stil apeluje da ilustruje osnovnu ideju percepcije građevine - kao velikog živog mehanizma. Bioritam mehanizma podrazumeva čitavu mrežu kreacija, iz kojih proističu nove ideje, novi koncepti i inovativne tehnologije, koje na kraju postaju stvarnost. To izričito oslikava sve prisutniju činjenicu pomirenja haosa i reda, tj. 'uređenog haosa', [1].



Slika 1. *Bioničke forme*

Strukturalna jasnoća ove forme je povezana sa plastičnošću i linijama koje npr. kod vozila nameću zakoni aerodinamike, [5]. Čak i u vodi, živi organizmi imaju isti oblik da bi umanjili silu trenja vode. U tom kontekstu, objekat koji se projektuje, može da se posmatra i kao veliki podvodni organizam koji dolazi iz dubina reke ili mora, kako bi se opustio posle dugog putovanja, predstavljajući svoju lepotu ljudima.

2. PRINCIPI BIONIKE

Pri svoj različitosti struktura stvorenih prirodom u toku mnogomilenijumskog izbora [6], u osnovi konstruisanja izdvajaju se neki opšti principi:

- karakteristike formi i oblika – maksimalna čvrstoća i dugovečnost konstrukcije u prirodi obezbeđuje se pre svega krivoobraznim formama
- odvojen prijem statičkih i dinamičkih opterećenja – statička opterećenja primaju se „pasivnim“ materijalima, za čije funkcionisanje se ne troši energija. Povremena i dinamička opterećenja prihvataju se učešćem „aktivnih“ materijala za koje se dozvoljava trošenje energije (tipa mišića)
- razmeštaj nosivog materijala u pravcu prostiranja glavnih opterećenja – nosivi materijal kod pasivnih prirodnih konstrukcija raspoređuje se u pravcima dejstva postojanog opterećenja
- povećanje opšte stabilnosti i prijem povremenih opterećenja vrši se nenosivim strukturama, koje u datom trenutku smanjuju opterećenje na nosivi sistem, pridajući mu nov kvalitet ukupnog povećanja stabilnosti uz minimalno korišćenja energije
- racionalan raspored nosivih i nenosivih materijala – sve konstrukcije žive prirode (ćelije, tkiva i celi organizmi) održavaju formu na račun toga što uporedo sa čvrstim skeletom postoji elastičan sistem sastavljen od opni ispunjenih viskoznom protoplazmom
- međusobna podela funkcija – obično svaki element ponaosob ima striktno određenu funkciju (nosivu, termozaštitnu, transportnu), pri čemu se neretko više funkcija vrše jednim elementom (polifunkcionalnost) [7].

Na osnovu tih principa bionike funkcionišu i elementi konstruktivnih sistema u građevinarstvu, npr. stubovi na pritisak, grede i međuspratne ploče na zatezanje, ljuske i kupole kao membrane i sferne strukture.

3. HARMONIJA SA PRIRODOM I RESURSIMA – EKOLOŠKA ETIKA

Narastajući ekološki problemi doveli su do saznanja o neophodnosti usmerenja čovečanstva na put održivog razvoja i postizanju harmonije u korelaciji tehničkih sistema i prirode. Novi način mišljenja [8] je neosporno prvi i osnovni korak u ekologizaciji uzajamnog odnosa čoveka i prirode, jer samo postojanim ekološkim obrazovanjem i vaspitanjem može zaživeti ekološka etika. Predznaci globalne ekološke katastrofe inicirali su najvažniju aktivnost čovečanstva u savremenoj epohi – saznanje da put razvitka mora biti u harmoničnim odnosima sa prirodom i njenim resursima. A upravo ovo postizanje harmonije u uzajamnim odnosima sa prirodom ne može biti ostvareno bez ekologizacije pristupa gradnji, koji potom za rezultat daje ekologizaciju normi i pravila, počev od globalne postavke razvoja sistema, preko njegovog projektovanja i realizacije. Svaki sistem mora biti u harmoniji sa prirodom. Ako je oponaša, uvažava i regeneriše, onda ima predispozicije da dobije atribute optimalnosti i trajnosti. Potrebna je krajnja opreznost u primeni sistema različitih od prirodnih, jer priroda je stvarana milionima godina i informacija njenog razvoja mora biti putokaz za sisteme, koji računaju na dugovečnost i ekološku stabilnost, [1]. Promene su nelinearne – i mala izmena jednog resursa može dovesti do velikih izmena drugih. Energija, vazduh i voda su osnovni izvori i uslovi postojanja ekosistema. Dok se pravilnim ekološkim mišljenjem i postupanjem vazduh i voda mogu obnavljati, energija sa tehnološkim razvojem čovečanstva, postaje deficitarna komponenta ekosistema.

4. EKOSTABILNO PROJEKTOVANJE I EKOSTABILNO KORIŠĆENJE ENERGIJE

Indikativan je podatak da se, pri dobijanju iz prirodnih sistema korisne produkcije, na njenu jedinicu troši sve više energije – na jednog čoveka izraženo u KJ/dan: u kamenom dobu se trošilo oko 17.000KJ/dan, u feudalnom dobu 50.000KJ/dan, u industrijskoj epohi 300.000KJ/dan, dok se danas, u najrazvijenijim zemljama, troši i preko 1.000.000KJ/dan, [9], [10], [11]. Pri tome je proces izdvajanja energije iz ekosistema nepovratan i kod njega se ne može govoriti o „kruženju“ energije pretvaranjem iz jednog oblika u drugi, [12].

Ako se analizira proces potrošnje energije, može se zaključiti da se u obratni tok vraća zanemarljivo mala količina energije, tj. ne više od 0,2%. U cilju očuvanja ekosistema, a time i čovečanstva, još je juna 1992. godine održana konferencija OUN u Rio de Žaneiru „Planeta Zemlja“, vezana za razvoj i očuvanje životne sredine. Konferenciji su prisustvovali najviši rukovodioci 179 zemalja sveta, kao i mnogobrojne međunarodne državne i nevladine organizacije. Konferencija je pokazala da se socijalno ekonomski problemi razvoja ne mogu više odvojeno posmatrati od njihovog uticaja na životnu sredinu. Prihvaćen je „Program mera za XXI vek“ sa pozivom svim zemljama sveta za „ekostabilnim“, održivim razvojem, da bi se zadovoljile postojeće potrebe [13], ali ne podvrgavajući riziku sposobnost i mogućnost budućih pokolenja da i one zadovolje svoje potrebe za resursima, čistom životnom sredinom i prostorom. Predlozi mera i zahteva za ostvarivanjem ekostabilne (ekološke, zelene) gradnje se mogu definisati kao:

- ekostabilno projektovanje i izgradnja – politika, prijem rešenja, upravljanje
- ekostabilno korišćenje energije, statistika korišćenja energije, energija pri zagrevanju i pri hlađenju, građevinska fizika, prozori
- zaštita od sunca, ekološki efekti poboljšanja toplotnog režima

- ekološki građevinski materijali, instrumenti i metode izbora adekvatnih građevinskih materijala, štetni sastojci, smanjenje ekološkog opterećenja od betona, revitalizacija postojećih objekata, prepreke i procesi na putu ponovne upotrebe
- ocene životnog ciklusa objekata, zelene ocene objekata, instrumenti ocene i dugovečnost objekata, ekološki status objekata, nacionalni sistem ekološkog ocenjivanja, kao izvor normativnih trebovanja za „zelenu“ gradnju, upoređivanje rezultata „zelenih“ objekata pri korišćenju raznih metoda ocene
- program rada za ekostabilnu - ekološki opravdanu gradnju.

Prepreke ka progresu u ekostabilnoj gradnji najčešće su:

- profesionalna i konzervativna inercija koja štiti „status-kvo“
- nedostatak razumevanja problema među profesionalnim učesnicima u projektovanju i gradnji
- nepostojanje normativnih dokumenata i manje deklarativne, a više konkretne podrške države i društva
- tržišna kretanja, niska kupovna moć stanovništva
- nedovoljni, nekompletni ili nekorektno iskazani izvorni podaci
- političko protežiranje lokalnih ili inostranih proizvođača
- nepostojanje ili neprimenjivanje paketa kazneno-vaspitnih mera zbog prikrivanja ili neistinitog prikazivanja izvornih podataka koji bitno utiču na donošenje odluka kod izbora materijala, ili funkcionisanja sistema.

5. BIONIKA U GRADITELJSTVU

Osnovna oblast izučavanja bionike predstavljaju životne forme u prirodi i njihove analogije u industrijskoj proizvodnji, idejama i rešenjima. Arhitektonsko-građevinska bionika izučava zakone formiranja i obrazovanja struktura živih organizama, polazeći od osnovnih principa stvaralaštva žive prirode - ekonomije materijala, ekonomije energije i postizanja maksimalne, u datim uslovima dugovečnosti. Poslednjih godina bionika potvrđuje da je većina ljudskih patenata već „zapatentovano“ prirodom. Priroda milenijumima, a ljudi, od ne tako davnih vremena, grade po istim zakonima, primenjujući u postupku stvaranja optimalna konstruktivna rešenja – preraspodelu funkcija, prijem opterećenja, dugovečnost, ekonomiju materijala i ekonomiju energije, [3].

Kako su „živi objekti“ sazdani prirodom daleko savršeniji od onih koje čovek stvara, osnovni zadatak na putu razvitka naučno-tehničkog progresa predstavlja upravo osvajanje svih prednosti i karakteristika živih struktura. Tu spada i istraživanje novih materijala i konstruktivnih sistema, koji neće sadržavati samo lepotu i harmoniju prirode, već i poštovati osnovni postulat izgradnje živih struktura – minimum energije uz maksimalnu dugovečnost. Na taj način, ne samo da će se dobiti mnogofunkcionalne „žive“ strukture („pametna kuća“ i sl.), već će se realizovati i osnovni zadatak ekološke gradnje – ostvarivanje harmonije sa prirodom i aktivno očuvanje životne sredine.

5.1 Modelski primeri bioničkog dizajniranja i gradnje

Na osnovu bioničkih principa sazdan je i Simprolit sistem – sistem ekološke gradnje, kreiran primenom osnovnih postulata bionike kao nauke, tj. bioničkog kreativnog inženjeringa. Nosivu ulogu u Simprolit sistemu (slika 2) na sebe preuzima beton kojim se u procesu gradnje zapunjavaju blokovi, kao i armatura koja se po potrebi umeće u šupljine Simprolit blokova. Ako bi se izidan zid od Simprolit blokova snimio „rentgenom“, na slici bi se video sistem vertikalnih betonskih stubova, gusto

raspoređenih – na svakih pola dužine bloka. Ovi stubovi sposobni su da prime ogromno vertikalno opterećenje – po Studiji IMK Građevinskog fakulteta u Beogradu, fasadni zid od Simprolit SBDS30 blokova može da ponese vertikalno opterećenje od preko 30 spratova, [14]. Sa druge strane, od Simprolit blokova, ili Simprolit SOP ili SUP ploča, formira se oplata za horizontalne betonske elemente (serklaže, nadvratnike, natprozornike, međuspratne i krovne ploče), a u svaki treći Simprolit blok, u za to posebno predviđenim kanalima, montira se horizontalna armatura, što sve zajedno, sa ugrađenim betonom, čini siguran sistem za prijem i prenos bočnih opterećenja, horizontalno stalno i pokretno opterećenje, kao i vertikalno povremeno opterećenje u vidu sila dejstva vetra i seizmike, [15].



Slika 2. *Simprolit sistem u skladu sa bioničkim principima gradnje*

Simprolit masa oko betonskih stubića unutar Simprolit blokova i sami Simprolit blokovi kao ogradni (fasadni) zidovi takođe vrše termičku zaštitu (otpornost na požar preko 180 minuta, otpornost na mraz preko 100 ciklusa, letnja stabilnost zidova, termoizolacija i spolja – zimi i unutar objekta – leti), hidrofoban je i na njemu se ne stvaraju buđ i gljivice, a što je najvažnije, Simprolit zidovi „dišu“, po čemu su jedinstven građevinski termoizolacioni materijal, koji tu karakteristiku zadržava u svim klimatskim zonama. Urađene su Preporuke Instituta građevinske fizike RASN RF o primeni Simprolit sistema na celoj teritoriji Ruske Federacije. Simprolit fasadni blokovi imaju jedinstvenu mogućnost da pri istoj debljini, pomoću umetaka, povećaju termoizolaciju zida i na taj način kompenzuju gubitak toplote, proizašao od isprojektovanih fasadnih otvora.

5.2. Dimenzija trajnosti bioničkih inovacija

Dugovečnost mora se obezbediti primenom materijala koji imaju neophodnu ukupnu otpornost i to: otpornost na mraz, hidrofobnost, biootpornost, otpornost na koroziju, otpornost na visoke temperature, postojanost pri cikličnim temperaturnim kolebanjima i drugim razarajućim dejstvima životne sredine. U suprotnom, zahteva se specijalna zaštita elemenata konstrukcije koji su izvedeni od nedovoljno otpornih materijala.

5.3. Razvoj i perspektive bioničkih formi

Bionička forma i stil su postojali još dosta ranije u teoriji i praksi, ali je ona tek sada krenula da se razvija i primenjuje, a i dalje je u fazi razvoja i istrazivanja. Danas timovi inženjera i naučnika rade na tome da naše veštačko stanište spoje sa prirodom, i nema sumnje da će doći do velike evolucije naših gradova u narednih 50 godina ako ne

i manje. Oblici koje možemo pronaći u prirodi, bilo da su u pitanju reljefi, biljke, životinje, pa i ljudi su efikasno proizvedeni evolucijom da najbolje služe svojoj svrsi. Osim toga njihova estetika je poželjna, lako uočljiva i prirodno prihvaćena. Ipak, u svetu inženjerstva, efikasna šema i dobra konstrukcija ne povlači sa sobom i proporcijonalnu estetiku. Mnogo je takvih građevina, koje imaju efikasnu strukturu, ali nikakvu estetsku vrednost. Preuzimanje formi iz prirode zapravo može da premosti jaz između konstrukcije i estetike, gde to dvoje funkcionišu kao jedna nerazdvojna celina. Građevinski inženjeri takođe mogu svojim radom prevazići monotoniju ustaljenih skeletnih sistema i stvarati konstrukcije koje oponašaju one veze i elemente koji se javljaju u prirodi, [16].

Modeliranje formi i struktura iz prirode kako bi se napravile efikasne zgrade je ukorenjeno u ljudskoj misli i rezultat je urođenog talenta čoveka da razume prirodu, čiji je i sam deo. Jedna od prvih manifestacija takvog načina ljudskog razmišljanja dešava se drugom polovinom XIX veka. Arhitekta engleskog porekla Pakston je počeo da izučava cirkularne čaure i radijalne strukture lotusovog lista, nakon što je primetio izdržljivost takvih struktura. Rezultat ovog istraživanja je pojava novih konstruktivnih sistema za lake staklene tavanice, pa je otuda i ,,Kristalna Palata“ 1851 na Svetskoj Izložbi u Londonu zasenila kritičare (slika 3).



Slika 3. *Kristalna Palata, London*

U poslednje dve decenije, koristeći sve jaču moć kompjutera, konstruktori imaju priliku da daju novu dimenziju. Alati savremenih projektanata su novi 3D softveri koji ne samo da prave trodimenzionalne modele i šeme, već mogu da stvore i komleksne matematičke modele, negeometrijske forme kao i da vrše proračune ponašanja struktura u skladu sa pravilima dinamike živih bića (slika 4).





Slika 4. *Kreativno rešenje i ekspresivan izgled, kao rezultat oblika „posuđenih“ iz životne sredine - bioničke forme.*

Mnoge pojave u prirodi i strukture formiranja veza imaju svoje matematičke principe u pozadini. Tako su vekovima filozofi, biolozi, matematičari i fizičari bili zapanjeni strukturama košnica pčela koje imaju svoje heksahedronske oblike gotovo savršene pravilnosti. Otuda je spona između inženjerstva i pojava u prirodi dvosmerna jer i dela ljudskih ruku, a i sama priroda oko nas funkcioniše po matematičkim principima od kojih su neki čoveku lako razumljivi, a one druge opet, čovek se trudimo da shvatimo upravo pomoću praktikovanja njihovih manifestacija na svakodnevno potrebne predmete između kojih su naravno i zgrade.

5.4. Strukture ,,korteksnog stila“

Građevine u obliku kupola, polulopti i sličnih sferičnih formi mogu se primetiti u izobilju. Isto tako vrlo slični oblici mogu se zapaziti i u prirodi (jaje, orah, bobice...). I jedne i druge strukture najčešće imaju tanke omotače (zidove) koji se savijaju kroz prostor, omogućavajući pravilan raspored sila. Ljuska jajeta smatra se jednom od najboljih prirodnih struktura sa svojim omotačem koji je 0,3 mm debeo, a sadrži sedam slojeva od kojih svaki ima svoju elastičnost i funkciju. Ovakve vrste strukture imaju najširu moguću primenu kod objekata velikih raspona gde je potrebno imati čist unutrašnji prostor bez potpornih zidova i stubova. Potrebna im je manja količina materijala i skoro sve su lake konstrukcije gde im debljina omotača ne prelazi nekoliko milimetara. Zapanjujuća pojava u prirodi je svakako i paukova mreža koja je nekoliko puta jača od čelika sa koeficijentom elastičnosti koji 1,25 nadmašuje pomenuti materijal. Te tanke i suptilne strukture su neverovatno izdržljive i predstavljaju jedno od glavnih polja izučavanja u biometrijsko-inženjerskim naukama. Sintetički materijal koji bi oponašao paukovu mrežu (slika 5) bi nadmašio poznate metale koje koristimo u konstrukcijama i omogućio da se mostovi, noseći kablovi, hale, brodovi, avioni, napregnute konstrukcije itd. grade lakše, a nekoliko puta čvršće.

Konstrukcije, oblici i raspored materijala u prirodi dešavaju se po ne toliko kompleksnim principima. Prvi bi svakako bio primanje, raspoređivanje, i izdržavanje svih sila koje deluju na tu strukturu. Drugi princip je učiniti tela i konstrukcije što jačim, ali sa utroškom što je moguće manje materijala. Oba ova principa savršeno se poklapaju sa ljudskim potrebama u smislu funkcionalnosti, ali isto tako i ekonomičnosti, profitabilnosti i održivosti.



Slika 5. *Olimpijsko selo u Minhenu, konstrukcija paukove mreže*

6. METODE I MATEMATIČKI ASPEKTI BIONIKE KAO MERA LEPOTE

Bionika kao interdisciplinarna nauka se odnosi na proučavanje i prenos "prirodnih izuma" u tehničke nauke. Informaciona bionika izučava sredstva prenosa podataka, strategije razvoja i strategije evolucije. U okviru matematičkih aspekata bionike značajno mesto zauzima tkzv. prikriveni matematički princip D'Arcy Thomson. Po mnogima je matematika, pored gena, druga tajna života. Fibonačijev niz (0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, ...), pravougaonici i spirale su samo deo korelacionih veza iz prirode, koje kada se uz inkorporiranje bioničkih principa, uvedu u sklad graditeljskih formi, predstavljaju vrhunac stvaralaštva. Još od Leonarda da Vinčija, zlatni presek, koga je on uveo kao termin, predstavlja meru Božanske lepote. Matematičar Fra Luca Paccioli napisao je specijalni traktat "Božanska proporcija" (1509). Grčki skulptor Fidijas je u svom radu poštovao ovaj princip. U njegovu čast se zlatni presek i obeležava sa fi (ϕ). Zlatni presek se dobija kada se duž podeli na delove "a" i "b", tako da je odnos manjeg "a" dela prema većem delu "b", jednak odnosu većeg dela "a" prema celoj duži "a+b". Idealna proporcija = zlatni presek (a+b) / a = a / b = 1,618. Ako se ove matematičke relacije primene u kreiranju novih konstrukcijskih sistema, vizuelno i funkcionalno, može se zaključiti da zlatni presek deluje jako prijatno, kao i da se ovi odnosi mogu pratiti i u prirodi. U najpoznatije metode u bioničkom dizajniranju se ubrajaju: Aalborg metod, koji je temeljno obrađen u literaturi [17], Biomimikrijski metod, zatim Spirala dizajna, Bio-inspirisan metod dizajniranja i Inverzni metod.

7. ZAKLJUČAK

Dizajn inspirisan oblicima i zakonitostima iz prirode, danas je imperativ i paradigma u funkciji istraživanja novih održivih formi i projekata u skladu sa zakonima životne sredine. Predložene su brojne metode dizajna, namenjene pre svega za istraživače i profesionalce iz više različitih disciplina, a sa ciljem razvoja biološki inspirisanog dizajna. Komparativnom analizom više metoda, dolazi se do ostvarenja četiri osnovna cilja: optimalan oblik, organizaciona efektivnost, ispunjeni zahtevi komfora i udobnosti korisnika prostora i paradigma inovacije za poboljšanje funkcionalnog efekta. Smatra se da je od izuzetne važnosti da se sa standardnog dizajna, pređe na inovativni bionički, što za rezultat ima: ostvarivanje inovativnog koncepta, optimizaciju specifičnosti ili performansi i održivost životne sredine.

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POBOLJŠANJE KVALITETA OTPADNE VODE ADSORPCIJOM OLOVA I CINKA NA METAKAOLINU

Tanja Glogovac[1], Mirjana Jokanović[2], Nikolina Miletić[3]

Rezime: Cilj ovog rada bio je ispitivanje mogućnosti primjene metakaolina, kao jeftinog adsorbensa, za odvajanje jona olova i cinka iz rastvora otpadnih voda. Ispitivanja su izvođena u zavisnosti od vremena, pH vrijednosti, mase adsorbensa i početne koncentracije. Najefikasnija adsorpcija ovih metala se postiže sa najmanjom masom adsorbensa, dok sa porastom mase koeficijent adsorpcije qe opada. To se pokazalo i kod vremenske zavisnosti. Sa najmanjom količinom adsorbensa korišćenom u ispitivanjima postignuta je najveća efikasnost i to poslije vremena od 1h. Pokazalo se da povećanje pH vrijednosti dovodi do povećanja qe, s tim da se kod olova javlja blagi pad ove vrijednosti nakon pH=7,5. Vrijednost početne koncentracije, c0, takođe utiče na efikasnost adsorpcije, ona raste sa porastom c0, i nakon određene vrijednosti početne koncentracije opada, u slučaju i Pb^{2+} i Zn^{2+}.

Ključne riječi: Adsorpcija, cink, olovo, metakaolin.

QUALITY IMPROVEMENT OF WASTE WATER BY ADSORPTION OF LEAN AND ZINC ON METAKAOLINE

Abstract: The aim of this work was to examine the possibility of using metakaoline as a cheap adsorbent for the separation of lead and zinc ions from the waste water. The tests were carried out in dependence of time, pH, mass of adsorbent and initial concentration. The most efficient adsorption of these metals is achieved with the smallest mass of adsorbents while the increase of that mass, adsorption coefficient qe decreases. This has also been shown in time dependency. The highest efficiency was achieved with the smallest amount of adsorbents used in the test, and after a time of 1h. It has been shown that an increase in pH value leads to an increase in qe, but for lead there is a slight decrease in this value after pH = 7.5. The initial concentration value, c0, also affects the adsorption efficiency that increases with the increase of c0 and after a certain initial concentration value decreases, in the case of both Pb2 + and Zn2 +.

Key words: Adsorption, lead, metakaoline, zinc.

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1 UVOD

Zagađenje voda procesnim i otpadnim vodama iz industrijskih postrojenja veliki je problem s kojim se savremeni svijet suočava. S obzirom na to da prijeti nestašica pitke vode, neophodno je da se rješavanju ovog problema pristupi ozbiljno. Zastrašujuće zvuči podatak da polovina zemalja u razvoju pati od bolesti koje prouzrokuje neispravna voda za piće. Iako voda predstavlja jedan od obnovljivih resursa, ona se u ciklusu kruženja vode od upotrebe do povratka u vidu atmosferske vode optereti štetnim materijama i česticama. Teški metali (olovo, cink, hrom, kadmijum, nikl ...) su jedan od velikih zagađujućih materija koji u rijeke, jezera dospijevaju otpuštanjem otpadnih voda iz različitih industrijskih procesa poput metalurgije, rudarstva, proizvodnje hemikalija, papira i tako dalje [1].

Adsorpcija se pokazala kao izuzetno efikasna metoda za uklanjanje teških metala iz vode. Cilj ovog rada je ispitivanje mogućnosti ekonomski prihvatljivog adsorbensa metakaolina za selektivno odvajanje olova i cinka iz rastvora otpadnih voda pod različitim ekperimentalnim uslovima.

Metakaolin se u dosadašnjim eksperimentima pokazao kao efikasan adsorbens kod prečišćavanja otpadnih industrijskih voda kontaminiranih teškim metalima. U ovom radu je ispitivan uticaj vremena, pH vrijednosti, mase adsorbensa i početne koncentracije na adsorpciju jona olova i cinka na metakaolinu.

2 ADSORPCIJA TEŠKIH METALA

Sa razvojem čovjek je nekontrolisano i koristio resurse i zagađivao svoju okolinu pa je danas rješavanje ekoloških pitanja nešto što se ne može dalje odlagati [2]. Čak i da u ovom trenutku sve fabrike prestanu ispuštati otpadne vode u rijeke i da svi proizvođači prestanu koristiti pesticide, bile bi potrebne decenije da ekosistem pročisti sam sebe [3].

Ono što karakteriše industrijske otpadne vode jeste raznolikost sastava, i skoro uvijek prisustvo teških metala: Co, Cu, Cr, Fe, Mn, Mo, Se i Zn. Teškim metalima se smatraju svi oni koji imaju gustinu veću od 5 g/cm^3, a među najtoksičnije, između ostalih, spadaju olovo i cink čija se adsorpcija iz otpadnih voda ispituje u ovom radu.

Olovo je metal IVa grupe periodnog sistema elemenata i halkofilni je element što znači da obrazuje veliki broj sulfidnih minerala. Nalazi se u vodama koje imaju visoke pH vrednosti, a smanjuje se u neutralnim i slaboalkalnim rastvorima [4].

Cink je prelazni element koji se nalazi u 4. periodi periodnog sistema elemenata. To je prelazni metal, heksagonalne kristalne strukture, čvrstog agregatnog stanja i gustine 7,14 g/cm^3, što ga svrstava u teške metale. Međutim, industrija posebno iz oblasti sa rudnicima ovog metala može da doprinese koncentracijama i do 50 g/l [5].

Kako je već navedeno, zagađenje voda je veliki problem pa se njegovom rješavanju mora pristupiti ozbiljno i djelovati tako da nestašica pitke vode ne pogodi Zemlju u bliskoj budućnosti. Postoji više načina za prečišćavanje otpadnih voda, a jedan od njih, koji spada u grupu hemijskih metoda je adsorpcija.

2.1 Adsorpcija

Primjena procesa adsorpcije ima dugu istoriju. Čak 450 g. p.n.e. prema zapisima Hindua, filteri ispunjeni ugljem i pijeskom korišćeni su u svrhu prečišćavanja vode. U 15. vijeku moreplovci su pitku vodu čuvali u drvenim bačvama premazanim ugljem kako bi ostala svježa [6].

Adsorpcija je proces formiranja filma molekula na površini nekog čvrstog materijala koji formiraju gasoviti ili tečni rastvori. Supstanca koja se adsorbuje zove se adsorbat, a supstanca, na čiju površinu se vezuje adsorbens. Atomi koji se nalaze na površini nekog meterijala imaju afinitet (jer nisu okruženi drugim sa svih strana) da formiraju veze sa atomima u okolini. U toj energiji površine materijala leži i osnova adsorpcije. Proces adsorpcije prati smanjenje slobodne energije sistema i odvija se spontano [7].

Veliki broj faktora ima uticaj na adsorpciju [8]:

- Površina i struktura adsorbensa - kapacitet adsorpcije direktno zavisi od površine adsorbensa, pa sa njenim povećanjem raste i adsorpcija određenih molekula.
- Veličina pora adsorbensa - površina adsorbensa koji je neporozan se povećava sa smanjenjem veličine njihovih čestica. Kao posljedica ovoga kapacitet adsorpcije se povećava sa smanjenjm prečnika čestica.
- Masa adsorbensa - povećanje površine adsorbensa povećava moguću površinu za kontakt između njega i aktivnih centara na površini molekula, što dovodi do rasta kapaciteta adsorpcije. Međutim, kada se desi preklapanje ili agregacija adsorpcionih mijesta smanji se ukupna površina adsorbensa i dolazi do povećanja difuzionog procesa. Porast mase adsorbensa smanjuje vrijeme neophodno da se dostigne ravnoteža.
- Uticaj početne koncentracije - kada je koncentracija niža, adsorpcija je intenzivnija i ravnoteža se brže uspostavlja.
- Uticaj brzine miješanja - miješanje prilikom adsorpcije je važan faktor koji uslovljava raspodijelu adsorbata u masi adsorbensa. Sa povećanjem brzine miješanja dolazi do smanjenja efekta prenosa mase.
- Temperatura - povećanje temperature najčešće dovodi do porasta kapaciteta adsorpcije.

3 EKSPERIMENTALNI DIO, REZULTATI I DISKUSIJA

U ovom radu ispitivana je adsorpcija olova i cinka, iz vodenog rastvora, na metakaolinu pri različitim uslovima. Eksperimenti su izvođeni u cilju određivanja zavisnosti adsorpcije metala od vremena, pH vrijednosti, mase adsorbensa i početne koncentracije matala. Sva ispitivanja izvođena su u šaržnom sistemu, na sobnoj temperaturi. Svi ispitivani rastvori su u toku predviđenog vremena za dato ispitivanje miješani.

Količina metala (olova i cinka) q_e (mg/g) adsorbovana do uspostavljanja ravnoteže računa se pomoću sljedećeg izraza:

$$q_e = \frac{(c_0 - c_e)V}{m} \tag{1}$$

Efikasnost adsorpcije R [%] se računa primjenom sljedećeg izraza:

$$R = \frac{c_0 - c_e}{c_0} 100 \tag{2}$$

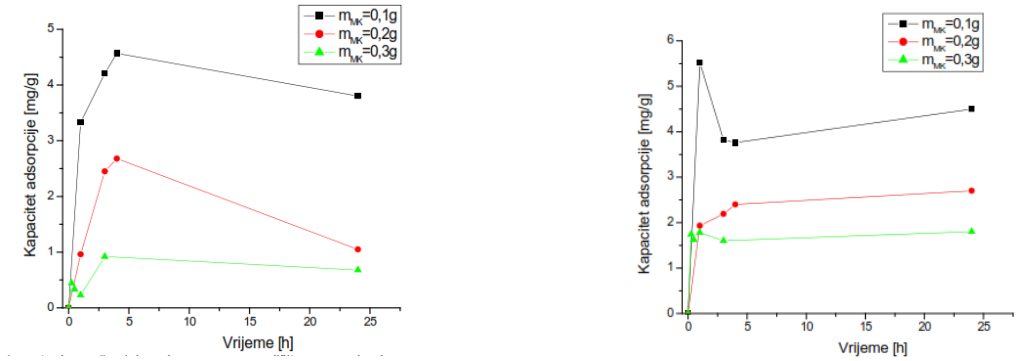
Veličine u izrazima su sljedeće:

- c_o – početna koncentracija rastvora [mg/dm^3],
- c_e- koncentracija rastvora nakon uspostavljanja ravnoteže, tzv. ravnotežna koncentracija [mg/dm^3],
- m – masa adsorbensa [g],
- V – zapremina rastvora [dm^3].

3.1 Uticaj vremena na adsorpciju

Kod ispitivanja zavisnosti adsorpcije olova i cinka na metakaolinu od vremena eksperimenti su izvođeni na 1 h, 3 h, 4 h i 24 h, sa dodatkom 0,1 g i 0,2 g metakaolina u 25,0 cm^3 smješe radnih rastvora olova i cinka, pri pH=7 i na sobnoj temperaturi. Eksperiment sa 0,3 g adsorbensa izvođen je na 15 min, 30 min, 1 h, 3 h, 24 h.

Grafički prikaz zavisnosti kapaciteta adsorpcije za olovo i cink od vremena dat je na slici 1.



(a) (b)

Slika 1. *Zavisnost kapaciteta adsorpcije od vremena za (a) olovo (b) cink*

Na dijagramu je prikazana zavisnost kapaciteta adsorpcije od vremena za tri različite mase adsorbensa, metakaolina. U sva tri slučaja adsorpcija počinje prilično brzo, u roku od 10 do 15 min. Povećana brzina adsorpcije na početku je zbog činjenice da je većina adsorpcionih mjesta još uvek slobodna, poslije čega dolazi do zasićenja, što dovodi do ravnoteže. Evidentno je da se adsorpcija većim dijelom odigrava u prvom, bržem stupnju, dok se kasnije smanjuje usljed smanjenja broja aktivnih centara i odigrava daleko sporije.

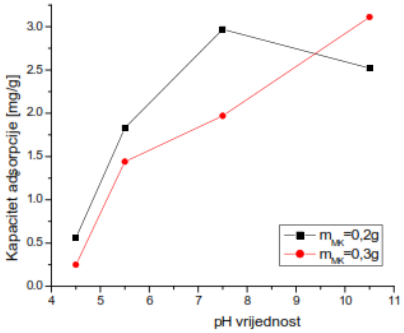
Na dijagramu zavisnosti adsorpcije cinka od vremena vidi se da je, kao i kod olova, prvi nivo dosta brži od drugog, sporijeg stupnja.

Kako se joni cinka i olova nalaze zajedno u rastvoru, nakon brze adsorpcije oba jona na početku procesa sa vremenom dolazi do kompeticije između ova dva jona za preostale adsorpcione lokacije na adsorbensu. Na osnovu prikazanih rezultata može se zaključiti da se olovo prvo vezuje i otuda blago povećanje vrijednosti adsorpcionog kapaciteta. Cink se vezuje za preostala mjesta pa zato sa vremenom dolazi do smanjenja vrijednosti q_e.

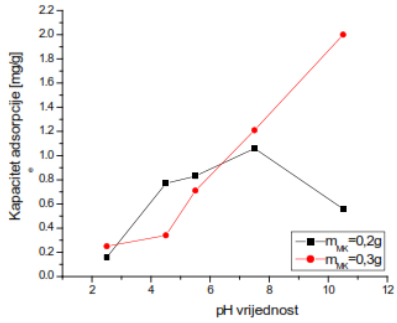
3.2 Uticaj pH vrijednosti na adsorpciju

Za određivanje zavisnosti adsorpcije od pH vrijednosti izvođeni su eksperimenti sa 0,2 g i 0,3 g metakaolina, miješanjem u trajanju od 3 sata.

Pomoću kiselina i baza pH je podešavan na 2,5; 4,5; 5,5; 7,5; 10,5. Grafički prikaz zavisnosti kapaciteta adsorpcije za olovo i cink od pH vrijednosti dat je na slici 2.



(a)



(b)

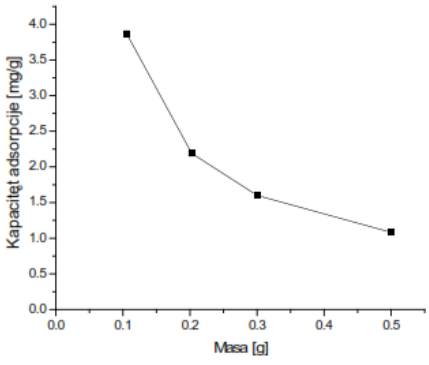
Slika 2. *Zavisnost kapaciteta adsorpcije od pH za (a) olovo (b) cink*

pH rastvora je važan parametar u postupku adsorpcije. Poznato je da pH medijuma utiče na rastvorljivost jona metala i koncentraciju kontra jona na funkcionalnim grupama adsorbensa. Kao što je prikazano na dijagramu nakon dostizanja najveće vrijednosti adsorpcionog kapaciteta na pH=7,5 adsorpcija cinka na metakaolinu naglo opada.

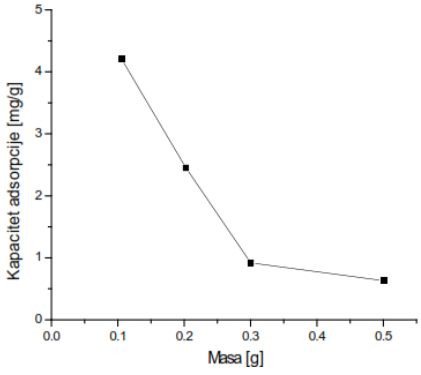
Pri eksperimentima sa 0,3 g adsorbensa, kao i kod adsorpcije olova, javlja se porast adsorpcionog kapaciteta cinka sa porastom pH vrijednosti. Na nižoj pH vrijednosti, uklanjanje jona cinka (II) je smanjeno. Ovo može biti zbog konkurencije između adsorpcionih lokacija, jer na niskom pH medijum sadrži višu koncentraciju vodonikovih jona nego pri višoj pH vrednosti, pa dolazi do kompeticije sa jonima metala.

3.3 Uticaj mase adsorbensa na adsorpciju

Grafički prikaz zavisnosti kapaciteta adsorpcije od mase adsorbensa za olovo i cink dat je na slici 3.



(a)



(b)

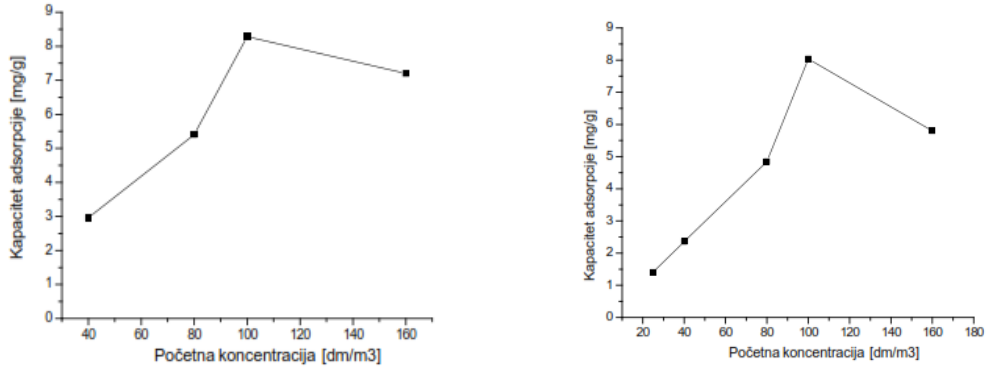
Slika 3. *Zavisnost kapaciteta adsorpcije od mase adsorbensa za (a) olovo (b) cink*

Smanjenje adsorbovane količine olova sa povećanjem mase može se objasniti činjenicom da se interakcije između čestica materijala povećavaju sa masom. Do smanjenja kapaciteta adsorpcije dolazi zbog preklapanja adsorpcionih lokacija, aglomeracije čestica (nagomilavanja), što onemogućava prilaz adsorpcionim lokacijama adsorbensa. Do istog zaključka može se doći i kad je u pitanju adsorbovana količina cinka. Iako je na raspolaganju veći broj adsorpcionih lokacija, zbog međusobne interakcije čestica adsorpcija se smanjuje.

3.4 Uticaj početne koncentracije metala na adsorpciju

Uticaj početne koncentracije na adsorpciju ispitivan je pri sljedećim vrijednostima c_0: 25, 40, 80, 100 i 160 cm^3. Rezultati određivanja adsorpcionog kapaciteta prikazani su na slici 4 za olovo i cink respektivno.

Na dijagramima zavisnosti adsorpcije olova i cinka od početne koncentracije vidi se da koeficijent adsorpcije u oba slučaja raste sa porastom početne koncentracije, dostiže svoj maksimum kada je početna koncentracija rastvora 100 mg/dm^3 i zatim opada. Ranija ispitivanja adsorpcije cinka na metakaolinu su pokazala da do pada koeficijenta q_e ne dolazi kada se povećava početna koncentracija [4].



(a) (b)

Slika 4. *Zavisnost kapaciteta adsorpcije od početne koncentracije metala za (a) olovo (b) cink*

4 ZAKLJUČAK

Cilj ovog rada bio je ispitivanje adsorpcije jona olova i cinka iz smješe na metakaolinu, u svrhu pronalaženja odgovora na pitanje da li metakaolin, kao jeftin materijal, može da se koristi za prečišćavanje otpadnih voda kontaminiranih ovim teškim metalima. Nakon ispitivanja adsorpcije u zavisnosti od vremena, pH vrijednosti, mase adsorbensa i početne koncentracije došlo se do sljedećih zaključaka, koji su ujedno i odgovor na postavljeno pitanje:

- Kod adsorpcije olova u zavisnosti od vremena, pokazalo se da je efikasnost adsorpcije najveća za masu metakaolina od 0,1 g, s tim da se maksimum postiže poslije 1 h nakon čega opada. Kod adsorpcije cinka, najveća efikasnost se takođe postiže sa 0,1 g metakaolina.U slučaju ovog jona maksimum koeficijenta adsorpcije se postiže nakon 4 h trajanja adsorpcije.

- pH vrijednost utiče na adsorpciju i to tako što se kod olova i cinka, kada je masa adsorbensa 0,2 g, postiže maksimum adsorpcije na pH=7,5. Kada se koristi masa metakaolina od 0,3 g, najefikasnija je adsorpcija na pH=10,5.
- Kao što je već navedeno najefikasnijom se pokazala adsorpcija kada je masa metakaolina najmanja, sa povećanjem mase, koeficijent q_e se smanjuje.
- U slučaju adsorpcije olova i cinka, efikasnost adsorpcije raste sa povećanjem početne koncentracije metala.

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MODELSKO ISPITIVANJE KAPLANOVE TURBINE

Anto Gajić[1], Slavica Šijaković[2]

Rezime: U radu su opisani zakoni sličnosti hidrauličnih turbina, zatim prikazani su rezultati modelskog ispitivanja Kaplanove turbine. Takođe prikazani su i rezultati ispitivanja. Eksperimentalni rezultati mogu poslužiti i kao koristan izvor informacija za poboljšanje postojećih teorijskih postupaka proračuna.

Ključne riječi: Modelsko ispitivanje, Zakoni sličnosti hidrauličnih turbina, Efikasnost turbine

MODELING TEST OF CAPLAN TURBINE

Abstract: In this paper are described the similarities of hydraulic turbines, then the results of the Kaplan turbine model test are shown. Also, test results are also shown. Experimental results can also serve as a useful source of information for improving existing theoretical processes of the calculate.

Key words: Model test, Similarities of hydraulic turbines, turbine efficiency

1 UVOD

Hidraulične turbine, mehanički sistemi u kojima se vrši razmjena energije sa vodom, konstruišu se kao jedinstveni geometrijski protočni prostori zavisno od zahtjevanih strujnih dijelova. Da bi se hidraulična energija transformisala u mehaničku, neophodno je obezbjediti neposrednu interakciju vode I mehaničkog sistema, pri čemu se dijelovi tog sistema - obrtno kolo mora da stavi u obrtno kretanje.

Istovremeno, u obrtnom kolu treba ostvariti skretanje vode u kome se vrši neposredno pretvaranje hidraulične energije u mehaničku. Ostali dijelovi turbine, koji su takođe neophodni, imaju zadatak stvaranja uslova da se u obrtnom kolu obavi što kvalitetnija razmjena energije, a da pri tom i gubici energije u njima budu minimalni, odnosno da stepen korisnosti bude najveći.

Težeći, da se udovolji prethodnim zahtjevima kao i zahtjevanim strujnim uslovima došlo se do saznanja da je nemoguće sa jednim geometrijskim oblikom-tipom

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turbine doći do visokog stepena korisnosti i ispunjenja zahtjevanih strujnih uslova. Tako su razvijeni različiti tipovi turbina: Peltonove, Fransisove, Dijagonalne, Kaplanove, Cijevne kao i čitav niz modifikovanih tipova turbina. Uzimajući u obzir zahtjevane strujne uslove i izborom tipa turbine u zavisnosti od specifične brzine obrtanja i specifičnog prečnika turbine, a koristeći statističke podatke već stečenih iskustava određuju se globalni parametri turbine. Posebna pažnja posvećuje se oblikovanju obrtnog kola, uvodnih organa i organa za odvođenje vode. Postupak dobijanja geometrije protočnih prostora i obrtnog kola se naziva indirektnim zadatkom. Prilikom rekonstrukcije i povećanja snage turbina jedne već izgrađene hidroelektrane promjena geometrije protočnih prostora uglavnom je usredsređena na obrtno kolo, jer uvodni i odvodni organi ostaju neizmjenjeni ili djelimično izmjenjeni, jer zbog već njihove izgrađenosti u betonu teško se mogu mijenjati bez značajnih zahvata i ogromnih materijalnih troškova. Proces usvajanja geometrijskog oblika turbine se verifikuje ispitivanjima na modelu turbine koji ispunjava uslov geometrijske sličnosti sa prototipom.

Nakon višedecenijskog rada većih hidroelektrana sprovedeni su ili se sprovode značajni zahvati rekonstrukcija. U sklopu obimnih poslova koji treba da dovedu do očekivanog ishoda rekonstrukcija hidroelektrana u cilju modernizacija I povećanja snaga, važno mjesto zauzimaju modelska ispitivanja projektovanog tipa turbine.

2 ZAKONI SLIČNOSTI HIDRAULIČNIH TURBINA

Eksperimentalna istraživanja obavljaju se u hidrauličkim laboratorijama na modelima turbine geometrijski sličnim velikim turbinama u hidroelektranama, koje se nazivaju i glavnim izvođenjima I prototipovima. Ispitivanja se obavljaju u saglasnosti sa odgovarajućim preporukama I standardima, a dobijeni rezultati imaju visoku tačnost i samim tim zadovoljavalju i zahtjeve tehničke prakse.

S druge strane dobijeni rezultati prevashodno se koriste za preračunavanje turbine predviđenih za ugradnju u hidroelektranu. Modelska ispitivanja turbine neuporedivo su jeftinija od cijene ispravki mogućih promašaja pri izradi velike turbine. Svi nedostaci pri projektovanju i proračunu otkrivaju se i otklanjaju modelskim ispitivanjima.

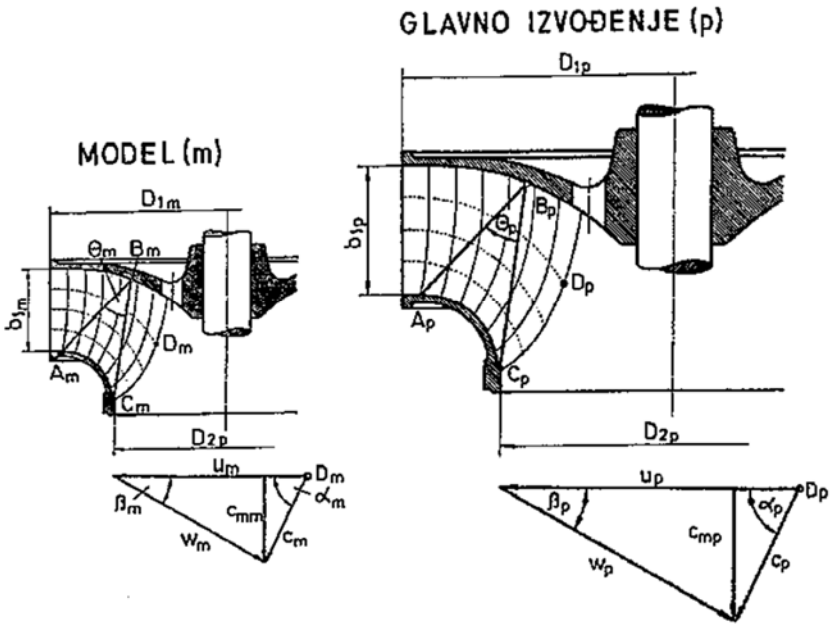
Rezultati dobijeni modelskim ispitivanjima svode se na karakteristične veličine – značice, koje predstavljaju jednoznačnu zavisnost osnovnih veličina utvrđenih pomoću zakona o sličnosti mehaničkih sistema. Primjenom značica moguće je preračunati geometrijske i opitne parametre modela turbine na glavno izvođenje, a takođe izvršiti I izbor turbine za date parametre vodotoka.

Sva razmatranja sličnosti modela I prototipa zasnivaju se na opštim zakonima mehaničke sličnosti [1].

2.1 Zakoni mehaničke sličnosti

Dva mehanička sistema su slična, ako su istovremeno zadovoljeni uslovi geometrijske, kinematske i dinamičke sličnosti.

Na slici 1. prikazan je model i prototip turbine.



Slika 1. *Model i prototip turbine* [2]

Uslovi geometrijske sličnosti dva strujna prostora modela (m) i prototipa (p) turbine su ispunjeni, ako su odnosi odgovarajućih dimenzija jednaki:

$$\boldsymbol{\lambda_1 = \frac{(AB)_p}{(AB)_m} = \frac{(BC)_p}{(BC)_m} = \frac{b_{1p}}{b_{1m}} = \frac{D_{1p}}{D_{1m}} = \frac{D_{2p}}{D_{2m}} = \cdots = const.} \qquad (1)$$

Gdje je λ_1 – prevodni koeficijent geometrijske sličnosti

Kinematska sličnost strujnih polja modela i prototipa turbine je ispunjena kada su pored geometrijske sličnosti i odnosi između odgovarajućih brzina u korespodentim tačkama modela i prototipa jednaki:

$$\boldsymbol{\lambda_c = \frac{u_p}{u_m} = \frac{\omega_p}{\omega_m} = \frac{c_p}{c_m} = \frac{c_{mp}}{c_{mm}} = \cdots = \frac{n_{1p}D_{1p}}{n_{1m}D_{1m}} = const.} \qquad (2)$$

λ_c – prevodni koeficijent kinematske sličnosti

Uslov dinamičke sličnosti je ispunjen ako su zadovoljena dva prethodna uslova mehaničke sličnosti: geometrijska i kinematska sličnost, a zatim da su odnosi odgovarajućih sila, koje djeluju na strujni prostor modela i prototipa jednaki[3].

Proces usvajanja oblika turbine se verifikuje ispitivanjima na modelu turbine koji ispunjava uslov geometrijske sličnosti sa prototipom.

Ciljevi modelskih ispitivanja turbina su [1]:

- Dobijanje pouzdanih energetskih, kavitacijskih i drugih karakteristika modela hidraulične turbine u cilju izgradnje novih i revitalizacije postojećih

hidroelektrana;
- Razvoj hidrauličkih turbina željenih karakteristika;
- Mogućnost upoređenja karakteristika dvije hidraulične turbine iste hidroelektrane radi podjele potencijala rijeke;
- Usavršavanje matematičkih modela proračuna hidraulike i strujanja kroz hidroturbine;
- Određivanje energetskih i kavitacijskih performansi prototipa turbina preračunavanjem izmjerenih karakteristika modela na prototip.

3 REZULTATI ISPITIVANJA

3.1 Izlaz

U tabeli 1. prikazani su rezultati maksimalnog izlaza turbine za date tačke.

U zavisnosti od neto pada, izlaz turbine se mijenja, gdje se za pad od 45,2 m i 43 m, snaga ne mijenja[2].

Tabela 1. *Maksimalni izlaz turbine*

Neto pad	Maksimalni izlaz turbine
47 m	111 MW
45.2 m	105 MW
43 m	105 MW
42.7 m	104 MW

3.2 Efikasnost turbina u navedenim tačkama

U tabeli 2. prikazani su rezultati efikasnosti turbina.

U tabeli su date garantovane performanse turbine, gdje se u zavisnosti od neto pada mijenja snaga.

Tabela 2*. Rezultati efikasnosti turbine*

Neto pad	Izlaz turbine (%)	100	90	80	70	60	50	40
47 m	Izlaz turbina (MW)	105	94.5	84	73.5	63	52.5	42
	Garantovana vrijednost (%)	93.8	93.9	93.9	93.8	93.7	92.7	91.0
45.2 m	Izlaz turbina (MW)	105	94.5	84	73.5	63	52.5	42

	Garantovana vrijednost (%)	93.7	93.9	94.0	93.9	93.9	92.7	91.1
43 m	Izlaz turbina (MW)	105	94.5	84	73.5	63	52.5	42
	Garantovana vrijednost (%)	93.4	93.9	94.0	94.0	93.7	02.8	91.1
42.7 m	Izlaz turbina (MW)	104	94.6	83.2	72.8	62.4	52	41.6
	Garantovana vrijednost (%)	93.4	93.9	94.0	94.0	93.6	92.7	90.9

3.3 Ponderisana prosječna efikasnost

U tabeli 3. prikazana je ponderisana prosječna efikasnost.

Tabela 3. *Ponderisana prosječna efikasnost*

Neto pad	Izlaz turbine (%)	100	90	80	70	60	50	Suma
47	Izlaz turbine (MW)	105	94.5	84	73.5	63	52.5	
	Težina w	1	1	1	1	1	1	6
45.2	Izlaz turbine (MW)	105	94.5	84	73.5	63	52.5	
	Težina w	3	6	8	4	2	1	24
43	Izlaz turbine (MW)	105	94.5	84	73.4	63	52.5	
	Težina w	10	13	15	11	8	3	60
42.7	Izlaz turbine (MW)	104	93.6	83.2	72.8	62.4	52	
	Težina w	2	2	2	1	1	1	10
Ukupno							100	

Garantovana ponderisana prosječna efikasnost w=93.974 %. Potvrđeno je da model zadovoljava sve garantovane vrijednosti efikasnosti u navedenim tačkama i ponderisanu prosječnu vrijednost.

4 ZAKLJUČAK

U radu su opisani zakoni sličnosti hidrauličnih turbina, takođe prikazani su rezultati ispitivanja, koja su upisana u odgovarajućim tabelama.

Na osnovu rada može se zaključiti sljedeće:

- Eksperimentalna ispitivanja modela turbina, i u tom smislu usvajanje odgovarajuće geometrije rekonstruisane i modernizovane turbine povećane snage željenih energetskih i kavitacijskih karakteristika, imaju neprocjenjivu važnost u razvoju i usavršavanju novih tipova turbine;
- Poseban značaj modelskih ispitivanja sastoji se u utvrđivanju energetskih i kavitacionih karakteristika ispitivanog modela turbine;
- Preračunavanjem rezultata modelskih ispitivanja utvrđuju se energetske i kavitacione performanse turbine koje se ugrađuju sa garantovanim;
- Ispitivanja se obavljaju u specifičnim opitnim postrojenjima snabdjevenim davačima mjernih veličina koji se moraju kalibrisati prije i poslije mjerenja, a takođe, po potrebi, i u toku mjerenja.

Kaplanova turbina vrlo je često upotrebljena za proizvodnju električne energije iz vodenog toka. Zbog svojih velikih dimenzija teško je napraviti ispitivanja na realnom objektu pa se primjenjuju modelska ispitivanja.

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MAINTENANCE AND TECHNICAL DIAGNOSTICS

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APPLICATION OF NON-DESTRUCTIVE METHODS IN THE DIAGNOSTICS OF THE TURBINE SHAFT IN THE HYDROELECTRIC POWER PLANT

Ljiljana Radovanovic[1], Jasmina Pekez[2], Eleonora Desnica[33], Ivan Palinkas[4], Dragoljub Ilic[5]

Abstract: Early detection of damage is very important to maintain the safety of power plants. The implementation of technical diagnostics involves the selection of the most important parameters in determining the safety of the functioning of the components. Timely application of non-destructive testing methods within the turbine shaft state diagnostics can contribute to reducing the failure of the shaft in the hydroelectric power plant.In this paper is presented non-destructive testing on the turbine shaft of Aggregate A6 at the hydroelectric power plant "Djerdap II" with methods: magnetic particle testing, visual and penetrant testing and ultrasonic inspection .

Key words: diagnostic, hydroelectric power plant, non-destructive testing, turbine shaft

1 INTRODUCTION

Nondestructive Testing (NDT) allows parts and materials to be inspected and measured without damaging them. Because it allows inspection without interfering with a product's final use, NDT provides an excellent balance between quality control and cost-effectiveness. Generally speaking, NDT applies to all kind of industrial inspections, including metallic and non metallic structures (NDT, 2005).
In recent years, the role of NDT has become even more important considering that the strong competition in the energy industry and the compromise between the demand of electricity (overcapacity) and the new environmental regulations have made more economically advantageous to keep older power plants running beyond their design life (considering also technological and economic revamping or conversion to different power generation methodologies and combined cycles) in respect to build new

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structures. In particular, the traditional demand for useful life was fixed to 200000 hours (about 25 years) plus a set number of start/stop cycles, while the requests of the today market can be longer than 400000 hours plus a proper number of start/stop cycles (Crespi, 2008).
There are many international, regional and national standards applied in NDT field so far. They are approved by the American National Standards Institute (ANSI) mostly in North America and part of Asia, and by International Organization for Standartization (ISO) in cooperation with International Electrotechnical Commission (IEC) in Europe and part of Latin America and Africa. In fact, ISO and IEC form the specialized systems for worldwide standartization.
At present, in the NDT field the international standards ISO 9001 and ISO/17025 are applied, in particular for accreditation and services. In the field of qualification and certification of personnel the ISO 9712:1999 NDT seems to be well accepted worldwide. (NDT, 2005).
NDT technology as applied for plant life assessment (PLA) is a trend in many developed and developing countries. NDT for plant life assessment deals with application of NDT techniques to detect discontinuities in an industrial manufacturing process that can affect the mechanical strength of a product and may cause its premature failure. Plant life assessment in many cases means the remaining life assessment of a structure, component or product.

2 METHODOLOGY

The non-destructive testing (NDT) methodologies traditionally applied during the production stage are: visual testing (VT), magnetic particles (MPI), dye penetrant (PT) and ultrasonic (UT); in most recent years, MPI has been substituted by arrays of eddy currents (ET) probes in automatic production lines (Stubbs, 2004; ASNT, 2007).
The most dangerous (and stressed) section of a rotor is the bore where cracks can initiate during both steady state regime due to creep fatigue and cyclic plasticity (low cycle fatigue) and start/stop cycles due to thermal fatigue and centrifugal forces. Possible defects not removed during the production stage or characterized by a size below a given level of acceptance can also initiate cracks due to high cycle fatigue. Other critical sections are blades (stress corrosion cracking, erosion, unexpected impacts), blade root fixings and grooves and stress concentrations (creep, thermal fatigue and stress corrosion cracking). The goal is then to localize and size (in terms of length and depth) such cracks in order to apply dedicated design or life prediction techniques for the determination of residual life and proper inspection intervals. From this point of view, the choice of the proper NDT technique is critical. The NDT methodologies traditionally applied during service are the same already seen for manufacturing: VT, MPI (or ET), PT and UT.

2.1 Visual Testing (VT)

The simplest investigation techniques are based on visual checks, which are mainly devoted to locate surface or, in some cases, sub-surface cracks and to evaluate their surface extension (but not their depths).
In Industrial applications, there are certain regions that can't be accessed through the naked eye and there Remote Visual Inspection methods prove to a promising solution. Even the facts recorded by these instruments can be further utilised for the purpose of R&D analysis. At Thermal Power Stations Visual Inspections are

mostly performed manually. But however, in recent years with prosper of technology certain advanced methods are used (Bachschmid et al., 2010).

2.2 Magnetic Particle Test (MPI)

This NDT technique is based on the concept that when the continuity of a magnet is broken (due to cracks, non-ferromagnetic inclusions, etc.), a north and south pole will form at each edge of the discontinuity.
Consequently, a so-called "flux leakage field" due to this double localized polarity is generated. If magnetic particles are sprinkled, they will be attracted, by magnetic field gradients, to and cluster not only at the poles at the ends of the magnet, but also at the poles at the edges of the crack. This cluster of particles is much easier to see than the actual discontinuity and this is the basis for magnetic particles inspection.
It is then obvious that, for a successful application of MPI, the material has to be ferromagnetic. It is useful to remember that some stainless steels have a magnetic permeability too low to allow the use of this technique.
It is also worth noting that MPI permits to reveal not only surface breaking defects but also sub-surface ones, at least until the flux leakage, and not the defect, is surface breaking.
The steps for the inspection are the following (Bachschmid et al., 2010):

- preparation of the surface to be inspected;
- magnetisation of the component to be inspected;
- sprinkling of magnetic particles;
- visual inspection;
- demagnetization of the component (if needed).

Different methods are available for the magnetization of the component: permanent magnets, magnetic yokes, electrical prods, coils and conductive cables. The most important aspect to be remembered is that magnetic inspection is more sensitive to discontinuities that are orthogonal to the magnetic flux direction. In the case of rotors, this means that the inspection, to be fully effective, should be carried out considering both longitudinal and circular magnetization. Just like liquid penetrants, also magnetic particles can be coloured or fluorescent.

2.3 Liquid (or dye) penetrant method (PT)

Liquid (or dye) penetrant testing is a non-destructive method used to detect surface breaking defects in any non-porous material. The steps are the following (Bachschmid et al., 2010):

- the surface is cleaned and prepared for inspection;
- liquid penetrant is applied to the surface and is drawn into cracks and pores by capillary action;
- after a preset dwell time, the liquid penetrant surplus is wiped off and the surface is dried;
- a developer (usually a chalk powder suspension) is sprayed on the surface in order to extract the liquid penetrant from possible defects;
- after a proper time for the development of indications, visual inspection is carried out in order to reveal defects;
- final cleaning of the surface.

If liquid penetrants are of the coloured type, they are visual checked in white light and the indications are revealed by the strong contrast between the colour of the penetrant (typically red) and the white colour of the chalk. If they are fluorescent, they are checked in black light (realised by means of a Wood's lamp) which evidences the

yellow-green ultraviolet (UV) shade of the penetrant. The fluorescent type of penetrant is more sensible than the coloured one, but it also requires higher investments (curtains in order to shadow the inspected parts and the lamp) in order to be carried out.

2.4 Ultrasonic Inspections (UT)

Ultrasonic inspections are based onto the measurement of the time of flight of high frequency sound waves introduced into the component at various surface locations. In particular, these beams of sound waves (that can be longitudinal, shear, surface, etc.) are transmitted from a probe and detected by the same or other probes. The interpretation of the reflection, refraction and diffraction echoes at particular boundaries leads to information about the discontinuities in the test piece. Since sound travels into many materials, the UT inspection method is the most widely used NDT technique and the only one, in particular, able to detect deep volumetric discontinuities and in conditions of difficult accessibility. The use of these techniques does not have limitations related to materials, except for those particularly porous or characterised by an inherently discontinuous structure (Bachschmid et al., 2010).

3. RESEARCH RESULTS ANALYSIS

3.1 Visual Inspection of the shaft turbine

Based on the results of the visual examination of the surface of the breakage of the shaft of the turbine A6 HPP "Djerdap II" in the transition zone R80, from the cylindrical part of the shaft to the flange to the hub of the impeller, it can be concluded that the shaft has been broken by the development of initial cracks formed on the surface of the transient radius R80 the consequence of the cyclic tensile stress in the corrosive environment (REVT, 2008).

Cyclic tensile stresses, which have a load on the shaft, correlated with corrosion in corrosion, have led to the occurrence of corrosion fatigue at the transient radius.

Tight corrosion damage, as far as the stress concentration is concerned, behaves as a crack, leading to their propagation, over a long period of exploitation, up to individual lengths of 20 to 30 mm. These were the initial cracks, whose rapid merging produced the dominant crack.

The dominant cracks have grown over a longer period of time, in conditions of high calcium fatigue in the corrosive environment of leaching water, which can explain the present products of corrosion on the surface of the fracture. The surfaces of this part of the fracture are relatively smooth, with pronounced corrosion.

At the sites of the close encounter of the dominant cracks, their joining is noticed, when stairs were created.

When the cross-sectional area in the cracks growth zone dropped below the critical value, the shaft breaks under lowcyclical fatigue conditions and the penetration of the oil from the interior, which can explain the absence of corrosion and after one year of standing on the surfaces of this part of the fracture. These surfaces are embossed, free from corrosion products, formed several hours before the aggregate stops and are very different from the surfaces described above, attributed to the operation of high-cyclical fatigue.

The steppe was created by the merging of the dominant cracks is shown in Figure 1.



Figure 1:*The steppe was created by the merging of the dominant cracks*

3.2 Magnetic particle testing of the shaft turbine

On the turbine shaft of Aggregate A6 at the hydroelectric power plant "Djerdap II" it was necessary to make a measurement using magnetic particle test method. It's executed testing of magnetic particles in the radius zone R80, at the transition from the cylindrical part of the shaft to the flange to the hub of the impeller.
In the whole area investigated, the existence of short linear indications in a series (lengths 5 to 50 mm) extending over the entire with (about 60 mm) of the transient radius and orientated administratively to the axis of the shaft. Photograph taken after testing with magnetic particles under UV light is shown on Figure 2 (REMT, 2007).

3.3 Penetrant method testing of the shaft turbine

An examination of the colored penetrants of the R80 radius of the passage from the cylinder part of the shaft to the flange to the hub of the impeller was performed.
The existence of an indication of the crack type in the radius zone from 0 to 2100 mm was observed (REPT, 2007).
The existence of linear and nonlinear indications of smaller lengths (from 5 to 20 mm) was observed in the radius zone from 2200 to 2800.
The appearance of the crack in the starting position is shown in the Figure 3.

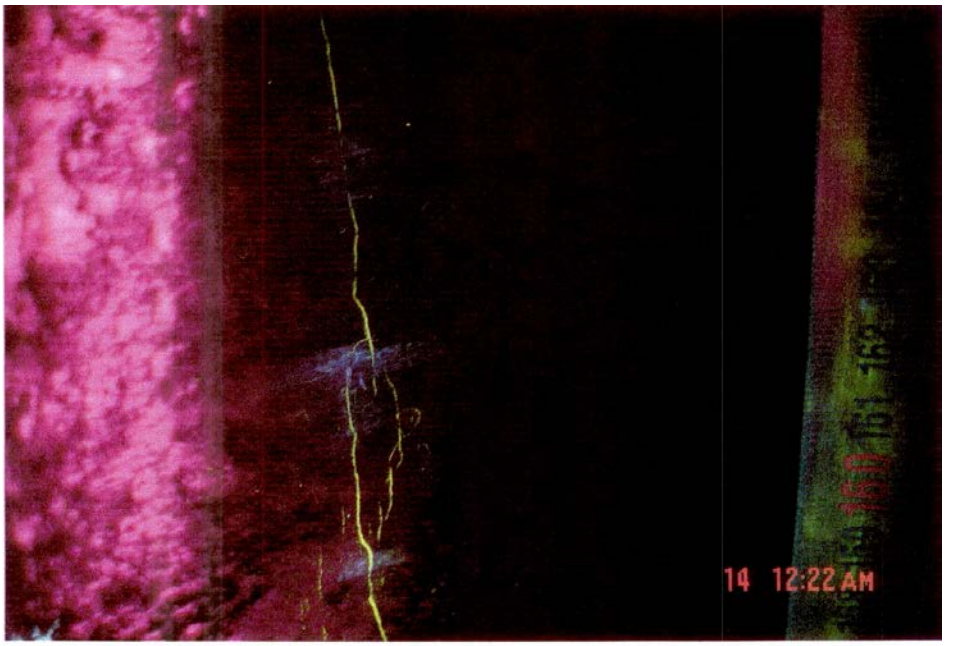


Figure 2*: Photograph taken after testing with magnetic particles under UV light*



Figure 3*: The look of the crack in the starting place*

3.4 Ultrasonic inspections of the shaft turbine

On the turbine shaft of Aggregate A6 at the hydroelectric power plant "Djerdap II" it was necessary to define the crack parameters in the passage zone of the cylindrical part of the shaft and the flange, using ultrasonic inspection. It was use impulse echo test method, with the Krautkramer USM-35S device.
On the basis of the findings determined according to the report LAB 02 UT-07-08, the homogeneity of the passage zone of the cylindrical part of the shaft and flanges was tested for the entire range by means of the spinning method l = 200 mm. A special activity is focused on defining crack parameters (depth and direction of expansion). It has been established:
In relation to the total crack length per surface (2600 mm), the most pronounced propagation was measured at a part of 400 -1600 mm, compared to the marked beginning.
The crack extends abutting (at an angle) to the geometric stepwise flange on the flange side, towards the hub of the impeller (805 mm). Each of the measuring axes (derivatives) is characterized by relatively different corresponding parameters.
The measured crankshaft values in the flange material are 220 mm.
The cracking spread across the entire cross-section (breakthrough zone) has not been fully confirmed due to the unprepared test surface, the inaccessibility of the most prominent zone, and the geometric flange limit relative to the available test surface.
Echograms of the measurement of crack spacing measurement at a distance 1200 mm are present at Figure 4 (REPT, 2007).

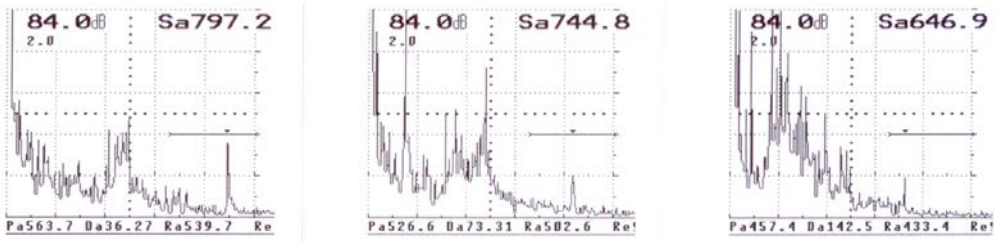


Figure 4: *Echograms of the measurement of crack spacing measurement*

5 CONCLUSIONS

In this paper are present measurements on the turbine shaft of Aggregate A6 at the hydroelectric power plant "Djerdap II".
In this study the analysis of the different NDT methods had shown that now there is optimal technique available. Different techniques can show different material properties and different defects.
Power plant life management and performance improvement critically reviews the fundamental degradation mechanisms that affect conventional power plant systems and components, as well as examining the operation and maintenance approaches and advanced plant rejuvenation and retrofit options that the industry are applying to ensure overall plant performance improvement and life management.
There are times when a single test method does not provide enough information about the material integrity and thereby combination of different methods is essential. Non destructive testing is widely applied in power plants.

It should be noted that advanced inspections are a key tool in aiding the analysis for the life analysis of components as accurate inspection data can help place older equipment back into service.

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OPTIMIZED TURBO MACHINES CONDITION MONITORING MODEL

Miloš Milovančević[1], Natalija Tomić[2], Ana Kitić[3]

Abstract: The optimization of a vibrodiagnostic model implies the definition of the minimum number of vibrodiagnostic formats which could be used for a precise and definite diagnosis of a broad range of failures or malfunctions with all types of rotational machines, e.g. turbo pumps in the standard use. In this investigation, the optimization is analyzed rather from the aspect of a new formulation of the optimization problem than from the aspect of the mathematical apparatus needed for the solving of the problem. In this case, the optimization is based on the establishing of the possibility of defect occurrence on turbo pumps and the implementation of causal relations between the diagnostic model and defined goal function values.

Key words: rotational machines, vibrations, diagnostics

1 INTRODUCTION

The optimization of a vibrodiagnostic model implies the definition of such a model which fulfills the condition for the minimum number of research vibration formats needed for the precise diagnostics of a broad range of defects on all types of rotational machines. Finding the optimal solution for a concrete structure of a defined application includes the selection of structure parameters so that the function of the set goal reaches the maximum value. Value functions that constitute the goal function represent the components used to form the final evaluation. Individual values of partial goal functions are defined with the weight factor, assigned to individual partial functions, depending on the priority of particular functions [3].

Values of partial functions depend directly on the optimization parameters, which are furthermore related to the basic independent variables. All these elements make the optimization hierarchy chain, which, in its integrity, represents the universal formula for finding the optimal solution [4].

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2 OPTIMIZATION PROBLEM

The function of the defined goal in our concrete example is the selection of an optimal vibrodiagnostic format set which provides the maximum possibility of the detection, selection and verification of the dynamic problem, together with the economic justification, and is simple to use. However, it is possible to conclude that the existence of dynamic problems is typical of certain types of rotational machines, which could be categorized into particular groups depending on the nominal power, speed, type of foundation, etc. According to the ISO 10816 standard, all machines are divided into four classes, and the references for the allowed level of vibrations, points for measuring vibrations, the way of measuring and the selection of measuring parameters are given for each class. Regarding the possibility of prospective dynamic problem causes, it is possible to bring together certain machine classes into two general groups [1, 2]:

- **GROUP 1 (G1)**
  - Class I machines according to ISO 10816-1, small machines with typically up to 15 kW electric motors;
  - Class II machines according to ISO 10816-1, medium machines with 15 kW to 75 kW electric motors, without special foundation, rotational machines with special foundation and with up to 300 kW electric motors [1].

The chief characteristic of this group of machines is embedment with rolling bearings. The most common causes of dynamic problems with this group of machines are: imbalance, rolling bearing defects, misalignment and support defects. Less frequent causes are defects of electrical origin, damages on the gears, defects caused by the effects of the aerodynamic and hydraulic force, defects in belt transmitters, defects caused by pulsation, and contacts between the rotor and stator [2, 3, 4, 5].

- **GROUP 2 (G2)**
  - Class III machines according to ISO 10816-1, large machines on rigid foundations;
  - Class IV machines according to ISO 10816-1, large machines on soft foundations [1].

Machines of this group may have sleeve or rolling element bearings. The most common causes of dynamic problems with this group of machines are: imbalance, misalignment, malfunctions on roller and sleeve bearings, support defects and resonance phenomenon.

Less frequent causes are defects of electrical origin, defects caused by the effects of the aerodynamic and hydraulic force, contacts (friction) between the rotor and stator, and anisotropy of the rotor [6, 7]. Based on our experimental research (over a thousand turbo aggregates were examined during the long-term research using also other sources from the literature [8]), frequency spectra components were statistically analyzed regarding causal dynamic problems in real exploitation conditions for these two groups of machines, as shown in the following tables:

Table 1. *Possibility of certain defect appearance on machines (G1)*

Damage type	
Misalignment	17.5%
Defects at roller and sleeve bearings	27.5%
Support defects	7.5%
Imbalance	40%

Other defects	7.5%

Table 2. *Possibility of certain defect appearance on machines (G2)*

Damage type	
Misalignment	15%
Defects at roller bearings	15%
Support defects	15%
Imbalance	25%
Other defects	15 %

*Tables contain data obtained in the scientific research project - optimization of turbo pumps exploitation, conducted in Niš / Water Supply Utility Company "Naissus"/

Each of these defects could be detected with certain probability, using the adequate vibrodiagnostic format, typical of this kind of defect.

When an adequate format set is selected, we start from the requirement for the minimum number of vibrodiagnostic formats which could precisely detect the existence of a certain dynamic problem cause in the machine systems. The minimum format set of vibrodiagnostics considered to be necessary, should consist of the measuring of the total vibration levels, the spectral analysis and the time-domain analysis. Other vibrodiagnostic sets are chosen to include the minimum number of vibrodiagnostic formats from a specific format group. The review of the chosen vibrodiagnostic sets is shown in Table 3.

Table 3. *Review of chosen vibrodiagnostic sets*

SET A	SET B	SET C	SET D	SET E	SET F	SET G
Measuring of total vibrations level	HFD level	Envelope spectral display	Bodeo's display	Cascade spectral display	Smax	Modal form of oscillation
Spectral display					X-Y position	
Polar trend display					Orbital display	
Time-domain analysis						

For finding the maximum of the established goal function independently for the mentioned machine groups, adequate diagnostic models were considered. A recommended composition of sets for intended/ applicable diagnostic models is shown in Tables 4a and 4b.

Table 4a. *Composition of sets for machines (G1)*

For GROUP 1 machines					
Marking	Model I	Model II	Model III	Model IV	Model V
Set composition	A	A+B	A+B+C	A+B+C+E	A+B+C+E+G

Table 4b. *Composition of sets for machines (G2)*

For GROUP 2 machines					
Marking	Model I	Model VI	Model VII	Model VIII	Model IX
Set composition	A	A+D	A+D+E	A+D+E+F	A+C+D+E+F+G

During the research we came to the conclusion that the optimal diagnostic model, i.e. the optimal vibrodiagnostic format set could be perceived in totality through these four value functions:

- dynamic problem cause identification,
- usage simplicity,
- early detection of the dynamic problem,
- economic aspect.

3 DYNAMIC PROBLEM CAUSE IDENTIFICATION

The probability for the occurrence of a certain dynamic problem in real conditions of exploitation is taken into consideration while generating the value function according to this criterion. Furthermore, each of the vibrodiagnostic formats provides a part of information regarding the existence of the given problem, so the probability of the problem detection for a certain format must be considered also. By analyzing the previous facts we can come to an equation for the calculation of the value function for certain vibrodiagnostic formats, i.e. vibrodiagnostic format sets, according to this criterion [8]:

$$V_D = \frac{\sum_{1}^{n} V_{Phenomena} * V_{Detection}}{100} \tag{1}$$

V_D identification of dynamic problem cause,

$V_{Phenomena}$ partial probability of distinct defect occurrence,

$V_{Detection}$ probability of dynamic problem cause detection,

n number of selected sample groups, for (G1) n=350, for (G2) n=400

The value function for some of the chosen models (vibrodiagnostic format sets) for machines (G1), according to the criterion of the dynamic problem cause identification, is shown in Tables 5a and 5b.

Table 5a. *Function value according to the criterion of dynamic problem cause identification for (G1)*

Analyst type	Γ
Model I	80.5%
Model II	85.5%
Model III	89%
Model IV	90.5%
Model V	91%

Table 5b. *Function value according to the criterion of dynamic problem cause identification for (G2)*

Analyst type	Γ
Model I	81%
Model VI	87%
Model VII	90%
Model VIII	92.3%
Model IX	93.7%

*Tables contain data obtained in the scientific research project conducted at the Faculty of Mechanical Engineering in Niš

4 SIMPLICITY IN DERIVATION AND APPLICATION

According to this criterion, the value function will be formed considering the following parameters with the specific significance coefficient (k_Z):

1. Setting and adjusting of the instruments $k_Z = 0{,}3$
2. Dynamic problem cause recognizability, $k_Z = 0{,}3$
3. Installation of measuring sensors, $k_Z = 0{,}2$
4. Memorizing and result transmission, $k_Z = 0{,}2$

Simplicity in derivation and use is defined as:

$$K = \sum_{i=1}^{4} k_Z^i \cdot V_{Parameter}^i \tag{2}$$

k_Z significance coefficient

$V_{Parameter}^i$ value of specific parameters

Table 6. Simplicity in derivation and use

Analyst type	ξ
Model I	100
Model II	100
Model III	87,5
Model IV	62,5
Model V	40
Model VI	75
Model VII	52,5
Model VIII	37,5
Model IX	12,5

5 EARLY DETECTION OF DYNAMIC PROBLEM CAUSES

While forming the value function according to this criterion, similarly to the first criterion, the probability for the occurrence of certain dynamic problems is considered in real exploitation conditions, along with the probability of early problem detection for the chosen specific format set. By analyzing the previous facts, it is possible to obtain the equation for the calculation of the value function for specific vibrodiagnostic format sets.

$$V_D^R = \frac{\sum_{1}^{n} V_{Phenomena} * V_{Early\,\det ection}}{100} \tag{3}$$

V_D^R value function according to the criterion of early dynamic problem cause detection,

$V_{phenomena}$ partial probability of specific defect occurrence,

$V_{Early\,\det ection}$ probability of dynamic problem cause detection in the early phase of formation,

n number of selected group samples.

According to this criterion, the value function for some of the chosen models (vibrodiagnostic format sets), for different machine groups, is shown in the following tables [8].

Table 7a. *Value function for machines G1*

Analyst type	Ψ
Model I	37,5
Model II	60
Model III	62
Model IV	74
Model V	76

Table 7b. *Value function for machines G2*

Analyst type	Ψ
Model I	50
Model VI	72
Model VII	81
Model VIII	88.5
Model IX	90

*Tables contain data obtained in the scientific research project conducted at the Faculty of Mechanical Engineering in Niš

6 ECONOMIC ASPECT

While forming the value function according to this criterion, the following parameters will be considered, with estimated significance coefficients [9, 10, 11]:

- Price of instruments, $k_z=0,3$
- Price of program support, $k_z=0,3$
- Maintenance costs, $k_z=0,3$
- Costs of operator training and necessary expert advice, $k_z=0,1$

Some of the value function parameters could have one of the given values: 25, 50, 75 or 100. Specific parameter values for certain models are given in Table 8, where greater number is related to lower cost.

Table 8. *Value parameters for economic function*

Analyst type	Price of hardware	Maintenance costs	Training costs	Price of software
Model I	100	100	100	100
Model II	75	100	100	75
Model III	75	75	75	50
Model IV	75	50	50	25
Model V	25	25	25	0
Model VI	100	75	75	75
Model VII	100	50	50	50
Model VIII	25	0	25	25
Model IX	0	25	25	0

Calculate the value functions for specific chosen models, according to the estimated criterion, using the following equation.

Economic aspects
$$E = \sum_{i=1}^{4} k_Z^i \cdot V_{Parameter} \tag{4}$$

k_z coefficient of parameter significance,

n values of specific parameters.

The value function for specific models is shown in Table 9. From the economic aspect, Model I is the best solution.

Table 9. *Economic aspect of considered analyst models*

Analyst type	Economic aspect
Model I	100
Model II	92,5
Model III	82,5
Model IV	65
Model V	17,5
Model VI	82,5
Model VII	65
Model VIII	42,5
Model IX	10

7 FUNCTION VALUE OF THE ASSIGNED GOAL

The value functions for the considered analysts are shown in the following tables, regarding the considered machine groups.

Table 10a. *Value functions of considered analyst models for machines (G1)*

GROUP 1				
Analyst type	Identification of dynamic problem	Simplicity in derivation and use	Early detection of dynamic problem	Economic aspect
Model I	80,5	100	37,5	100
Model II	85,5	100	60	92,5
Model III	89	87,5	62	82,5
Model IV	90,5	62,5	74	65
Model V	91	40	76	17,5

Table 10b. *Value functions of considered analyst models for machines (G2)*

GROUP 2				
Analyst type	Identification of dynamic problem	Simplicity in derivation and use	Early detection of dynamic problem	Economic aspect
Model I	81	100	50	100
Model VI	87	75	72	82,5
Model VII	90	52,5	81	65
Model VIII	92,3	37,5	88,5	42.5
Model IX	93,7	12,5	90	10

After the completion of the value functions calculation, it is possible to provide the final result on the optimal vibrodiagnostic format set for the considered machine groups.

The specific values of the significance levels for the corresponding value functions are given as follows:

- identification of dynamic problem cause *y=0,5*
- simplicity in derivation and use *y=0,2*
- early detection of dynamic problem cause *y=0,2*

- economic aspect *y=0,2*

The goal function is formed from the already defined value functions, taken with the corresponding significance level. So, the value of the goal function can be calculated by using the following equation:

Value of goal function: $\Delta = \Sigma y_i \cdot V_i$

V_i value of corresponding value function

y_i specific significance level of corresponding value function

The calculated values of the goal function for specific models are given in the following tables:

Table 11a. *Value of goal function of considered model for machines (G1)*

Analyst type	Goal value (Δ)
Model I	78,75
Model II	84,00
Model III	82,65
Model IV	79,05
Model V	70,45

Table 11b. *Value of goal function of considered model for machines (G2)*

Analyst type	Goal value (Δ)
Model I	80,5
Model VI	81,2
Model VII	78,2
Model VIII	75,6
Model IX	67,4

8 CONCLUSION

The examination of the vibration phenomenon provides data on the volume of working parameter changes and the intensity of vibrations. On the basis of the obtained results we evaluate the safety level for the pump and the whole plant. Furthermore, in most cases it is necessary to determine the cause of non-stationary occurrences that should be either removed or amortized. The working ranges that should be avoided are determined in many cases. Primary sources of vibrations on centrifugal pumps are mechanical, hydraulic and electric processes caused by the design of a pump, its manufacturing technology, working regime and exploitation.

From previous analyses we can conclude that the optimal composition of vibrodiagnostic format sets, (which have maximum possibility of the identification of dynamic problem causes, along with the probability of early defect detection and simplicity in derivation and use, considering the economic aspect also), are found in the following models:

For GROUP 1 (G1) machines – the optimal vibrodiagnostic model is **Model II**. Its program structure includes the basic format set and a HFD level display.

For GROUP 2 (G2) machines – the optimal vibrodiagnostic model is **Model VI**. Its program structure includes the basic format set and a Bodeo's display.

This is one way of how to perform the optimization of vibrodiagnostic models, i.e. how to choose the optimal analyst models, which in their programme structure include the presented vibrodiagnostic format sets.

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FUZZY LOGIC IN MACHINE CONDITION MONITORING

Miloš Milovančević[1], Natalija Tomić[2], Ana Kitić[3]

Abstract: In this paper, a low-cost optimal micro configuration of measurement and status monitoring of the data collection system of pellet mills power transmission is introduced. The scheme is founded on the PIC (Programmable Interface Controller) microcontrollers and represents the complete solution for condition monitoring regarding vibration, temperature and RPM measurement. The microcontroller based system also delivers an integrated function with a control application based on fuzzy logic.

Key words: Condition monitoring, Fuzzy logic, Vibrations

1 INTRODUCTION

The goal of the predictive condition monitoring of planetary power transmissions in pellet mills is to indicate deterioration in the condition of the power transmissions before the actual failure occurs. In many instances, the flaw does not have an immediate disruption of the operation. If this is the case, the defective part can be replaced or fixed during normal, scheduled maintenance periods, offered that the blemish has been ground in a sufficiently early point. The most usual cases of failure of rotary machines are faults in bearings, the stator and the rotor.

Thither are many methods for the predictive condition monitoring of rotary machines. The analysis can be established on different measured quantities. These include, for example, temperature, current, magnetic flux density and vibration.

The basic design idea is to create a measurement and data aggregation system for condition monitoring in which the data analyses and decision-making are based on fuzzy logic programming.

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2 CONFIGURATION FOR CONDITION MONITORING

The data aggregation system for a pellet mill consists of several sensor units attached to data-collecting units. In that location can be one or more collector units all having one or more sensor units connected. In order to keep the sensors inexpensive, they are based on a simple microcontroller with no external memory. Thus, the collector units provide a temporary depot for the measurement data. If a particular measurement generates data more than the internal RAM of the microcontroller can store, the data transmission between the sensor unit and the collector unit has to be in genuine time. Nevertheless, the data transmission from the collector unit, onward can be slower and can be packet-based.

The advantages of a multichannel collector unit realization include a simple communications protocol, because each transmission line takes in only one communicating pair, the collector unit and the sensor unit. Furthermore, the interface between the sensor unit and the transmission cable can be made fixed (i.e. Connection-less), so creating the connection both more authentic and less expensive. In the case of the bus based realization, the connections can be made fixed too, but this makes it very difficult to modify an existing system. Moreover, in the event of the multichannel collector unit, the whole system is more reliable, since a defect in one position of the line cancels the connection between the collector unit and single sensor unit only, instead of, in the worst instance, hitting all of the sensors unavailable to the collector unit.

2.1 MEMS- *(Micro-Electro-Mechanical Systems)* sensor application

A sensor unit with the capability of measuring acceleration and temperature was developed. The unit was based on Ana¬log Devices' ADXL311 micro machined accelerometer. The ADXL311 was found suitable for bearing condition monitoring when vibration levels were not especially high, within the region of ±5g. The acceleration signal was sampled at a frequency of 20 kHz and digitized using 12 bits [1, 2].

The duration of one vibration measurement was set to 32768 samples, and each sample was padded to 16 acts. It could be estimated that the space needed to lay in one acceleration measurement was 64 kilobytes, which was far more than the content of the internal SRAM of the microcontroller. Thus, the measured data needed to be transported to the collector unit in actual time. The minimum acceptable transfer rate could be figured when the sampling frequency and the duration of a sample were known. With a sam¬pling frequency of 20 kHz and 16 bits per sample, this was 320,000 bps.

2.2 PIC microcontroller application

The PIC is a family of Harvard architecture microcontrollers made by Microchip Technology, derived from the PIC1640 originally developed by General Instrument's Microelectronics Division. The name PIC initially referred to "Programmable Interface Controller".

The collector unit features the Microchip PIC16F877A microcontroller with 64 kilo words of 16-bit wide external SRAM memory. This memory is used to store the measurement data fetched from the sensor units. Its capability is sufficient to have two of the previously described vibration measurements at a time.

2.2.1 Kernel architecture

The PIC architecture is distinctively minimalist. It is qualified by the following characteristics:

- Separate code and data spaces (Harvard architecture),
- A modest number of fixed length instructions,
- Most instructions are single cycle executions (4 clock cycles), with single delay cycles upon the branches and skips,
- A single accumulator (W), the use of which (as source operand) is implied (i.e. is not encoded in the opcode),
- All RAM locations function as registers of both source and/or destination of math and other functions,
- A hardware stack for storing return addresses,
- A fairly small amount of addressable data space (typically 256 bytes), extended through banking,
- Data space mapped CPU, port, and peripheral registers,
- The program counter is also mapped into the data space and writable (this is used to implement indirect jumps).

Unlike most other CPUs, there is no distinction between memory space and register space because the RAM does the job of both memory and registers, and the RAM is usually just referred to as the register file or simply as the registers.

2.2.2 Data acquisition and processing

The collector unit acts as a master on the sensor bus. But by its request can a sensor unit start sending data. The collector unit initiates the information transfer by sending an attention sequence followed by the routine of the sensor the request is addressed to and the number of the measurement wanted. After broadcasting the request, the collector unit starts to listen for incoming data from the sensor bus and store it in the memory. When there is a pause long enough in the incoming data or the transmission has exceeded a set time limit, the collector unit deems the transmission stopped. The routine of the detector and the measurement as well as the commencement address of the storing of the measurement can be define by the user of the collector unit. The amount of data the measurement should generate can also be set, which builds it possible for the collector unit to estimate whether the measurement is successful or not. On the whole, the collector unit is versatile in the gumption that it can be utilized to regain data from many dissimilar types of sensors or other devices [3].

In that respect are various possibilities for realizing communications from the collector unit to a higher degree in the information base. Setting up new cables is not usually economically feasible. Alternatively, wireless communications or existing infrastructure, such as field buses or power cabling, can be applied. In the developed system, the physical connection was gone through with a similar RS-232 connection as in the example of the sensor bus. A picture of the newly developed collector unit is presented in Fig. 1.

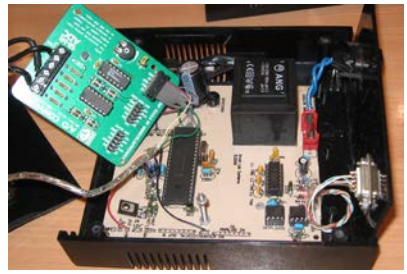


Figure 1. *Optimal PIC based monitoring system*

The optimal micro system shown in Fig. 1 is shown disassembled. The scheme delivers a main table, where microcontroller is imbedded. A little electronic circuit card with ADC is added and connected to the main instrument panel through the SPI communication protocol.

2.3 PIC initiation algorithm

The optimal micro configuration based on PIC microcontroller is created as a complex integrated system in Figure 2. Condition monitoring based primarily on vibration, but also on temperature measuring is not the only social function as it can be saved from the algorithms. The microcontroller is programmed to simultaneously collect data from sensors and to control relays in order to have a full pellet mill working order control based on fuzzy logic [4, 5].

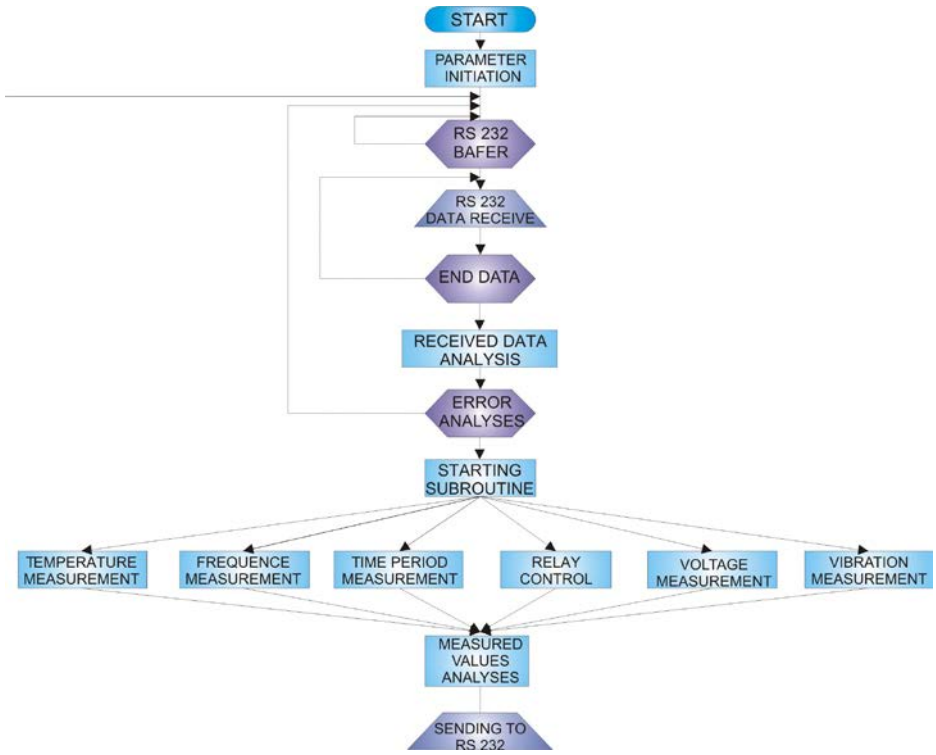


Figure 2. *PIC initiation algorithm*

3 PELLET MILLS CONDITION MONITORING

Wood pellets are a case of wood fuel, mostly made from compact sawdust. They are normally brought forth as a byproduct of sawmilling and other wood transformation activities. The pellets are extremely dense and can be produced with a low humidity content (below 10%) that allows them to burn with a very high combustion efficiency. Further, their regular geometry and small size allow automatic feeding with very fine calibration. They can be feasted to a burner by auger feeding or by pneumatic conveying.

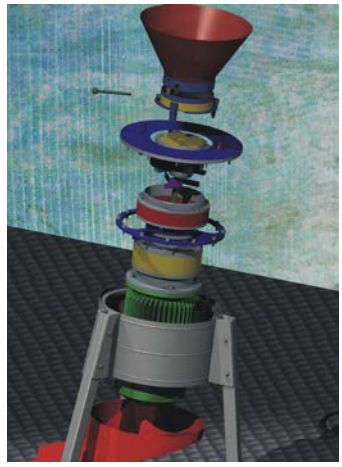


Figure 3. *Exploded 3D view of pellet mill*

Pellets are produced by compressing the wood material which first passes through a hammer mill to provide a uniform dough-like mass. This mass is fed into a press where it is squeezed through a die having holes of the required size (normally 6 mm in diameter, sometimes 8 mm or larger). The high pressure of the press causes the temperature of the wood to increase greatly, and the lining post-office slightly, forming a natural 'glue' that holds the pellet together as it cools.

In order to obtain a complete pellet mill monitoring, the optimal micro configuration system (see Fig. 1) was developed on a PIC16F877A microcontroller platform. To enhance system resolution from 10-bit to 12-bit, ADC-MCP3204 was added. The system was developed a new both from the aspect of hardware and software at the Faculty of Mechanical Engineering in Niš.

The optimal configuration for vibration monitoring is created by applying axiomatic design postulates to incorporate industry demands in functional requirements and design parameters [6].

Apart from the applied condition monitoring techniques at a subsystem level (die temperature, planetary power transmission vibrations), there is already a lot of information available in the pellet mill. Usually, this information is only used at the level of safeguarding. Thus, temperature monitoring is of importance, since over-heating of the die can cause pellets deformation or collapse. Exceeding the alarm levels often simply results in a pellet mill shut down and then wait for remote restart or repair. By

application of more advanced methods of signal analysis, focused on the trends of representative signals or combination of signals, significant changes in mill behavior can be detected at an early stage [7, 8].

3.1 Fault detection

Nowadays, condition monitoring of a pellet mill system is restricted to the individual performance of the servo motors themselves at the level of detection of maximum current, as shown in Fig. 4. However, model based condition monitoring of all three servo systems is a promising possibility in this situation. Model based condition monitoring is suitable for non-stationary operation.

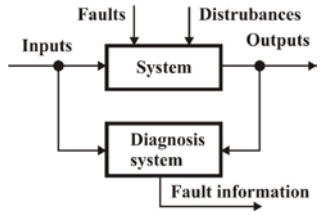


Figure 4. *Principle of model based fault detection*

The diagnosis can be based on the residual of the process and estimator output signals (see Fig. 5). In this situation, a constant model is used. The difference between the output of the system and the output of the model can be monitored. A trend analysis of this residual can be used to detect the changing characteristics of the system [9].

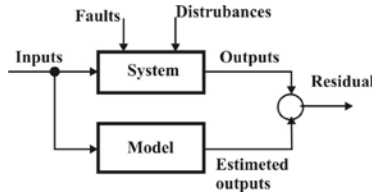


Figure 5. *Fault estimation based in residual*

Another possibility of model based fault detection is continuous estimation of the model parameters, based on the measured I/O values and monitoring of trends in the parameters (see Fig. 6). The performance strongly depends on the accuracy of the estimation procedure. It is important that the number of I/O signals and the measurement accuracy of these signals be able to detect changes in trends at an early stage.

Because the application of this technique is very specific for this operation, the algorithms were developed. This required specific knowledge of the system, control and model development. On the other hand, the application of the technique in a real pellet mill does not or hardly requires additional hardware and sensors [10].

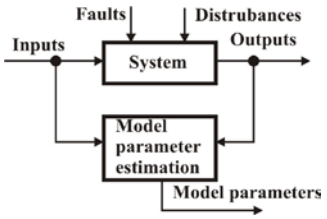


Figure 6. *Fault estimation based on model parameters*

3.2 Gear transmission vibration monitoring

There are three types of controllers that are applied in the management of a pellet mill:

1. Hardware PID (*Proportional–Integral–Derivative*) controllers,
2. Software PID controllers,
3. Fuzzy-based controllers.

The application of hardware and software PID controllers is difficult because there are significant problems in determining the parameters of the controllers themselves [10, 11].

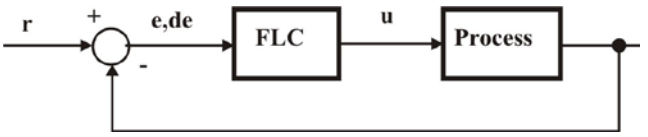


Figure 7. *Fault estimation based on fuzzy logic decision*

These parameters depend on the system design and are usually to be determined experimentally during the first hours of exploitation of a pellet mill. This process of determining the parameters can be very long and uncertain and accompanied by emergency situations. A software regulator is time consuming, despite the existence of an automatic function for determining the relevant parameters. The application of fuzzy logic based controller solves these problems (Fig. 7). The implementation of fuzzy logic in pallet mill condition monitoring is based on regulation of rotation velocity depending on input (vibration and temperature) parameters. The planetary gear transmission is the focus of input parameters monitoring since it deters mill production process.

The designed pellet mill has one stage planetary power transmission manufactured by GOSA FOM with following characteristics: transmission ratio i=9, power P=30kW and input rpm nin=1470 rpm. The newly developed planetary power transmission is applied in the pellet mill, with the research being part of the project for pellet mill development. The planetary transmission is of type , variant (Fig. 8) with two central gears, one with external, and the other with internal gearing (tooth numbers and), satellite carrier and satellite, double in this variant (tooth numbers and). One line of satellites is in contact with the central sun pinion (a) and the other with the internal gear (toothed rim)- , making external and internal geared pairs with equal centre distance. The toothed rim is an immovable element. The rational gear ratio in this type of transmission is 7/16 with approximate efficiency of 0.99□0.97.

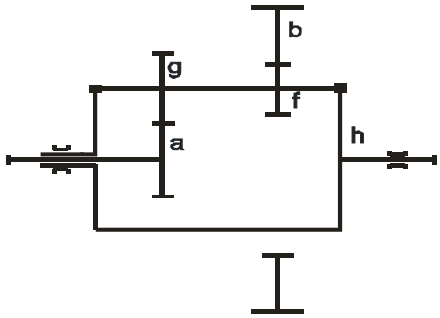


Figure 8. *Type 2K – h variant B planetary gear*

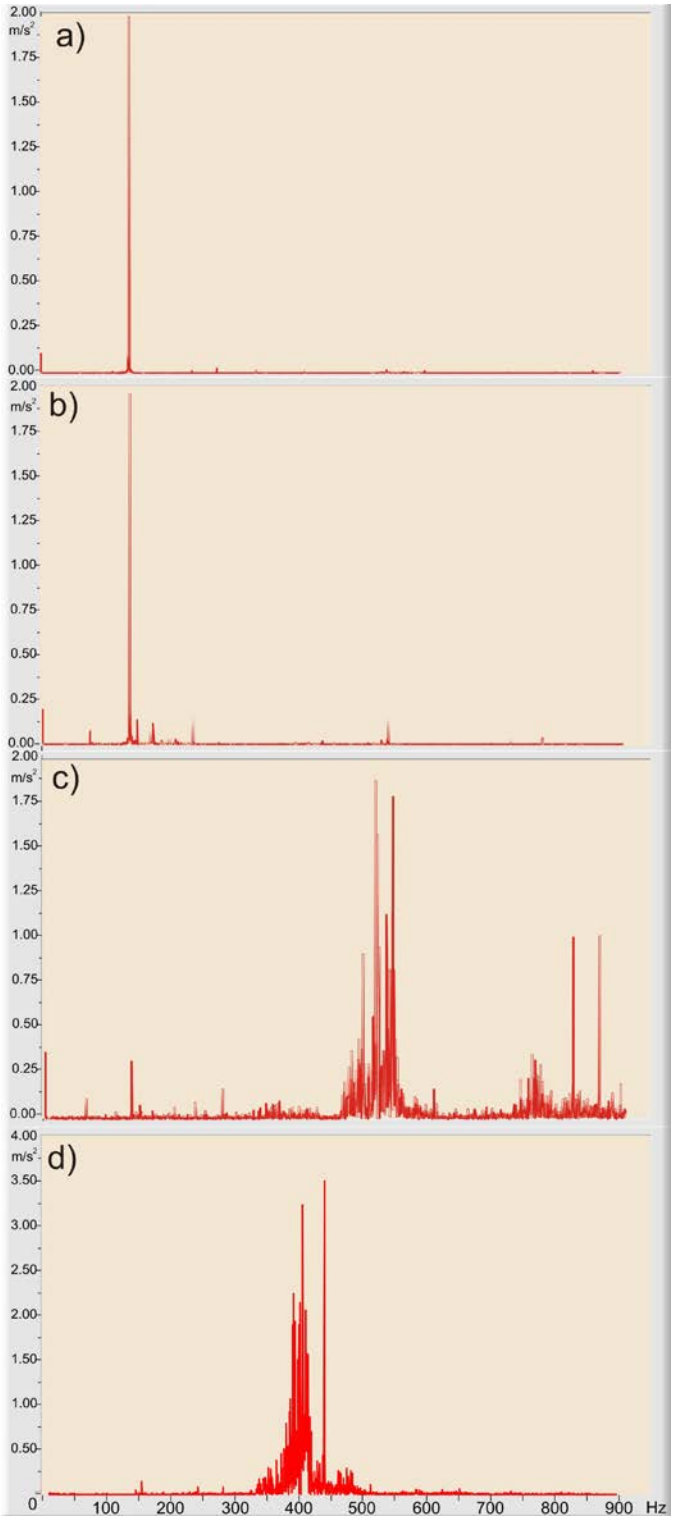


Figure 9. *Example of fault detection based on FFT*

The fault detection is often based on frequency analysis and level detection for certain frequency bands. Based on the level of amplitudes, status signals can often be defined and generated. Presented diagrams of fault detection based on FFT analyses are a product of newly developed software for vibration signal acquisition and analyses (Fig. 9).

Vibration diagram a) in Figure 9 represents a vibration spectrum of the planetary gear transmission in regular working order. Wood feeding to press was automatically controlled during vibration monitoring. Vibration diagram b), in Figure 9 is a vibration spectrum that is different from vibration spectrum a) because wood humidity has changed. Vibration spectrums c) and d) in Figure 9, were captured while wood feeding of the press was switched off. At first, vibration spectrum c) showed a wide vibration spectrum with amplitudes of up to 1,75m/s2. After a certain period of time, the vibration spectrum narrowed and amplitudes were up to 3,5 m/s2, with the die temperature also increasing by 15%. During the data acquisition, rotation velocity was constant. Thus, without the rotation regulation, the production process is inefficient. The rotation velocity regulation in relation to input parameters is complex. The regulation is based on the idea that vibration acceleration and temperature fluctuations are controlled by constant rpm variations. Software for data acquisition and signal analyses was created and customized for planetary gear vibration monitoring. The analyses of pellet mill exploitation and the results of vibration monitoring using the newly developed configuration proved that strict industry requirements could be fulfilled completely by applying PIC technology.

4 CONCLUSION

The embedded system based on PIC microcontroller condition monitoring can be applied successfully for pellet mill monitoring and control. The integration of functional requirements, design parameters and industry demands resulted in the creation of a new software and hardware for pellet mills safeguarding. In other industries, condition monitoring provisions are normally separate systems, apart from the machine control and safeguarding functions. In this paper, the pellet mills monitoring was focused on an embedded, a microcontroller based integrated functional control system developed on fuzzy logic. The application of MEMS accelerometers and PIC microcontrollers in pellet mills condition monitoring has an important roll in expanding the product life cycle as well as in reducing production costs. Application of embedded system in pallet mills has proven to be possible in the sense of gear transmission vibration and die temperature monitoring. Also, fuzzy logic control of pallet mill based on vibration and temperature in relation to main shaft rotation is possible. The effectiveness of these systems is not yet evident, since prototype testing is completely different from exploitation tastings. Due to the non stationary operation, it appears to be difficult to develop effective algorithms for mills early fault detection, especially for variable speed operations. Practical experience builds up very slowly, because component degeneration is a slow process, and additional information about mill transmission gear loads and operational conditions is only fragmentarily available. Further research is this particular project is focused on integration of vibration/temperature monitoring, rotation and wood feed control. Embedded systems research in the first faze, is going to be oriented to further development of single chipset monitoring systems based on PIC technology and in the second faze energy harvesting in the function of mechanical systems condition monitoring.

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REVIEW OF PERFORMED RECONSTRUCTIONS OF MECHANICAL SYSTEMS

Rade Vasiljević[1], Dragan Pantelić[2]

Abstract: Problematics of the reconstructions plays an important role in the maintenance of machines. First of all, the goal of reconstruction is to avoid purchasing a new machine. In this sense, the aim of this paper is to look at some examples of published works in the area of reconstruction of mechanical systems. In those papers the examples of performed reconstructions of machines were shown. That some of the mentioned reconstructions of machines have been successfully realized shows the fact that after a decade and more of working it is still in exploitation use.

Key words: Mechanical system, Maintenance, Reconstruction

1 INTRODUCTION

Maintenance represents a set of measures and activities to prevent a failure or to eliminate a failure. There are several types of division of maintenance methods in numerous literature from the maintenance of mechanical systems. One of the given divisions is given in [1]. According to this division, basic activities in order to improve the technical characteristics of the system are modification and reconstruction. Modification represents an activity that achieves the adaptation of technical systems by using newer generation spare parts. Reconstruction of technical systems implies an activity by which it replaces the whole subsets, subsystems and systems with technical solutions that represent the current level of technical development. This paper considers the activity of reconstructing the mechanical systems in order to improve their technical characteristics. To better understand this problem, we give an overview of some performed reconstructions of the mechanical systems.

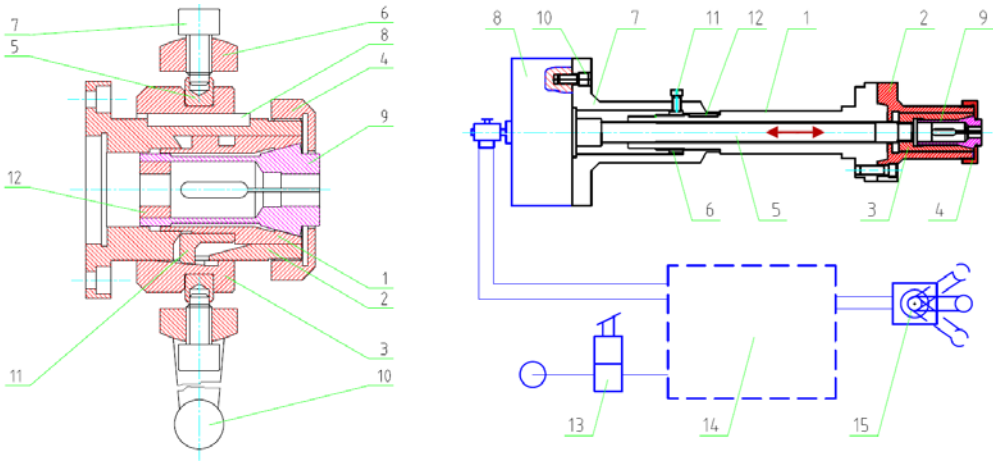
2 PROBLEMATICS OF RECONSTRUCTIONS IN MAINTENANCE

In this subheading, some examples of performed reconstructions of mechanical systems in which the technical characteristics are enhanced will be presented and outlined briefly. Details are given in appropriate works.

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2.1 Reconstruction of universal lathe

In paper [2], Pantelić and Vasiljević presented the reconstruction of the universal lathe using the pneumatic clamp in the company AutoValve J-SC from Užice. On the reconstructed object, the existing clamping solution (mechanical clamp, Fig. 1(a) was replaced by a newly-designed solution of the pneumatic clamp, Fig. 1(b)).



a) Mechanical clamp *b) Newly-designed clamping system*

Figure 1. *Reconstruction of universal lathe [2]*

Main parts of the mechanical clamp are: 1-collet holder, 2-collet chuck carrier, 3 - collet, 4-nut, 5-segment, 6-carrier, 7-hexagon hollow screw for adjustment, 8-flat wedge, 9-clamping collet, 10-activation tool handle, 11-clamping segment, and 12-collet insert.

Main parts of the newly-designed clamping system are: 1-axle, 2-flange of collet chuck, 3-collet chuck, 4-clamping nut, 5-clamping force transmission lever, 6-nut, 7-flange of rotating cylinder, 8-rotating cylinder, 9-collet chuck, 10 and 11-hexagon hollow screw, 12-flat wedge, 13- air tap, 14-control unit, and 15-activation side valve.

The newly designed clamping system of the workpiece (valve) is made so that the clamping shell serves as an executive body of the clamping device and performs the clamping of the valve. The existing constructive form of the shell is retained. The reconstruction ensured the reliable execution of a technological operation for removing surplus welds on the valve. A detailed description of the mechanical and newly projected clamp on the subjected universal lathe is given in [2].

Reconstruction of the clamping device significantly improved the operation of the same device. Analyzing the work of the newly designed clamping device, it has been established that in relation to manual (original) clamping, it has a number of advantages:

If you need to use a bullet list then this should be as follows:

- Significantly less time in mass, serial and medium-serial production;
- Greater processing accuracy;
- Small clamping force without the physical stress of workers;
- Easy and quick adjustment of the clamping force, which is especially suitable for clamping of the working items made of thin walls and softer material;
- Maximum safety of workers and machinery in the conditions of exploitation regarding the aspect of safety at work;

- Greater utilization of the machine.

Besides the technological operation on the valve, according to which a new clamping device is designed, other technological operations are successfully performed on the on the valve (eg. alignment of the valve head surface, drilling of valve guides, etc.).

The universal lathe with a newly-projected clamping system responded to the requirements of the production process. The costs of the performed reconstruction were several times lower than the cost of purchasing a new machine. This avoided the acquisition of a new lathe.

Positive assessment of the performed reconstruction has been confirmed by appropriate examinations and atest approvals. Finally, the success of the reconstruction of the object in question is indicated by the fact that in years of operation after reconstruction there have been no slowdowns due to the failure of the clamping device.

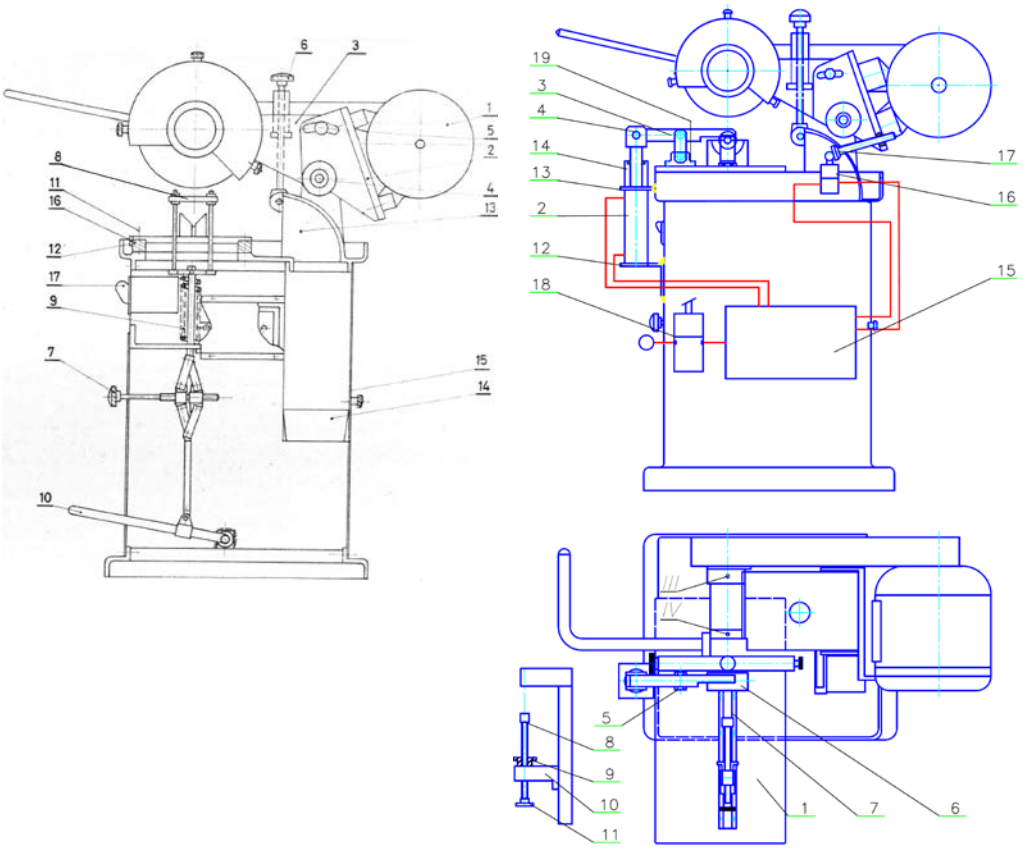
2.2 Reconstruction of abrasive circular

Pantelić and Vasiljević [3] presented the reconstruction of the abrasive circular using a pneumatic clamp. The subject reconstruction was carried out at the company AutoValve from Užice. The newly designed system of clamping of the workpiece (head of the valve) was made so that the existing structural shape of the circular was retained, only instead of the mechanical clamping mechanism (Fig. 2(a)), a newly designed projecting clamping mechanism - pneumatic clamp was integrated (Fig. 2(b)). Details of the description of the factory produced and the newly designed mechanism for clamping on the given circular are given in [3].

Reconstruction of the clamping device significantly improved the operation of the given device. Analyzing the newly developed solution of the pneumatic clamp on the abrasive circular in the technological process of preparing the surface of the valve head for the connection with the valve body it has been found that in relation to the factory solution it has the following advantages:

- Additional time in mass, serial and medium-serial production is significantly lower;
- The accuracy of processing is higher;
- Small clamping force is required which does not require a worker's physical stress;
- Higher degree of utilization of the machine is achieved;
- Seated workplace was obtained;
- Less processing time resulting in a larger number of finished pieces;
- Quick replacement and positioning of the clamping device;
- Easy and smooth adjusting of the limiter to the desired length of the valve;
- Easy distribution of the clamping force which is particularly important in clamping the thin wall pieces;
- Keeping the constant torque while under workload and overload.

Reconstruction of the clamping device significantly improved the operation of the given device. Analyzing the newly developed solution of the pneumatic clamp on the abrasive circular in the technological process of preparing the surface of the valve head for the connection with the valve body it has been found that in relation to the factory solution it has the following advantages.



a) Factory clamp b) Newly-designed clamp

Figure 2. *Abrasive circular [3]*

Main parts of the abrasive circular with factory clamp are: 1-electric motor, 2-panel, 3-console, 4-axle, 5-screw, 6-button for adjusting the pendulum, 7-button for lifting/lowering the clamp, 8-clamp, 9 - spring, 10-pedal, 11-nut, 12-plate, 13-hole, 14-pan, and 15-door.

Main parts of the abrasive circular for newly-designed clamp are: 1-base plate, 2-pneumatic cylinder, 3-lever-clamp, 4-clevis fastener, 5-lever, 6-tool carrier, 7-fixed limiter holder, 8 - spindle, 9 - safety nut, 10 - movable limiter holder, 11 - limiter handle, 12-lower limiter holder, 13-upper limiter holder, 14-guide, 15-preparatory group, 16-distributor 3/2, 17-activation bar, 18-cock, and 19-friction bearing.

2.3 Reconstruction of grinder with spikes

The authors of the paper [4] (Pantelić, Nedić and Vasiljević) described and illustrated the performed reconstruction of the grinder with the installation of a frequency regulator. The reconstruction facility was located in the production plant of AutoValve from Užice.

The scheme of the original solution of the electric motor drive of the grinder with spikes is shown in Figure 3 [4]. The scheme of a new-designed solution for the electromotor drive of the grinder with spikes is shown in Figure 4 [4]. Details of the implementation of the grinder reconstruction are given in [4].

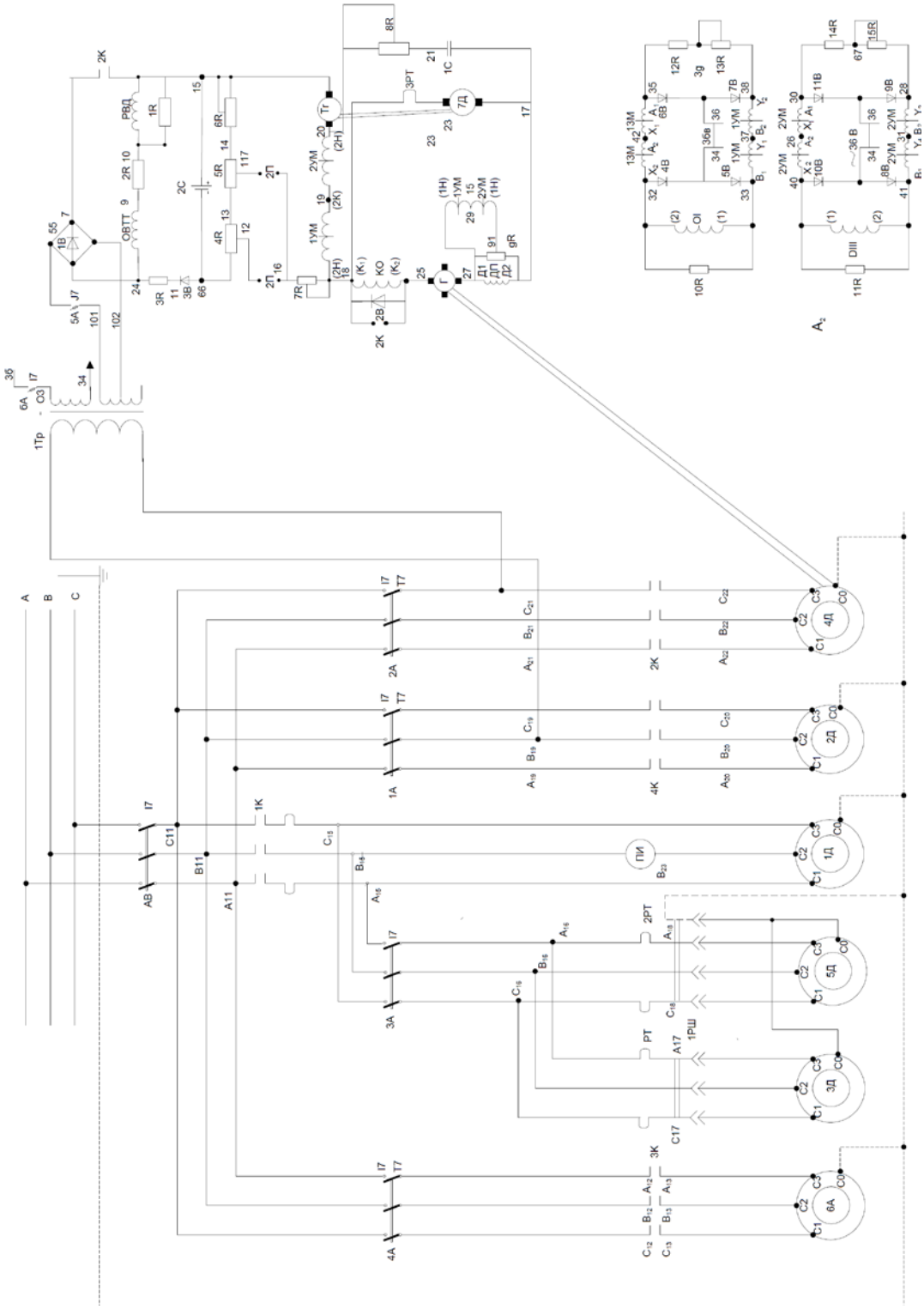


Figure 3. *Scheme of the original electromotor drive [4]*

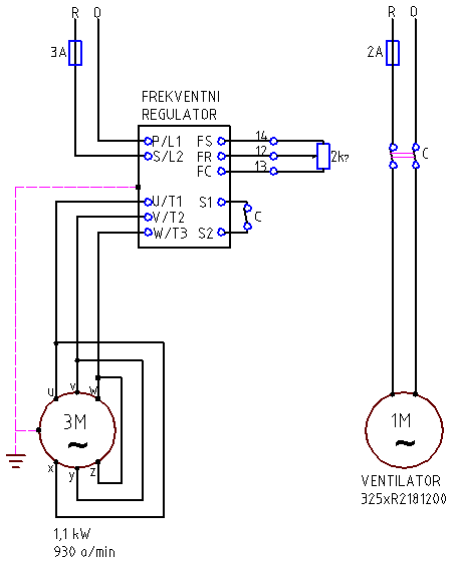


Figure 4. *Scheme of a new-designed electomotor drive [4]*

Replacing the original solution of the electromotor drive system with a new-designed solution eliminated diagnosed weaknesses in the production process.

The new-designed solution for the electric motor drive of the grinder with spikes has a number of advantages:

- The correct operation of the towing grinding stone, accordingly the required number of revolutions of the grinding stone;
- Energy savings because the speed of rotation of the drive motor of the wheel corresponds to the requirements at any moment of load;
- Optimizing production through cost reduction and at the same time increase in production;
- "Soft" operation of the machine with a significant reduction in stress and load stroke, and a reduction in maintenance costs because the preventive controller does not require absolutely no maintenance;
- Less maintenance cost because preventive regulator does not require any maintenance;
- Quick maintaning constant torque both in the operating regime and in the dressing regime.

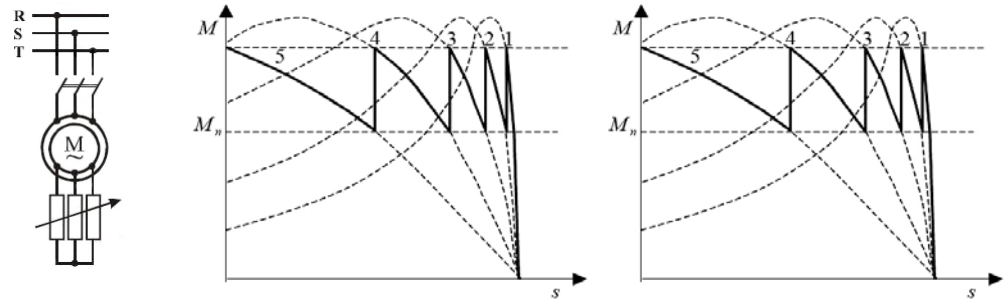
The grinder with a newly designed electromotor drive system responded to the requirements of the production process. The costs of the reconstruction were several times lower than the purchase cost of the new grinding machine, which avoided the acquisition of a new machine. The reconstruction of the considered grinder has been successfully carried out are confirmed by the appropriate tests and attests, while on the other hand, the success of the reconstruction is illustrated by the fact that in the exploitation of more than fifteen years after the reconstruction there were no delays due to the failure of the operating of the towing wheel.

2.4 Reconstruction of bridge crane

In the paper [5], a reconstruction of the crane was performed using a frequency converter. The subject crane is located at the Faculty of Technical Sciences in Novi Sad. The reconstructed reconstruction, by Dabić, Oros and Vasić, included two activities.

Within the first activity in the lifting unit (the slip rings asynchronous motor), the windings of the rotor are carried out on the slip rings and in this way it is possible to add external resistors to the wheel of the rotor (Figure 5(a)). Using the overcurrent resistor decades a slower run-off with weaker hitch is obtained, and the starting moment of the motor can be equal and transverse (Figure 5(b)).

In second activity, in order to slow down the run-off in the crane drive and the carrier drive, the so-called "KUSA" switch (type of soft release) (Figure 5(c)). An appropriate resistor is added to one phase of the motor, which after a few seconds of shutdown turns off ("bridges" with a timer switch). The details of the reconstruction of the subject crane were described in [5].



a) Slip-ring asynchronous motor with additional resistors in the rotor circuit

b) A family of mechanical characteristics obtained by changing the resistance of the rotor

c) "KUSA" switch of the asynchronous motor

Figure 5. *Reconstruction of bridge crane [5]*

A single frequency converter is installed on the bridge crane, which supplies three drives: a lifting device with a slip ring motor, a drive for moving the carrier with a cage asynchronous motor, and a drive for the movement of a crane with two separate asynchronous brake motors. By starting one of these drives, the appropriate setup on the frequency converter with the programmed parameters for that drive is selected. It is not possible to simultaneously operate two drives.

By installing a frequency controller for a crane a number of advantages are obtained:

- Launching and stopping without hitch;
- Holding the load in idle state without the use of an electrohydraulic brake;
- It is possible to continuously change the speed in a wide range regardless of the resistance of the working device;
- The possibility of achieving a "fine" working machine stroke, and therefore its precise positioning when stopping;
- By setting the rounded so called S-ramps for start-up and stopping are achieved without a hitch, much better than the "Kusa" system;
- Lesser influence of the change of network parameters (voltage and frequency) on engine operation;

- Energy saving at start-up, since it takes about as much energy from the power supply as it gives to the shaft as a mechanical force;
- Cheaper maintenance, and others.

The shortcomings of the frequency converter are:

- The output current always has a high-frequency part of the waves, which leads to increased omni-directional losses;
- Sudden increase in the output voltage causes a potential difference in stator windings;
- When installing frequency regulators on older generation motors (eg, the subject crane) there is a risk of breakdown of the insulation.

3 CONCLUSION

This paper presents four examples of reconstructions of mechanical systems in order to improve technical characteristics. Accent is given to machines tools and transport machinery.

Reconstructed mechanical systems responded to the requirements of the corresponding manufacturing processes in the industry. This avoided the acquisition of new mechanical systems. The costs of all reconstructions carried out were several times less than the costs of procuring new machinery systems.

The reconstructions of the considered machine systems have been successfully carried out according to the data which shows that in years-long exploitation after the reconstructions there were no delays at all.

Four presented examples of performed machine system reconstructions are useful material for engineers to solve similar problems in practice.

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MODEL POVEZIVANJA UPRAVLJAČKIH UREĐAJA U VOZILU KORIŠTENJEM SABIRNICA PODATAKA

Miroslav Grubišić[1], Boris Crnokić[2]

Rezime: Zbog povećanja broja mehatroničkih sustava ugrađenih u vozila, neophodno je povezivanje njihovih upravljačkih uređaja radi međusobne razmjene podataka. U ovom radu je analiziran način povezivanja upravljačkih uređaja u vozilu preko četiri sabirnice podataka, CAN, LIN, MOST i FlexRay u cilju izrade optimalnog modela njihovog međusobnog povezivanja. Primjenom ovog modela olakšao bi se proces dijagnostike mehatroničkih sustava u vozilu i njihovo održavanje.

Ključne riječi: dijagnostika, mehatronički sustavi, motorna vozila, sabirnice podataka

CONNECTION MODEL OF THE ELECTRONIC CONTROL UNIT IN A VEHICLE USING DATA BUSES

Abstract: Due to the increase in numbers of mechatronic systems installed in vehicles, it is necessary to connect their electronic control units to exchange data between one another. This paper analyzes the way of linking the electronic control units in the vehicle using the four data buses CAN, LIN, MOST and FlexRay in order to create an optimal model for their interconnection. Using this model would facilitate the process of diagnosing mechatronic systems in the vehicle and their maintenance.

Key words: diagnostics, mechatronic systems, motor vehicles, data bus

1 UVOD

Sve značajniji zahtjevi u pogledu sigurnosti i komfora vožnje u motornim vozilima, predstavljaju razloge što proizvođači ugrađuju veliki broj mehatroničkih sustava u svoja motorna vozila. Izravna posljedica toga je ugradnja velikog broja upravljačkih uređaja, različitih vrsta senzora i aktuatora, povećanje broja kabelskih snopova, problemi s iznimno velikim brojem konektora kao i potreba za sve učestalijom razmjenom podataka između upravljačkih uređaja. Kako bi se eliminirali ovi problemi i osigurala pravodobna razmjena podataka među upravljačkim uređajima potrebno je jedno pogodno cjelovito tehničko rješenje. Upravo sabirnica podataka nudi takvo rješenje. Sabirnica podataka podrazumijeva međusobno umrežene upravljačke uređaje koji na

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temelju mrežne tehnologije zasnovane na računalnoj tehnici vrše brzu međusobnu razmjenu informacija. Prijenos signala više se ne odvija preko pojedinačnih snopova kabela, nego preko zajedničke sabirnice podataka koju koriste svi upravljački uređaji. Pored navedenih prednosti, korištenjem sabirnice potreban je manji broj senzora, jer nakon mjerenja podatak se šalje svim upravljačkim uređajima kojima taj podatak treba, a zbog značajno smanjenog ožičenja javlja se ušteda u masi i cijeni. U mehatroničkim sustavima suvremenih motornih vozila u uporabi su slijedeće sabirnice podataka [1]:

- CAN,
- LIN,
- MOST,
- FlexRay.

Topologija jedne sabirnice podataka opisuje vrstu i način na koji su pojedini upravljački uređaji međusobno spojeni. U motornim vozilima primjenjuju se tri različite topologije sabirnica podataka i to [2]:

- zvjezdasta topologija
- linijska topologija
- prstenasta topologija.

Povezivanje automobilskih mehatroničkih sustava u jednu cjelinu preko sabirnica podataka provodi se kod svih proizvođača suvremenih automobila. Međutim, kako bi vozilo bilo cjenovno prihvatljivo i s druge strane suvremeno, potrebno je odrediti optimalan način povezivanja sustava primjenom odgovarajućih sabirnica podataka. U ovom radu je provedena analiza pojedinačnih sabirnica podataka na temelju čega su dobivene informacije o prednostima i nedostacima svake sabirnice i u skladu s tim izrađen je model umrežavanja upravljačkih uređaja automobilskih sustava.

2 SABIRNICE PODATAKA

Sabirnice podataka CAN, LIN, MOST i FlexRay su značajno zastupljene u suvremenim motornim vozilima. Svaka sabirnica podataka ima svoje karakteristike, a u tablici 1. je prikazana usporedba svih sabirnica koje se koriste u motornim vozilima.

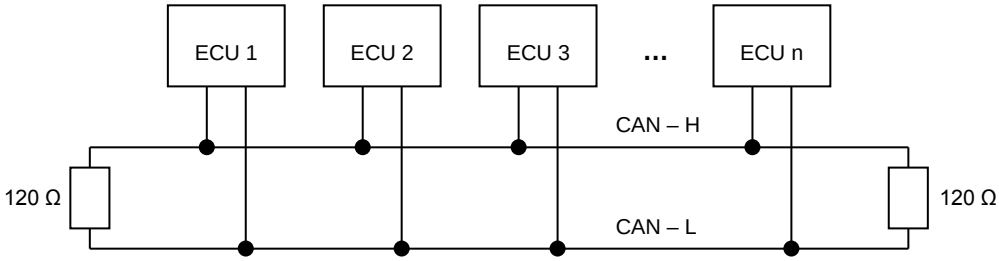
Tabela 1. *Karakteristike sabirnica podataka*

Naziv sabirnice	Maksimalna brzina prijenosa podataka	Medij za prijenos podataka	Topologija
CAN	1 MBit/s	Bakarni vodiči	Linijska
LIN	20 kBit/s	Bakarni vodiči	Linijska
MOST	50 MBit/s	Optički vodiči	Prstenasta
FlexRay	10 MBit/s	Bakarni i optički vodiči	Linijska i zvjezdasta

2.1 CAN sabirnica

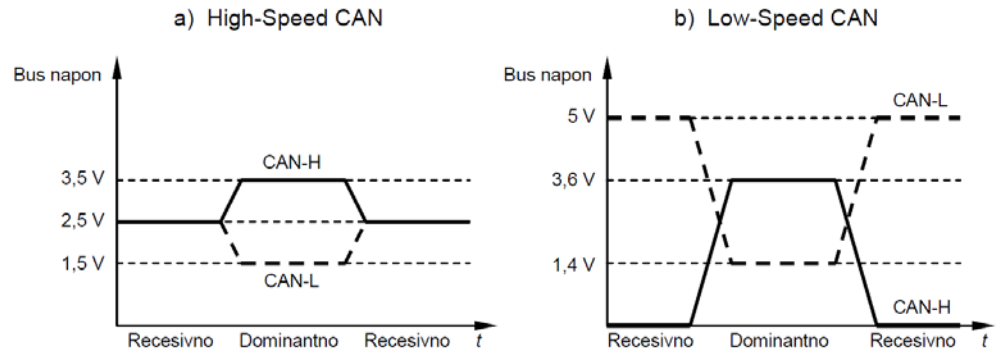
CAN-Bus (engl. Controller Area Network) predstavlja sabirnicu koja je razvijena specijalno za automobile i njenom primjenom omogućen je transport velikog broja informacija. Kod CAN sabirnice se informacije između upravljačkih uređaja razmjenjuju

preko samo dva vodiča, neovisno o broju informacija i sudionika (upravljačkih uređaja) na sabirnici. U ovisnosti o brzini prijenosa podataka, danas u primjeni postoje dvije vrste CAN sabirnica i to CAN s velikom brzinom (High-Speed CAN), koja koristi brzinu prijenosa podataka do 1 MBit/s i CAN s malom brzinom (Low-Speed CAN), koja radi s brzinama prijenosa podataka do 125 kBit/s. Zbog svoje velike i široke primjene CAN sabirnica je standardizirana [3, 4], što omogućava da se upravljački uređaji različitih proizvođača mogu međusobno spajati i razmjenjivati podatke. Na slici 1. prikazan je način povezivanja upravljačkih uređaja preko CAN sabirnice.



Slika 1. *Povezivanje upravljačkih uređaja preko CAN sabirnice*

Električni signali CAN sabirnice su u biti promjene napona na CAN vodovima. Kod High-Speed CAN sabirnice, u stanju mirovanja (logično stanje CAN transceivera 1) oba voda su na istoj naponskoj razini i ta vrijednost iznosi 2,5 V. Razina u mirovanju naziva se recesivno stanje, pošto ga je moguće promijeniti sa svakog priključenog upravljačkog uređaja na sabirnici. Kada se CAN transceiver nalazi u logičnom stanju 0, napon na vodu CAN-H raste za minimalno 1 V, a na vodu CAN-L opada za istu tu vrijednost (slika 2. a), a ovo stanje sabirnice se naziva dominantno [5]. Razlika napona između CAN-H i CAN-L voda u recesivnom stanju iznosi 0 V, a u dominantnom stanju minimalno 2 V. Kod Low-Speed CAN sabirnice (sabirnica komfornog i infotainment sustava) u recesivnom stanju napon na CAN-H vodu je 0 V, dok je na CAN-L vodu 5 V. U dominantnom stanju napon na CAN-H vodu iznosi 3,6 V, a na CAN-L vodu napon je 1,4 V, (slika 2. b), [5].



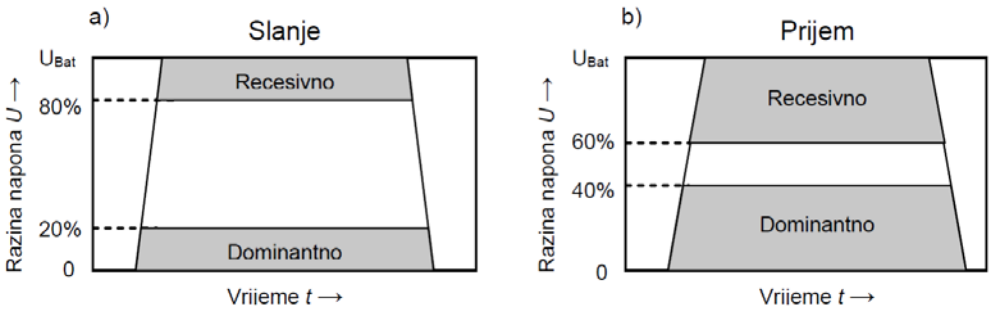
Slika 2. *Razina signala na High-Speed CAN i Low-Speed CAN*

Svaka CAN sabirnica se sastoji od slijedećih komponenti: CAN kontroler, CAN transceiver (odašiljačko i prijemno pojačalo), dva voda sabirnice i dva završna elementa. Osim vodova sabirnice sve ostale komponente nalaze se u upravljačkim uređajima.

2.2 LIN sabirnica

Povećano korištenje mehatroničkih sustava u motornim vozilima dovelo je do razvoja ideje o uvođenju jedne cjenovno povoljne sabirnice podataka koja bi bila alternativa za Lov-Speed CAN sabirnicu. Idući prema tom cilju stvorena je nova sabirnica nazvana LIN (engl. Local Interconnect Network). Kod LIN sabirnice se svi upravljački uređaji nalaze unutar jednog ograničenog ugradbenog prostora vozila (npr. krov, vrata i sl.), te se stoga LIN označava još kao i lokalni podsustav (Local Subsystem). LIN sabirnica se bazira na konceptu "Single Master / Multiple Slave" [5], što znači da postoji jedan upravljački uređaj "gospodar" (Master) i više uređaja "robova" (Slave). LIN koristi serijski komunikacijski protokol gdje se razmjena podataka vrši između LIN-Master upravljačkog uređaja i do maksimalno 16 LIN-Slave uređaja, a povezivanje ovih komponenti u svrhu razmjene podataka vrši se preko samo jednog voda. LIN sabirnica podržava maksimalnu brzinu prijenosa podataka od 20 kBit/s, što odgovara jednoj petini brzine prijenosa kod Low-Speed CAN. Zbog svoje niske cijene i velike učinkovitosti LIN–Bus ima značajnu primjenu u automobilima.

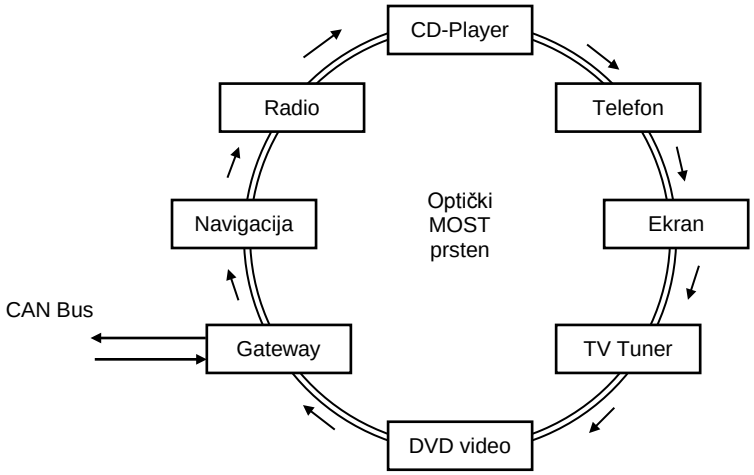
Kao i kod CAN sabirnice i LIN sabirnica može preuzeti dva logična stanja, recesivno i dominantno. Ukoliko se na LIN sabirnicu podataka ne pošalje poruka (logično stanje transceivera 1), tada na vodu sabirnice postoji električni napon koji odgovara naponu baterije (akumulatora) vozila U_{Bat}, a sabirnica se nalazi na recesivnoj razini. Prilikom slanja poruka preko LIN sabirnice (logično stanje 0), sabirnica se nalazi na dominantnoj razini a napon na vodu sabirnice iznosi 0 V. Da bi se osigurao stabilan i siguran prijenos podataka LIN sabirnicom uvedene su tolerancije pri slanju i primanju poruka u oblasti recesivne i dominantne razine. Prilikom slanja poruka tolerancije propisuju da se za recesivnu razinu koriste vrijednosti između napona baterije vozila U_{Bat} i do minimalno 80% vrijednosti U_{Bat}, a za dominantnu razinu naponi od 0 V do maksimalno 20% vrijednosti napona baterije vozila U_{Bat} (slika 3. a). Da bi se i pored nastalih smetnji mogli prihvatiti važeći signali, prilikom prijema poruka dopuštene su još veće tolerancije u područjima napona. Tako se za recesivnu razinu koriste vrijednosti između napona baterije vozila U_{Bat} i do minimalno 60% vrijednosti U_{Bat}, a za dominantnu razinu naponi od 0 V do maksimalno 40% vrijednosti napona baterije vozila U_{Bat} (slika 3. b).



Slika 3. *Razina signala na LIN sabirnici pri slanju i prijemu poruka*

2.3 MOST sabirnica

MOST–Bus (engl. Media Oriented Systems Transport) je sabirnica podataka koja je specijalno razvijena za umrežavanje multimedijskih i infotainment komponenti u motornim vozilima. MOST sabirnica omogućava velike brzine prijenosa podataka, do 25 MBit/s za varijantu sabirnice MOST25, do 50 MBit/s za MOST50 i do 150 MBit/s za MOST150 [7]. Pojam MOST (Media Oriented Systems Transport) označava mrežu sa medijski orijentiranim prijenosom podataka, što znači da se adresirane poruke dostavljaju točno određenom prijemniku. Informacije na MOST sabirnici se prenose putem svjetlosnih valova preko svjetlovodnih kabela (optičkih vodiča), a upravljački uređaji su povezani u strukturu prstena, tj. imaju prstenastu topologiju, slika 4.



Slika 4. *Prstenasta topologija MOST sabirnice*

2.4 FlexRay

FlexRay–Bus je sabirnica koja se koristi za povezivanje sustava u vozilu među kojima je potrebna velika brzina prijenosa podataka. FlexRay protokol primjenjuje brzinu prijenosa podataka do 10 MBit/s, a koristi linijsku i zvjezdastu topologiju, kao i njihovu kombinaciju [1]. FlexRay se koristi kod naprednih tzv. X-By-Wire sustava, koji u cijelosti zamjenjuju postojeće mehaničke i hidrauličke veze elektroničkim [5]. Elektroničko upravljanje funkcijom zakretanja prednjih kotača vozila predstavlja jedan primjer X-By-Wire sustava. Preko FlexRay sabirnice se poruke prenose putem definiranog komunikacijskog protokola u komunikacijskim ciklusima u trajanju od 5 milisekundi. S obzirom na činjenicu da se FlexRay nalazi još uvijek u razvoju, ona ima svojih prednosti i nedostataka u odnosu na CAN sabirnicu [8]. Šira primjena ove sabirnice očekuje se u budućem vremenu.

2.5 Model umrežavanja upravljačkih uređaja u vozilu

Kako su elektronički sustavi motornih vozila umreženi različitim vrstama sabirnica podataka (CAN, LIN, MOST, FlexRay) za funkcioniranje vozila, kao jednog cjelokupnog sustava, potrebno je vršiti razmjenu podataka između ovih sabirnica. Zbog različitih brzina prijenosa podataka, različitih komunikacijskih protokola, kao i različitih razina napona, ove sabirnice nisu kompatibilne i njihovo jednostavno povezivanje nije moguće. Stoga se problem rješava uspostavom posebne veze imeđu različitih tipova

sabirnica podataka, tj. ugradnjom gateway uređaja. On se može usporediti s prevoditeljem koji predstavlja sponu između osoba koje govore različitim jezicima, a u tehničkom smislu to je računalo koje podatke poslane na mrežu najprije pročita, a potom ih prevede u drugi odgovarajući format. Na taj način upravljački uređaji u vozilima koji se nalaze na različitim sabirnicama podataka mogu međusobno razmjenjivati informacije. Gateway se također može iskoristiti i kao dijagnostičko sučelje preko kojeg bi se vršilo povezivanje vozila s vanjskim dijagnostičkim uređajem. Ovaj model umrežavanja upravljačkih uređaja u vozilu predstavlja jedan vrlo efikasan način za međusobnu razmjenu podataka između različitih mehatroničkih sustava u vozilu.

3 ZAKLJUČCI

Povezivanje upravljačkih uređaja mehatroničkih sustava u vozilu u jednu cjelinu, provodi se kod svih proizvođača suvremenih automobila. Međutim, kako bi vozilo bilo cjenovno prihvatljivo i s druge strane suvremeno, potrebno je odrediti optimalan način povezivanja sustava primjenom odgovarajućih sabirnica podataka. Model povezivanja upravljačkih uređaja u vozilu preko različitih vrsta sabirnica (koje se značajno razlikuju po brzini prijenosa podataka i komunikacijskim protokolima) korištenjem gateway-a, predstavlja jedno cjelovito rješenje u cilju prijenosa i međusobne razmjene podataka.

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QUANTIFICATION OF THE DAMAGE TO THE GEAR TOOTH

Ljupco Trajchevski[1]

Abstract: The purpose of this paper is to create a scheme for measuring damage to the tooth of the gears based on the analysis of the WVD energy components. The WVD's analysis in this paper is based on image processing techniques, especially on the moments of the images.First, we begin by calculating the moments used to describe the geometry of a picture. Based on the analysis of the presented examples, only a few features of all possible moments of the images are easily analyzed for analysis. It has also been shown that the joint probability density of two Gaussian arbitrary variables can be used to approximate the energy distributions most commonly encountered in WVD images. In particular, the WVD image can be presented with acceptable accuracy through a set of Gaussian functions of a common probability. In order to analyze the individual energy components of the WVD, this paper created a method for extracting the energy components from the WVD image. Each WVD component can then be analyzed according to the features of the moment and be classified either as an error component or as a component without error. The sum of the energy contained in all components of the fault of the WVD images can be used to measure the extent of damage to the gears. Finally, we will test the error detection and quantification procedures for the experimental vibration data of the BREVINI EM1010 reducers.

Key words: damage gear tooth, FFT, Image procesing techniques, quantification, signal procesing techniques, WVD distribution.

1 INTRODUCTION

The objective of this paper is to develop a gear tooth damage quantification scheme based on the analysis of the WVD energy components. The calculation of the moments used to describe the geometry of an image. In this paper presents examples thet demonstrate the difficulties in interpreting most of the image moments, even for an image with a simple geometry, such as a line, an ellipse, or a circle. Based on the analysis of the presented examples, only a few, easily interpreted moment-based features were retained for the image analysis from all the possible image moments. In

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order to analyze the individual energy components of the WVD, a method of extracting the energy components from the WVD image is developed in this paper. Each WVD component may then be analyzed according to the selected moment-based features and classified as either fault components ot non-fault components. The sum of the energy contained in all the WVD image fault components may be usgear damage.

1.1 WVD Image Analysis with Moments

This paper will deal extensively with the processing of the WVD image. The term image refers here to a two-dimensional picture representing an array of real numbers. The WVD image is an array of real numbers produced by computing the WVD of a signal or a function.

In order to analyze the information contained in the WVD, one needs to select a set of the features that are useful for arriving at meaningful conclusions about the WVD under analysis. A set of features called image moments dicucssed in this paper is a popular tool in the field of the image analysis. The term »image moments« includes non-central moments, central moments and normalized central moments. These image moments can be used to describe the geometry of the selected image.

The continuous version of the non-central moments of order p+q of an image function f(x,y) is given in [1]

$$m_{pq} = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} x^p y^q f(x,y)dxdy \quad p,q = 0,1, \ldots ,\infty . \tag{1}$$

For a spatially discretized MxN image, the function f(i,j) in equation (1) can be represented by a double summation as

$$m_{pq} = \sum_{i=0}^{M}\sum_{j=0}^{N} i^p j^q f(i,j) . \tag{2}$$

The zero order moment m_{oo} is simply the sum of the values of the image function f(i,j) over the whole image. From the first order moments m_{1o} and m_{o1}, one can calculate the coordinates of the center of gravity og centroid of the image. For the continuous case, these are denoted as x and y, and are given by

$$\bar{x} = m_{10}/m_{00} , \ \bar{y} = m_{01}/m_{00} . \tag{3}$$

In order to obtain image moments that are invariant to the image translation, i.e. independent of the location of the image centroid, the central moments are introduced. The central moments of f(x,y) are given by

$$\mu_{pq} = \int_{-\infty-\infty}^{+\infty+\infty}(x-\bar{x})^p(y-\bar{y})^q f(x,y)dxdy \quad p,q = 0,1,\ldots,\infty \tag{4}$$

or, in the discrete version,

$$\mu_{pq} = \sum_{i=0}^{M}\sum_{j=0}^{M}(i-\hat{i})^p(j-\hat{j})^q f(i,j)$$

$$\hat{i} = m_{10}/m_{00} , \ \hat{j} = m_{01}/m_{00} \tag{5}$$

Where i, j are the discrete equivalents of centroid coordinates x,y. The central moments can be expessed in the terms of the non-central momnets as

$$\mu_{00} = m_{00} = \mu$$
$$\mu_{11} = m_{11} - \mu\bar{x}\,\bar{y}$$
$$\mu_{20} = m_{20} - \mu\bar{x}^2$$
$$\mu_{02} = m_{02} - \mu\bar{y}^2$$
$$\mu_{30} = m_{30} - 3m_{20}\bar{x} + 2\mu\bar{x}^3$$
$$\mu_{21} = m_{21} - m_{20}\bar{y} - 2m_{11}\bar{x} + 2\mu\bar{x}^2\bar{y}$$
$$\mu_{12} = m_{12} - m_{02}\bar{x} - 2m_{11}\bar{y} + 2\mu\bar{x}\,\bar{y}^2$$
$$\mu_{03} = m_{03} - 3m_{02}\bar{y} + 2\mu\bar{x}\,\bar{y}^3$$
$$\mu_{30} = m_{30} - 3m_{20}\bar{x} + 2\mu\bar{x}^3 \tag{6}$$

These equations simplify the computational load since the analyzed image does not need to be stored for consecutive calculations of the equations (2) and (5)

The second order central moments provide the information about the principal axec of the image. The lengths of the principal axes of the region are given by the principal moments

$$\lambda_{min} = \frac{1}{2}(\mu_{20} + \mu_{02}) - \frac{1}{2}\sqrt{\mu_{20}^2 + \mu_{02}^2 - 2\mu_{20}\mu_{02} + 4\mu_{11}^2}\,.$$

$$\lambda_{max} = \frac{1}{2}(\mu_{20} + \mu_{02}) + \frac{1}{2}\sqrt{\mu_{20}^2 + \mu_{02}^2 - 2\mu_{20}\mu_{02} + 4\mu_{11}^2}\,. \tag{7}$$

The angle between the horizontal axes and the largest principal axes is calculated as

$$\theta = \tan^{-1}\left(\frac{\lambda_{max} - \mu_{20}}{\mu_{11}}\right). \tag{8}$$

The angle θ specifies the orientation of a region. The eccentricity of the image is defined as a square root of the ratio of the principal moments

$$e = \sqrt{\frac{\lambda_{max}}{\lambda_{min}}}\,. \tag{9}$$

The central moments can be made invariant to scaling of the image by normalizing them as

$$\eta_{pq} = \mu_{pq} / \mu_{00}^{[(p+q)/2+1]} \quad p+q = 2,3, \ldots, \infty. \tag{10}$$

From (5) and (12) a set of seven invariant moment is given as follows

$$
\begin{aligned}
\phi_1 &= \eta_{20} + \eta_{02} \\
\phi_2 &= (\eta_{20} - \eta_{02})^2 + 4\eta_{11}^2 \\
\phi_3 &= (\eta_{30} - 3\eta_{12})^2 + (3\eta_{21} - \eta_{03})^2 \\
\phi_4 &= (\eta_{30} + \eta_{12})^2 + (\eta_{21} + \eta_{03})^2 \\
\phi_5 &= (\eta_{30} - 3\eta_{12})(\eta_{30} + \eta_{12})[(\eta_{30} + \eta_{12})^2 - 3(\eta_{21} + \eta_{03})^2] + \\
&+ (3\eta_{21} - \eta_{03})(\eta_{21} + \eta_{03})[3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2] \\
\phi_6 &= (\eta_{20} - \eta_{02})[(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2] + \\
&+ 4\eta_{11}(\eta_{30} + \eta_{12})(\eta_{21} + \eta_{03}) \\
\phi_7 &= (3\eta_{21} - \eta_{03})(\eta_{30} + \eta_{12})[(\eta_{30} + \eta_{12})^2 - 3(\eta_{21} + \eta_{03})^2] - \\
&- (\eta_{30} - 3\eta_{12})(\eta_{21} + \eta_{03})[3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2].
\end{aligned}
\tag{11}
$$

The invariant moments do not change under rotation, scaling and translation of the image.

1.2 Examples of the image momentsBullets

In order to understand the properties of the image moments and other geometric momentbased features of the images, the examples shown in Figures 2-8 were included in this paper.The second order moments have a direct analogy with the moments of ineria associated with rotating bodies in mechanics [2]. The calculation of the image moments and the their properties also exhibit a number of similarities with the parameters used to describe the probability distributions. The Gaussian joint probability density function was chosen to generate all of the examples presented in figure 2-8 . The joint probability density of two Gaussian random variables is given by [1]

$$
p(x,y) = \frac{1}{2\pi\sigma_x\sigma_y\sqrt{1-r^2}} \exp\left(\frac{-1}{2(1-r^2)} \left\{ \frac{(x-\mu_x)^2}{\sigma_x^2} - \frac{2r(x-\mu_x)(y-\mu_y)}{\sigma_x\sigma_y} + \frac{(y-\mu_y)^2}{\sigma_y^2} \right\} \right) \tag{12}
$$

The center of the ellipse is given by the coordinates ($x_c=\mu_x$, $y_c=\mu_y$), which are the expectations in the probablity theory. The parameters σ_x and σ_y are the standard deviations. In the calculation of the image moments the parameters σ_x and σ_y correspond to $2\sqrt{\frac{\mu_{20}}{m_{00}}}$, resprectively. The parameter r is called the correlation coefficient

$$
r = \frac{Cov(x,y)}{\sigma_x\sigma_y} \tag{13}
$$

Where the parameter Cov(x,y) is the covarience. The projections of the ellipse dimensions on the principal axis are shown in Figure 1.

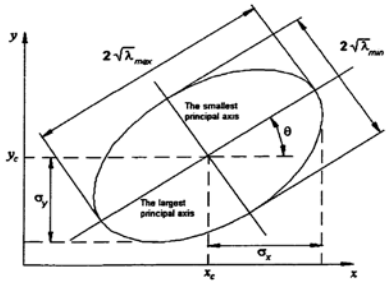


Figure 1. *Contour plot of an ellipse*

Let us considera function f(x,y,C,x_c,y_c, ,σ_x,σ_y ,r) constructed in a similar manner to p(x,y) as

$$f(x,y,C,x_c,y_c,\sigma_x,\sigma_y,r) = C\exp\left(\frac{-1}{2(1-r^2)}\left\{\frac{(x-x_c)^2}{\sigma_x^2} - \frac{2r(x-x_c)(y-y_c)}{\sigma_x\sigma_y} + \frac{(y-y_c)^2}{\sigma_y^2}\right\}\right) \quad (14)$$

where the constant C is an amplitude parameter. The value of the parameters of the function and resulting moments calculated from the image are summarized in the table under each of figure 2-8.

Figure 2 and 3 display a flooded contour plot of the concentric circles with different centroid coordinates. In other words, the region drom Figure 2 transformed by translation into the image shown in Figure 3. The principal moments, eccentricity, orientation, invariant image moments, the central image moments and the normalized central image moments are the same for both images. It should be noted that due to the symmary of the concentric circles the principal axes of the region are the same and the eccentricity is equal to one. Therefore, the orentation of the region has no preferred direction. The orientation of the region was set to 90 degrees by default.

Figures 4 and 5 show the identical ellipsoidal regions with different orientation. The principal axes in the both figures are oriented 90 degrees with respect to the horizontal axis. Again, the invariant image moments are the same for both images. The other image moments reflected the changes due to rotation. Figure 5 shows the ellipsoidal region, which has the largest principal axis oriented approximately 62 degrees with respect to the horizontal axis. Note that the eccentricity is 2.9 times larger than the eccentricity of the regions shown in two previous figures. Figures 7 and 8 display the difference in the moments between the vertical and horizontal lines.

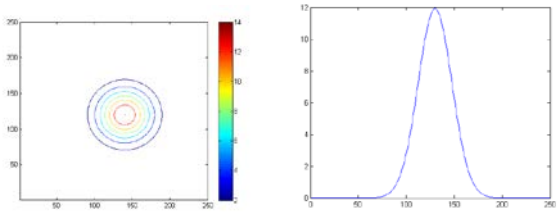


Figure 2. *Flooded contour plot of the function f(x,y,14,140,120,25,25,0) consisting of the concentric circles*

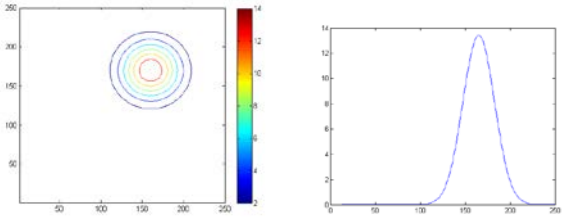


Figure 3. *Flooded contour plot of the function f(x,y,14,160,170,25,25,0) consisting of the concentric circles*



Figure 4 and Figure 5*. Flooded contour plot of the function f(x,y,14,120,120,35,20,0) and f(x,y,14,120,120,20,35,0) consisting of the concentric ellipses with the largest principal axes oriented vertically*

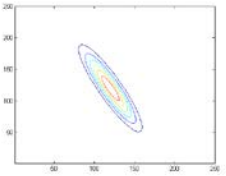


Figure 6. *Flooded contour plot of the function f(x,y,14,120,120,20,35,-0.9) consisting of the concentric ellipses with the largest principal axes oriented 61.6 degrees to the horizontal axes*

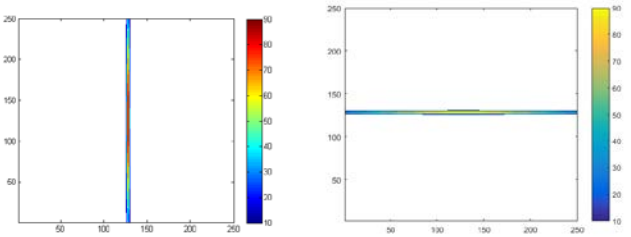


Figure 7 and Figure 8 . *Flooded contour plot of the function f(x, y, 94, 128, 128, 1, 95, 0) and f(x, y, 94, 128, 128, 95,1, 0*) *consisting of the concentric ellipses with the oriented vertical and horizontal axes*

The analysis of the described examples suggests the dificulty in the use of the image moments, since they do not easily relate to the geometry of the image region. However, the region orientation, eccentricity and volume could prove useful in the analysis of the WVD image components.

1.3 Extraction of the Signal Energy Components from WVD

The WVD image is composed of many energy components: gearmesh energy distribution,rotor-bearing-gear system excitations, interference terms, and energy distributions due to the gear damage. One way do deal with the complexity is to

separate te WVD image into its components. Then, selected features are calculated for each WVD image component. The obtained features of the WVD image components are easier to analyse than the whole WVD image. The image component extraction algoritam presented below is initiated from a so-called seed point. The selection of the seed point plays an important role in the image component extraction algoritam, which is discussed later. Recall that a threshold number must be specified to define the image component. The algoritham is formulated in Table 1.

Table 1. *Image component extraction algoritam*

1. Set the threshold T. At each following step record the coordinates of the image point with values the greater the threshold value.
2. Set the seed point coordinates (x_s,y_s).
3. Set the starting point to the seed point $x=x_s$, $y=y_s$.
4. Ceck if the image value at the seed point is greater than the threshold T. If the image value is less than the threshold T, then go to step 2 to select new seed point.
5. Move one point up on the image, i.e. move to the point (x,y+1). If the image value f(x,y) at the current point is greater that the threshold T, then continue to move up. If the image value is less than the threshold T, then go to step 6.
6. Set the starting point to the seed point $x=x_s$, $y=y_s$.
7. Move one point down on the image, i.e. move to the point (x,y-1). If the image value f(x,y) at the current point is greater than the threshold T, then continue to move down. If the image value is less than the threshold T, then go to step 8.
8. Search for new seed point on the left(right). Start from the last point and begin to move one point up. If the image value of the point on the left f(x-1,y) (right f(x+1,y)) is greater than the threshold T, then set new seed point $x_s=x-1$($x_s=x+1$),$y_s=y$. Repeat from step 3.
9. Construct the extracted image component. It consists of all image point with the coordinates recorded at the previous steps.

The algorithm given in Table 1 does not assume that the seed point belongs to the image component to be extracted. It is obvious that the selection of the seed point is important. For instance, the algorithm stop at step 4., if the initial seed point is not one of the component's points. Different strategies can be applied for the seed point selection.Much depends on the objectives of the image component extraction, same of wich could be the following

a) Objective 1: extract all image components for a given threshold number T.
b) Objective 2: extract the image components containing the point with largest image value.

A straightforward but inefficient approach to achieving the first objective is checking image point in same order, and picking the first one whose image value is larger than the treshold T. After having found the seed point, the image component can be extracted. Than, the extracted image component is subtracted from the orginal image. The search for the next seed point continues on the image remaining after subtraction.

The second objective can be achieved by searching for the image point with the largest value and setting it as a seed point for the component extraction algorithm. This image point is also a good choice of the starting seed point for the first objective. If the largest image point is smaller than a given threshold number, than there are no

image components to be extracted.

Figure 9 and 10 illustrate the algorithm. The image components typically encountered in the analysis of the WVD images were selected for the examples. With a suitable choice of the threshold, the algorithm properly extracted the line in Figure 10.

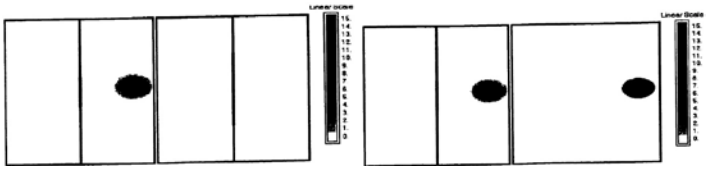


Figure 9 . *Line extract from the orginal image left, and ellipse extract from the orginal image rigth*

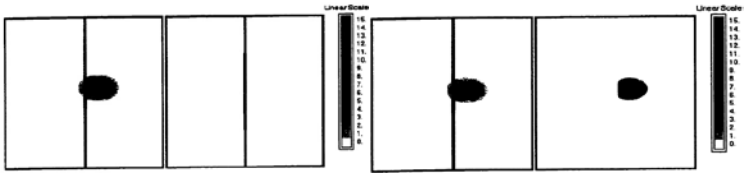


Figure 10. *Overlappingline and elipse, line extract from the orginal image left, and ellipse extract from the orginal image rigth*

However, the subtraction of the line from the orginal image caused the overlapping part of the ellipse to be cut out. The part of the ellipse with larger image value was then extracted from the remaining image.

1.4 Experimental results

The measured data were performed on the test bench shown in Fig. 11, respectively, on the planetary gearbox BREVINI type EM1010. When analyzing the same, the Matlab software package was used and toolbox TFRWV. The picture gives an example of a menu for generating the basic energy components of the WVD distribution.

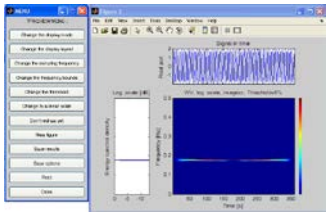


Figure 11.*WVD signal analysig in MATLAB toolbox TFRWV*

Analysing file **G14033**

WVD of the signal for one rotation of the carrier (2231 samples or 0.27898 seconds) with the normalization of the signal in the range -1 to 1 spectrum (FFT of the signal) is given in Fig. 12

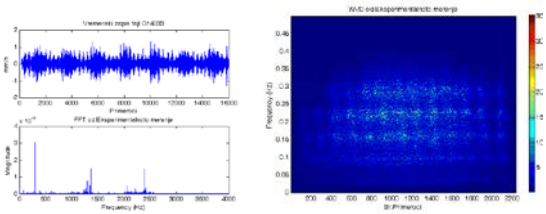


Figure 12. *Signal, signal range (FFT), WVD signal record for file G14033*

From Figure 12 you can see the energy concentration of the signal between 150^{o} and 230^{o} of rotation. For this signal NP4 (0) = - 4.2298, and the cytosis is -1.6253. The WVD of the residual signal by deleting the dominant maximum frequency is given in Figure13.

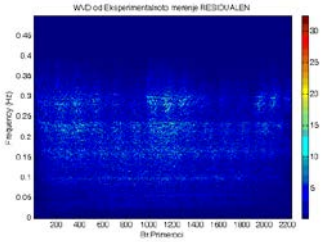
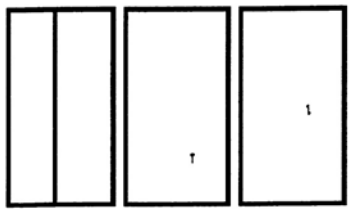


Figure 13. *WVD record for a residual signal for file G14033*

For this signal NP4 (1) = - 3.0068, and the kurtosis is -1.6710. If we use the detection strategy, we get the following: NP4 (0) <0 but NP4 (0)> - 1 multiple tone error possible - point 3 NP4 (1) <0 and NP4 (0) <0 - do not set an error alarm - point 6.[3]. Using the algoritham from Table 3 we have this images (Figure 14).



a) *b)* *c)*

Figure 14. WVD of the vibration signal for file G14033 with damage 0%
a) 1-st WVD image component
b) 2-nd WVD image component
c) 3-rd WVD image component

Analysing file **G04045**

WVD of the signal for one rotation of the carrier (772 samples or 0.0402 seconds) with the normalization of the signal in the range -1 to 1 spectrum (FFT of the signal) is given in Fig. 15

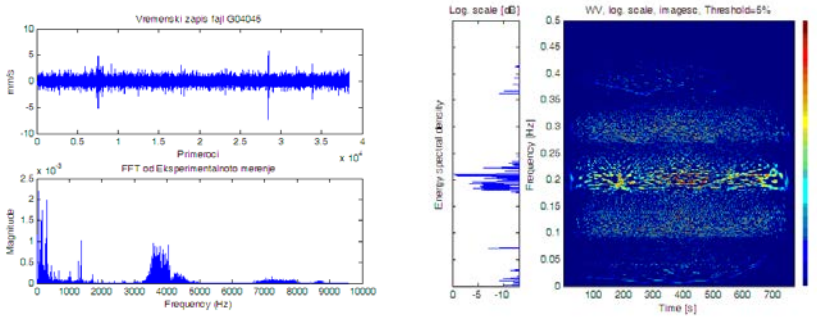


Figure 15. *Signal, signal range (FFT), WVD signal record for file G04045*

For this signal NP4 (0) = 0.0233, and the kurtosis is 0.5387. The WVD of the residual signal by deleting the dominant frequency of the coupling of 349 Hz is given in Fig. 16

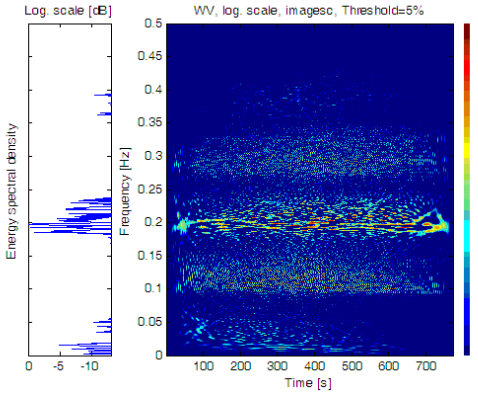
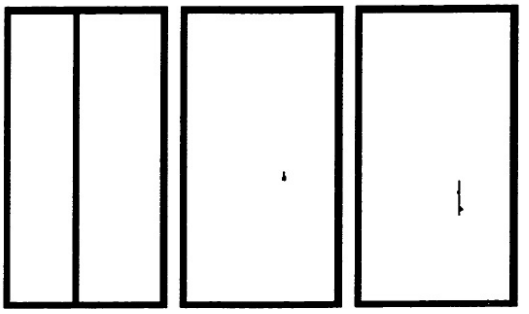


Figure 16. *WVD record for a residual signal for file G04045*

For such a signal, NP4 (1) = 0.12, and the cytosus is -0.0682. If we use the detection strategy, we get the following: NP4 (0)> 0 to set an alarm for error - point 2 NP4 (1)> 0 calculation for verification of NP4 (0) - item 4. Because NP4 (0)> 0 and NP4 (1)> 0, an error is detected due to damage to one tooth - point 5. [3] Using the algoritham from Table 3 we have this images (Figure 17).



a) b) c)

Figure 14. *WVD of the vibration signal for file G14033 with damage 0%*

a) 1-st WVD image component
b) 2-nd WVD image component
c) 3-rd WVD image component

2 CONCLUSION

The gear damage detection and quantification procedure was tested on the simulated and experimental data. This procedure provides the tool to detect and quantify the gear damage using a fundamental concept of the vibration energy and its distribution in the time-frequency domain. The choice of the thresholds used in the damage detection and quantification algoritam is critical to the effectiveness of the algorithm. However regardless of the thresholds used, the development of the algorithms and concepts for detection and quantification is an essential contribution to machine health-monitoring technology. It should be mentioned that the damage detection and quantification algorithm has a potencial to be further developed for other types of the rotating machinery faults.

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ODRŽAVANJE U AVIO-INDUSTRIJI I PODACIMA VOĐENI MODELI

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Rezime: Prilike za rješavanje problema i optimizaciju procesa i zadataka održavanja vazduhoplova u osnovi dolaze sa novim, moćnim tehnologijama i okruženjem koje obiluje podacima. U radu će biti prikazan savremeni, prediktivni pristup problemu održavanja, (potreba prepoznata od strane glavnih aktera avio-industrije), ilustrovan implementacijom dva različita modela predikcija temeljena na podacima: model za predikciju broja preostalih ciklusa avionskog motora i model za predikciju kvara u određenom vremenskom periodu.

Ključne riječi: održavanje vazduhoplova, podacima vođeni modeli, prediktivno održavanje

MAINTENANCE IN AIRCRAFT INDUSTRY AND DATA DRIVEN MODELS

Abstract: Problem-solving opportunities and optimization processes and aircraft maintenance tasks are basically coming up with new powerful technologies and data-rich environment. In this paper will be presented modern predictive maintenance approach, (the need for it is recognized by the main actors of the aircraft industry), which is illustrated by the implementation of two different data-driven models for prediction: model for prediction the number of remaining cycles of aircraft engine and model for fault prediction in a given time period.

Key words: aircraft maintenance, data-driven models, predictive maintenance approach

1 UVOD

Održavanje vazduhoplova u osnovi je preventivno održavanje, poznato kao planirano održavanje (*scheduled maintenance*) koje se, da bi se sprječio kvar i sistem očuvao u operativnom stanju, obično izvršava u pravilnim intervalima; aktivnosti održavanja koje se koriste za rješavanje problema i kvarova koji se dešavaju iznenada, u nepravilnim vremenskim intervalima predstavljaju drugu vrstu, neplanirano održavanja (*unscheduled maintenance*) vazduhoplova, koje se vrši radi vraćanja stavke u zadovoljavajuće stanje korekcijom poznate ili pretpostavljajuće neispravnosti

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i/ili defekta. U [1] se navodi da održavanje, koje predstavlja veliki dio troškova aviokompanije, značajno doprinosi sigurnosti, dostupnosti, određivanju cijene karata putnika i integritetu mreže poslovnih operacija.

Aktuelni radovi na probleme modernog održavanje vazduhoplova uglavnom ukazuju i razmatraju, kroz različite aspekte, tendencije i izazove esencijalnih tehnologija koje su u službi prediktivnih pristupa. Prema [2], jedan od glavnih izazova primjene prediktivnog održavanja u vazduhoplovnoj industriji je prevođenje velikih količina senzorskih podataka u pouzdano predviđanje kvara, proces nazvan prognostika. U radu će biti prikazana implementacija modela predikcije koji su temeljeni na podacima (*data driven*): model za predikciju broja preostalih ciklusa avionskog motora i model za predikciju kvara u određenom vremenskom periodu.

2 ODRŽAVANJE U AVIO INDUSTRIJI

Avio-industrija slovi za stratešku industriju dvaju područja, vojno, u čijoj sferi vazduhoplovni proizvodi predstavljaju centralnu komponentu nacionalne odbrane i ekonomsko, uz dodatno šire ekonomske koristi (posebno izražene tokom sukoba), u obliku radnih mjesta, izvoza i napredne tehnologije, što avio industriju svrstava u važnu i vodeću industriju za nacionalni ekonomski razvoj, pri čemu se, najčešće, ne adresira pitanje troškova i alternativna upotreba vrijednosti nacionalnih sredstava dodjeljenih vazduhoplovstvu [3]. U knjizi [4], koja se prvenstveno bavi važnim faktorom, političkom ekonomijom, avio-industrije, autor navodi, široko korištenu, radnu definiciju, po kojoj avio-industrija obuhvata sve one firme uključene u istraživanje, dizajn, razvoj, proizvodnju, popravak, održavanje i odlaganje vazduhoplovnih proizvoda, što uključuje vojne i civilne avione i helikoptere, poslovne i privatne avione, rakete i svemirske sisteme, te firme koje snabdjevaju dijelovima i komponentama.

U knjizi koja predstavlja održavanje, popravak i remont, najkritičnija i razvijajuća područja vazduhoplovne industrije [5], održavanje je akcija neophodna da se održi ili povrati integritet i performanse aviona. Autori [6] navode tipične definicije tehničkih polisa i priručnika avio kompanija, za koje smatraju da su u većini slučajeva uopšteno odgovarajuće, ali da nisu potpuno opisne u tome o čemu je proces održavanja. Održavanje vazduhoplova obezbeđuje sigurnost letenja, pouzdanost i plovidbenost [6], a odjeljenje za održavanje je odgovorno za postizanje svih zadatih zadataka održavanja prema proizvođaču aviona i zahtjevima kompanije. Važno je istači da, niti jedna količina održavanja ne može povećati pouzdanost sistema, koja bi bila viša od dizajniranog nivoa, inherentne pouzdanosti, ali da je poželjno da se, u svakom trenutku, taj nivo održava.

3 TRADICIONALNI PROGRAMI ODRŽAVANJA

U ranim danima vazduhoplovstva, jednostavne i bez analitičke osnove, programe održavanja razvili su mehaničari [7]. Sa ulaskom velikih mlaznih aviona na komercijalno tržište, pedesetih godina prošlog vijeka, proizvođač aviona postao je izvor razvoja programa održavanja, sa osnovnim konceptom remonta svake komponentu u određeno vrijeme (poznat kao limitirano vrijeme korišćenja HT (*Hard Time*) proces).

3.1 MSG pristup

Porast avijacije, formiranje aviokompanija, naknadna analiza nesreća, bili su neki od glavnih faktora stvaranja potrebe za novim propisima i širim učešćem regulatornih tijela u domenu održavanja. U svrhu istraživanje mogućnosti novog,

ekonomičnijeg, podjednako bezbjednih procesa, preventivnog održavanja, formirana je 1960. godine, radna grupa (sastavljena od predstavnika FAA, avio kompanija,...) čiji nalazi su naknadno doveli do izrade serije smjernica za avio kompanije i proizvođače aviona, za potrebe uspostavljanja planiranog održavanja aviona, i do novog tipa održavanja baziranog na stanju (*on-condition*). Upravljačka grupa za održavanje MSG (Maintenance Steering Group) 1968. godine, razvila je logiku odlučivanja i postupak analize zahtjeva za održavanjem, za potrebe osiguranja bezbjednost aviona Boeing 747, priručnik poznat i kao MSG-1. MSG pristup razvoju programa održavanja pokazao se veoma uspješan, neznatno modifikovan doveo je 1970-ih do MSG-2 i primjene na druge avione (Lockheed L-1011 i DC-10). Filozofija MSG-2 bila je usmjerena na komponente, odozdo prema gore (*bottom-up*) i procesno orijentisana. Procesno orijentisan pristup održavanju, MSG-2, koristi tri primarna procesa za izvršavanje planiranih aktivnosti održavanja, limitirano vrijeme korišćenja HT, prema (nađenom) stanju OC (On Condition) i praćenje stanja CM (Condition Monitoring).

3.2 MSG-3 i zadatkom usmjereno održavanje

Na temelju iskustava i utvrđenih slabosti MSG-2, nakon i na osnovu ispitanih i dokazanih praksi aviokompanija, objavljen je 1980. godine MSG-3 dokument, sa novim procedurama logike odlučivanja i analize; MSG-3 logika koristi ka zadatku usmjeren (*task-oriented*) pristup održavanju i sa nivoa sistema ili odozgo prema dolje (*top-down*) razmatra modalitete kvara sistema, pri čemu se zadaci održavanja izvode iz bezbjednosnih, operativnih ili ekonomskih razloga [7]. Osnovni cilj MSG-3 je da identifikuje zadatke održavanja koji su efektivni i efikasni u omogućavanju dizajniranja i korišćenja novog aviona na način koji postiže zadovoljavajući nivo sigurnosti i pouzdanosti u toku svog života; primarna svrha dokumenta kodne oznake ATA MSG-3 [8] je izrada predloga za pomoć regulatornom autoritetu u uspostavljanju početnih planiranih zadataka održavanja i intervala za nove vrste aviona (*aircraft*) i/ili pogonskih grupa (*powerplant*). MSG-3 metodologija, od svog nastanka je, u vidu amandmana, podložna reviziji, sa baznim ciljem doprinosa obezbjeđenju dodatnih pojašnjenja i poboljšanja.

Metodologija MSG-3 usko je povezana s RCM (Reliability Centered Maintenance) metodologijom, konceptu održavanja baziranog na pouzdanosti, u kojoj se procjenjuje rizik očekivanih posljedica kvara. [9] definiše RCM kao proces koji se koristi za određivanje onoga što se mora učiniti kako bi se osiguralo da svako fizičko sredstvo nastavi da radi, ono što njegovi korisnici žele da radi, u svom sadašnjem operativnom kontekstu. Prema [10] MSG-3 je temeljna izvedba RCM procesa koji je izdržao test vremena i koji ostaje na snazi za razvoj programa održavanja aviona. [11] ukazuje na razlike pomenutih pristupa metodologija planiranog održavanja vazduhoplova, sa ciljem pronalaženja potencijalne oblasti poboljšanja primjene MSG-3 metodologije za sisteme aviona.

3.3 Izrada programa održavanja

Proces izrade programa održavanje novog vazduhoplova evoluirao je, od onog u kojem svaki operator predlaže vlastiti, jedinstveni program, do onoga, u kojem regulatorni organi i industrija rade zajedno da razviju inicijalne, minimalne, zahtjeve za planirano održavanje/inspekciju vazduhoplova i/ili pogonskih grupa (agregata), koji se koriste kao osnova programa održavanja vazduhoplova AMP (Aircraft Maintenance Programme) operatora [8]. Uobičajena praksa vazduhoplovstva je da su početni zadaci i intervali planiranog održavanja, navedeni u Izvještaju odbora za razmatranje održavanja MRBR (Maintenance Review Board Report). Korištenje MSG-3

metodologije za razvoj inicijalnog planiranog programa održavanja, aktuelan je i široko korišten pristup (FAA [12], EASA [8],...), u svrhu izrade MRB izvještaja, na bazi kojeg proizvođač izdaje osnovni dokument za planiranje održavanja MPD vezan za dati tip aviona (pruža dodatne informacije organizacijama koje obavljaju održavanje u skladu sa Part M (zahtjevi za kontinuiranu plovidbenost) i Part 145 (odobrenja organizacije za održavanje) EASA propisima i sadrži zahtjeve i preporuke proizvođača). Program održavanja, kojim su obuhvaćeni zadaci koje je, tokom životnog vijeka vazduhoplova, potrebno obaviti kako bi zadovoljio zahtjeve za sigurnu, kontinuiranu plovidbenost, mora biti prilagođen pojedinačnoj konfiguraciji aviona i upotrebi operatora vazduhoplova, te se uz MPD moraju uzeti u obzir specifični zahtjevi operatora i osnovni (organizacioni) postupci upravljanja održavanjem [13].

4 PRIMJERI PREDIKTIVNIH PRISTUPA - MODELI TEMELJENI NA PODACIMA

Vrijednosti prediktivnog održavanja već su dobro prepoznate od strane velikih igrača avio industrije (Airbus, Boeing, ...), a prilike za rješavanje problema i optimizaciju procesa i zadataka održavanja u osnovi dolaze sa novim, moćnim, tehnologijama, četvrtom industrijskom revolucijom koja je pokrenuta novim informacionim i komunikacionim tehnologijama (IKT), metodologijama koje obiluju podacima (npr. vještačka inteligencija, velike količine podataka (Big Data), ...), korištenjem IoT tehnologija u industrijskim aplikacijama (IIoT), ... U [14] se navodi da sledeća granica za prediktivno održavanja u vazdušnom saobraćaju dolazi sa lakoćom pristupa podacima potpunog leta (Full-Flight Data) - svim detaljnim parametrima snimljenim tokom leta.

Pristup zasnovan na podacima (*data-driven*) uglavnom se oslanja na tehnike oblasti vještačke inteligencije koje imaju gotove alate koji se, s manjim modifikacijama, mogu direktno primijeniti. Niski troškovi razvoja algoritama i u osnovi nizak nivo znanja koja se traže za fiziku sistema, čine ovaj pristup preferiranim od strane programera sistema za predviđanje. Ideja o ovom pristupu je korištenje izmjerenih parametara performansi sistema, kao što su temperatura, pritisak, brzina, vibracija, struja ..., da bi se napravio model, koji koreliše varijacije ovih parametara sa degradacijom sistema i progresijom grešaka, koji se može koristiti za procjenu preostalog životnog vijeka posmatranog sistema. Tehnike pristupa temeljenog na podacima mogu se klasifikovati u konvencionalne numeričke metode i metode mašinskog učenja [15].

Ključni uslov za razvoj algoritama prognostičkih alata temeljenih na podacima je dostupnost multivarijantnih istorijskih podataka o ponašanju sistema, koji moraju pokrivati sve faze normalnog i neispravnog rada sistema, kao i scenarije degradacije pod određenim radnim uslovima. Dostupnost pomenutih podataka za obuku algoritama je izazovni zadatak, za dobijanje podataka radom do otkaza, mogu se koristiti: aplikacije područja (*fielded applications*) koje se nose sa činjenicom da sistemi koji se posmatraju imaju manjak podataka vezano za pojavu kvara – ukoliko isti postoje onda pitanja vlasništva otežavaju da isti postanu javno dostupni; eksperimentalni ispitni stolovi (*experimental test beds*), koji su skupi i vremenski zahtjevni za izradu, i računarske simulacije. Računarska simulacija [16,17] je složena i teška, jer izgradnja simulacionog modela visokog rizika nije lak zadatak, ali kada je model dostupan, računarska simulacija može se smatrati najboljim načinom za dobijanje radom do otkaza (*run to failure*) podataka o grešci.

4.1 Primjeri razvoja modela temeljenog na podacima

„Turbofan Engine Degradation Simulation Dataset“, nastao simulacijom modela propagacije kvara radom do otkaza [16] će biti korišten kao polazni, ulazni skup za izgradnju prediktivnih modela; koraci metodologije za predviđanje temeljene na podacima [18] korišteni su kao smjernica pri programiranju modela za prognozu. Dostupni podaci, koji će biti korišteni kao ulaz su: podaci avionskog motora radom do otkaza - podaci za obučavanje modela (Train_FD003.txt.); operativni podaci koji ne sadrže zapis o kvaru - podaci za testiranje (Test_FD003.txt); i podaci sa tačnom informacijom o preostalom periodu vremena/ciklusa za svaki motor koji se nalazi u testnim podacima - referentni (ground trouth) podaci (RUL_FD003.txt).

Korištene karakteristike uključene u trening podacima su svi sirovi atributi (ukupno 26 atributa: ID motora, oznaka ciklusa, tri operativne postavke motora i preostali 21 atribut su podaci sa senzora), uključeni u originalne ulazne podatke i dodatno kreirani agregirani atributi kojima se sažima istorijska aktivnost za posmatranu problematiku vezanu za avionski motor; kreirane agregirane karakteristike za svaki od 21 senzora u konkretnom slučaju odnose se na kretanje prosječne vrijednosti – srednja vrijednost sa senzora u najviše W prethodnih ciklusa (označene sa SSenzor1–SSenzor21). Postavka uključuje vrijednosti parametra vremenskog prozora W=7 (veće vrijednosti, za posmatrani motor (opremu, ...) omogućavaju sagledavanje dužeg, cjelovitijeg istorijskog perioda) za koje se vrši agregiranje. Analogan postupak je korišten i za testne podatke(u tu svrhu je korištena razvijena programska podrška (C#)).

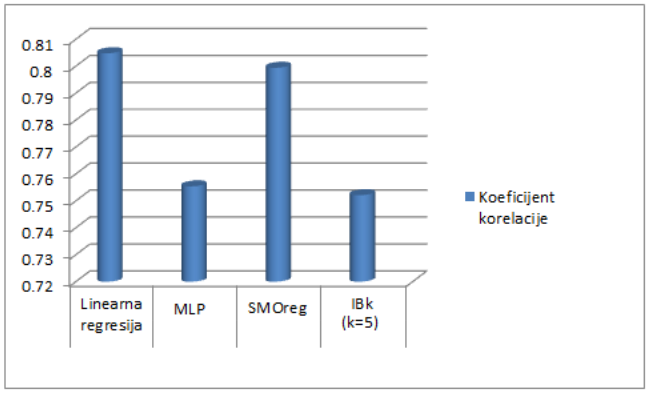
4.1.1 Model za predikciju broja preostalih ciklusa avionskog motora

Za izgradnju prediktivnog modela, za potrebe predviđanja kvara - broja preostalih ciklusa (mjernih jedinica vremena) avionskog motora (u kontekstu izabranog seta), koji po prirodi problema formalno spada u problem regresije [19], korišteni su klasifikatori (dati u Tabeli 1) Weka softverskog alata za rudarenje podacima: jedan od najpoznatijih algoritama mašinskog učenja - linearna regresija (Linear Regresion), implementacija višeslojnog perceptrona (Multilayer Perceptron, MLP) najistaknutijeg tipa vještačke neuronske mreže, implementacija algoritma vektora podrške za regresiju SMOreg i algoritam k najbližeg susjeda (IBk) za k=5.

Table 1. *Eksperimentalni rezultati prediktivnih modela za predikciju broja preostalih ciklusa avionskog motora (regresija)*

Statistički parametri	**Klasifikatori**			
	Linearna regresija	MLP	SMOreg	IBk (k=5)
Koeficijent korelacije	**0.8048**	0.7554	0.7994	0.7521
Srednja apsolutna greška - MAE (Mean Asolute Error)	42.0806	29.1506	36.2147	30.072
Korijen srednje kvadratne greške - RMSE (Root Mean Square Error)	52.1576	40.2858	45.1544	47.1976
Rrelativna apsolutna greška- RAE (Relative Absolute Error) (%)	66.5087	46.0727	57.2375	47.529
Korijen relativne kvadratne greške -RRSE (Root Relative Squared Error).(%)	69.3769	53.5857	60.0617	62.7794

Da bi se izvršila predikcija korištenjem regresije, neophodno je prethodno označavanje uzoraka. U tu svrhu kreiran je atribut “Preostali ciklus”, sa vrijednostima preostalog broja ciklusa avionskog motora za svaku instancu skupa (na bazi referentnih podataka izvršeno je označavanje testnih podataka). Procjena performansi modela je izvršena korištenjem 100 testnih primjeraka - po jedan maksimalni ciklus, za svaki motor (ne preporučuju se uobičajeni postupci evaluacije korištenjem k-struke unakrsne validacije). Fitnes dobijenih modela, Tabela 1, dat je sa statističkim parametrima: koeficijent korelacije kao specifičan pokazatelj reprezentativnosti regresije (vrijednosti u rasponu od 0 do 1, reprezentativnija veća vrijednost), srednja apsolutna greška, korijen srednje kvadratne greške, relativna apsolutna greška i korijen relativne kvadratne greške. Posmatrano u kontekstu parametra koeficijent korelacije, Slika 1, najbolji rezultat, neznatno veći od algoritma vektora podrške za regresiju SMOreg, postigao je algoritam linearne regresije; SMOreg, posmatrano generalno, u značajnoj mjeri je vremenski najzahtjevniji.



Slika 1. *Grafički prikaz vrijednosti koeficijenta korelacije prediktivnih modela korištenih klasifikatora*

4.1.2 Model za predikciju kvara motora za određeni vremenski period

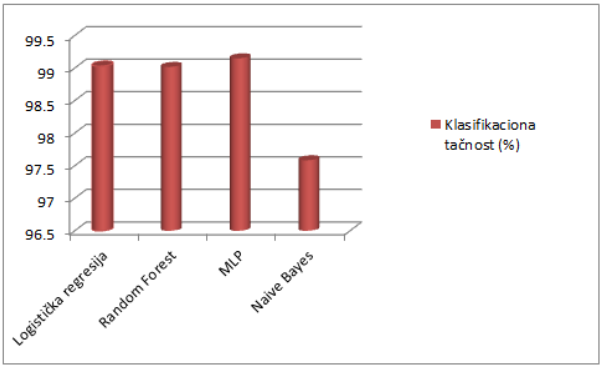
Da se predvidi da će oprema - avionski motor imati kvar u nekom budućem periodu (izraženom kroz broj ciklusa), korištena je binarna klasifikacija [20] (razvrstavanja elemenata određenog skupa u dvije grupe na temelju prethodno određenih pravila klasifikacije). Period za koji se vrši predviđanje, u praksi neko minimalno vrijeme da se nabave rezervni dio na primjer, naziva se obično horizont “X”; za potrebe izgradnje ovog modela X=30. Da bi se kreirao prediktivni model, koji će u osnovi dati vjerovatnoću dešavanja kvara motora u sledećih 30 ciklusa, potrebno je izvršiti označavanje instanci oznakama klase. Oznaka klase (prethodno kreiran atribut Klasa {0,1}) je urađena uzimajući 30 poslednjih primjeraka za svaki ID_motora i označavajući ih 1 (blizina kvara), dok su svi preostali označeni sa 0 (normalno, tj. nema kvara). Procedura označavanja je ista za trening i testni set podataka.

Četiri različita klasifikatora su korištena za izgradnje prediktivnog modela: logistička regresija (Logistic Regresion), algoritam stabla odlučivanja slučajna šuma (Random Forest), višeslojni perceptron MLP i Naivni Bajesov algoritam temeljen na Bajesovim mrežama (Naive Bayes). U Tabeli 2, navedena je korištena metrika i pripadajući rezultati prediktivnih modela za četiri pomenuta klasifikatora; modeli su trenirani kompletnim (prethodno opisanim) trening setom i evaluacija je izvršena korištenjem kompletnog seta podataka za testiranje.

Table 2. *Eksperimentalni rezultati prediktivnih modela za predikciju kvara motora za određeni vremenski period (binarna klasifikacija)*

Statistički parametri	**Klasifikatori**			
	Logistička regresija	Random Forest	MLP	Naive Bayes
Klasifikaciona tačnost (%) (broj netačno klasificiranih)	99.0299 (161)	99.0178 (163)	**99.150 (141)**	97.5838 (401)
Kappa koeficijent	0.6837	0.6399	**0.7165**	0.5175
Srednja apsolutna greška - MAE (Mean Asolute Error)	0.021	0.0132	**0.0088**	0.0243
Korijen srednje kvadratne greške - RMSE (Root Mean Square Error)	**0.086**	0..0849	0.0891	0.1529
Rrelativna apsolutna greška- RAE (Relative Absolute Error) (%)	9.1077	9,9225	**6.612**	18.305
Korijen relativne kvadratne greške -RRSE (Root Relative Squared Error).(%)	53.295	**52.5888**	55.1821	94.7297

Uvidom u Tabelu 2, može se zaključiti da je najbolji prediktivni model za posmatrani problem predikcije, postignut korištenjem modela neuronske mreže MLP klasifikatora: klasifikaciona tačnost od 99.150% (Slika 2 ilustruje grafičko poređenje klasifikacione tačnosti za sve klasifikatore) i 141 netačno klasificirana instanca od ukupno 16.596, vrijednost Kappa koeficijenta 0.7165, vrijednosti srednje apsolutne greške 0.0088 i relativna apsolutna greška 6.612%; najlošije rezultate ostvario je Naivni Bajesov klasifikator (klasifikaciona tačnost 97.5828%).



Slika 2. *Grafički prikaz klasifikacione tačnosti prediktivnih modela klasifikatora*

4.2 ZAKLJUČCI

U scenariju primjene mašinskog učenja u oblasti prediktivnog održavanja u principu se koriste različite tehnike, sa svojim za i protiv, postoje i prisutne su i određene tendencije upotrebe, ali trenutno nije dostupan analitički postupak odlučivanja za odabir tehnika mašinskog učenja, što predstavlja svojevrstan izazov i otvara dodatan prostor za nova eksperimentisanja i istraživanja.

U radu je prikazan prediktivni pristup problemu održavanja temeljen na podacima - implementacija modela prediktivnog održavanja avionskog motora, zasnovana na mašinskom učenju, korištenjem (kao polazna osnova) javno dostupnog seta podataka koji predstavlja simulaciju degradacije avionskog motora**.**

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Conference on Mechanical Engineering Technologies and Applications

EKSPERIMENTALNA ISTRAŽIVANJA TRANSPORTNIH MAŠINA ZA VERTIKALNI TRANSPORT U RUDNICIMA

Goran Radoičić[1], Miomir Jovanović[2], Miodrag Arsić[3], Vojislav Tomić[4]

Rezime: Ovim radom daj je pregled više eksperimentalnih ispitivanja izvoznih rudarskih mašina. Ispitivanja su tenzometrijska i optička. Njima se utvrđuju dinamičke sile u užadnom sistemu transportnih kabina i promenljivost brzina (ubrzanja) pokretnih masa. Poseban deo istraživanja odnosi se na magnetnu kontrolu užadi i telemetrijski prenos mernih signala kroz vertikalno rudarsko okno. Rad ilustruje ekstremne dinamičke pojave i zanimljiva zapažanja u vezi mernih sistema. Publikacija je ilustrovana dijagramima izvedenih merenja u RTB Bor na izvoznoj mašini ASEA HSDE 2.5. Merenja su obavljena na postrojenju dubine 500 m pri brzini od 5 m/s.

Ključne reči: Izvozna mašina, liftovi, električna merenja, telemetrijski prenos signala, užadni sistem

EXPERIMENTAL RESEARCH OF LIFTING MACHINES FOR VERTICAL MINING TRANSPORT

Abstract: This paper gives an overview of several experimental tests of export mining machines. The tests are tensometric and optical. They determine the dynamic forces in the rope lifting system and the variability of velocity (acceleration) of the moving masses. A special part of the research refers to the magnetic control of the rope and the telemetry transfer of measuring signals through the vertical mining shaft. The paper illustrates extreme dynamic phenomena and interesting observations on measuring systems. It is illustrated with diagrams of performed measurements in the mine RTB Bor on the export machine ASEA HSDE 2.5. The measurements were made at a depth of 500 m at a speed of 5 m/s.

Key words: Export mining machine, Lifts, Measurement, Telemetric signal transmission, Rope system

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1 UVOD

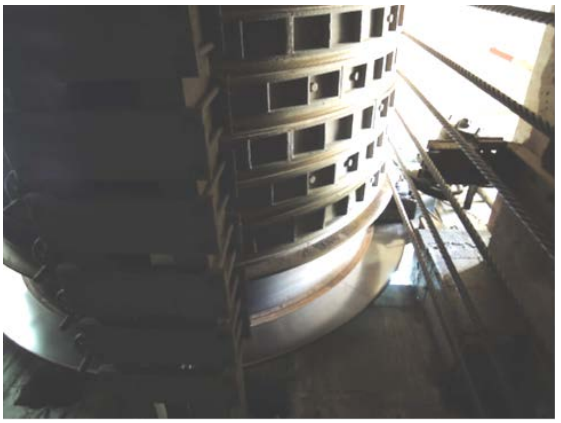
Izvozne mašine su mega mašine i karakterišu se većim brzinama, kapacitetima, snagama i visinama dizanja od putničkih liftova pa zato predstavljaju posebne mašine u tehnici [1]. Prvo kompleksno ispitivanje u RTB Bor izvedeno je 2006. godine kada su ispitane četiri izvozne mašine [2,3,4]. Ispitivanjima su merene elektronskim putem kinematske i dinamičke karakteristike, prelazni režimi kretanja, prisustvo defekata u kočionim diskovima primenom ultrazvuka i penetranata. Ispitivanja su ponovljena 2010, 2012. i 2013. godine. Za ta merenja razvijena je specijalizovana elektronska merna oprema u saradnji sa Elektronskim fakultetom iz Niša [5,6]. Specijalizovana merenja velikih oscilacija, prigušenja i posredno karakteristika užadi, obavljeno je 2014. i 2015. godine. Tada su dve nezavisne ekipe obavile paralelna merenja kinematike koša i užetnjače i dinamike užeta sa telemetrijskim prenosom signala kroz okno na jedan akvizicioni medijum [1,2]. Iskustva iz tih merenja služe za dinamičko modeliranje izvoznih mašina čime se bolje definišu radna opterećenja komponenata transportnog sistema.

U daljem tekstu, dat je pregled rezultata eksperimentalnih ispitivanja više kategorija (parametara) izvoznih mašina. Prvom grupom ispitivanja u ovom radu predstavljena su eksperimentalna ispitivanja kinematike izvoznih mašina. Drugom grupom ispitivanja predstavljena je kontrola užadi magnetnim fluksom. Trećom grupom iznetih ispitivanja u ovom radu, predstavljen je merni sistem za kontrolu (monitoring) kapaciteta izvoznog postrojenja.

U ovom radu su predstavljena ispitivanja na izvoznoj mašini ASEA HSDE 2.5 koja se koristi na Servisnom oknu Rudnika bakra Bor. To je mašina snage 1500/2820 kW, brzine dizanja 5/16 m/s i nosivosti 22 t. Ova rudarska mašina opslužuje vertikalnu jamu dubine 500 m. Pogonski je izvedena direktnom spregom motora i užetnjače (bubnja) po Koepe modelu [10,11,12]. Uravnoteženje koša je izvedeno tegom koji se nalazi na drugoj strani bubnja.

Balkanski prostor ima veliku eksploataciju ruda obojenih metala kao i uglja pa zato ima veliki broj rudnika sa podzemnom eksploatacijom. Za podzemnu eksploataciju koriste se izvozne mašine koje se karakterišu dubinama transporta od 1000 m, brzinama izvoza ruda do 20 m/s i kapacitetima do 250 t/h. Pri tome su instalirane snage izvoznih mašina do 2.5 MW a trenutne električne snage preko 5.0 MW. Uvedena regulativa u rudarsku delatnost [8,9] i nacionalni zakoni, podstakli su istraživanja u oblasti opreme i bezbednosti. To se pre svega odnosi na uvođenje informacionih tehnologija i primenu paralelnih (dvojnih) mernih uređaja u jamsku tehnologiju izvlačenja rude. Težina rada u podzemnoj eksploataciji je uslovljena geološkim uticajima, dejstvom vode, bazne i kisele sredine, eksplozivnih gasova, mehaničke abrazije, prisustvom čvrstog taloga i incidentima. Uvođenjem elektronskih mernih sistema može se kontrolisati stanje kinematike i naprezanja izvoznih mašina, može se pratiti korozija u užadnim sistemima, oscilacije velikih masa, ispravnost uravnoteženosti tegovima, tekući protok ruda (iskop). Takođe elektronskim putem se može kontrolisati ravnomernost sila u užadnom sistemu (spojnom priboru) i ravnomernost užadne athezije. U cilju kontrole sigurnosti postrojenja, testirana je poslednjih desetak godina u Rudniku bakra u Boru (u jamskoj eksploataciji) koncepcija mernog elektronskog sistema razvijenog specijalno za rudnike sa izvoznim mašinama [7]. Koepe sistem vuče pogonskom užetnjačom (bubnjem) pokreće noseću užad. Na jednom kraju užadi je koš za transport materijala, ljudi i opreme a na drugom kraju užadi je teg. Ceo sistem je uravnotežen balansnim užetom koje sa donje strane

spaja koš i teg. Sigurnost vertikalnog transporta direktno zavisi od veza užadi sa košem i tegom što se ostvaruje spojnim priborom. U svrhu sigurnosti oprema je robusna sa visokim rezervama u nosivosti. Pogoni su izvedeni sa jednosmernom strujom što omogućava dobru regulaciju kinematike. Izvozni Koepe sistemi imaju 2÷8 užadi na koju se veša koš. Mašina ASEA HSDE-2.5 u Boru ima 6 užadi, slika 1. Kočenje sistema se izvodi na bubnju sa 6-8 hidrauličnih disk kočnica (pritisci su do 200 bara). Upravljački sistemi koriste tahometre klasičnog tipa. Svi kontrolni i napojni sistemi su dupli. Izvozne mašine su uglavnom na vrhu izvoznog okna ili su u tornju za izvoz.



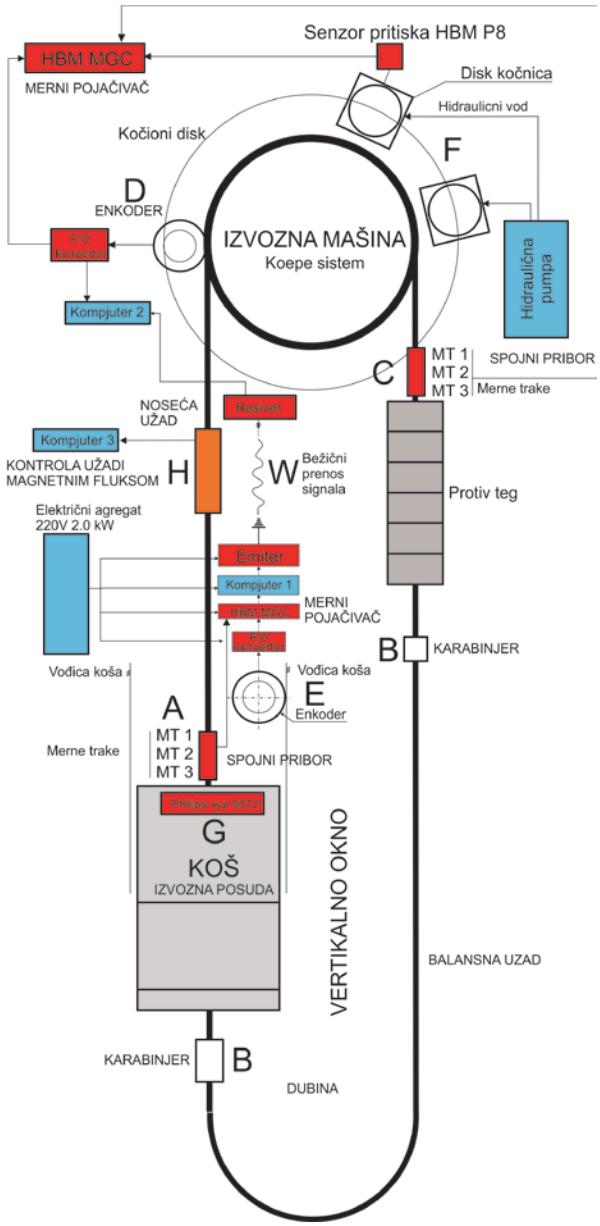
Slika 1. *Pogonski bubanj Koepe sistema sa užadima i tahometrom za kontrolu brzine*

2 TEHNIČKO REŠENJE KONTROLNOG-MERNOG SISTEMA

Na sl.2 pokazana je koncepcija merno-informacionog sistema tehničkog rešenja za praćenje rada izvoznih mašina. Elektronski tenzometrijski se u zoni spojnog pribora (A, S) mere deformacije (sile), u zoni B se kontroliše pokretljivost obrtne spojnice, u zoni (D, E) se kontroliše brzina, u zoni (F) se kontroliše kočioni pritisak, u zoni (G) se kontroliše ubrzanje koša dok se u zoni (H) kontroliše ispravnost užadi. U zoni (W) se obavlja bežični prenos signala. Tehničke karakteristike mernog sistema:

- Sistem-1 za tenzometrijsko merenje deformacija i sila u grupi užadi, tačnost 0.2%.
- Sistem-2 za merenje brzine kretanja koša i brzine okretanja bubnja, tačnosti 0.5%.
- Sistem-3 za merenje ubrzanja (vibracija) koša, tačnosti 0.5%.
- Sistem-4 za merenje pritiska ulja u kočionoj instalaciji, tačnosti 0.5%.
- Sistem-5 za kontrolu homogenosti i neprekinutosti žica u užadi, tačnosti 1.0%.
- Sistem-6 za bežični serijski prenos signala na rastojanju do 1000 m,
- Aplikativni softver za električna merenja zasnovan na platformi HBM Catman-AP,
- Aplikativni softver za merenje magnetnog fluksa, zasnovan na opremi Zawada-PL,
- Agregat za napajanje strujom 220/240 V, 2.5 kW,
- Minimalna merna brzina svih sistema: 1000 uzorka/s.
- Merno područje radnih brzina vertikalnog transporta: 0÷20 m/s,
- Merni sistem vertikalnog transporta: Sekvencijalni, periode 500 impulsa/obrtaju,

- Prosečan merni kapacitet *Koepe* sistema: 300 t/h (Parametri rada: 10 ciklusa/čas, prosečni teret skipa 15 t, broj skipova 2, srednja brzina izvoza rude 5 m/s),
- Brzina odgovora elektronskih sistema: 0.01 s.
- Klasa električne zaštite izvedenog rešenja: IP65.



Slika 2. *Šema mernog sistema na izvoznoj mašini (koncepcija sa Koepe pogonom)*

Merni Sistem-1 za tenzometrijsko merenje deformacija i sila u grupi užadi, zasniva se na mernom pojačivaču (recimo HBM QUANTUM-X), mernim trakama (HBM LY10/120), slika 3, računaru (kompjuteru-1) kojim se upotrebom softvera HBM Catman-AP mogu meriti paralelno i brzina i ubrzanja koša, slika 4. Sistem-1 je pokretan i smešten na krovu koša ili glavi skipa. Na osnovu prosečnih izmerenih deformacija na spojnom priboru i površine poprečnog preseka prizme (A), izračunava se dinamička sila u užetu ($\Delta S=\Delta\varepsilon \cdot A$). Rezultat merenja deformacija spojnog pribora je pokazan na slici 5.

Merni Sistem-2 koristi se za merenje brzine okretanja bubnja, slika 2. Ovaj merni sistem se sastoji od pojačivača (korišćen je HBM MGC+ i HBM QUANTUM-X), F/V konvertora, enkodera sa minimalno 500 imp/okretaju. Merenje se obavlja takođe softvera HBM Catman-AP. Akvizicija i merenje se obavlja računarom (kompjuter-2) koji je stacionaran na vrhu okna, neposredno pored izvozne mašine. Ovaj računar komunicira sa kompjuterom-1 koji je smešten na košu preko perifernih komunikacionih komponenti (Merni Sistem-6). Rezultat merenja brzine koša je pokazan na slici 7.

Merni Sistem-3 služi za merenje ubrzanja koša u tri pravca, slika 4. U tu svrhu se koristi kompjuter-1, merni pojačivač (HBM QUANTUM-X) i senzor ubrzanja (Philips 9369/10). Rezultat merenja jedne komponente ubrzanja koša je pokazan na slici 6.

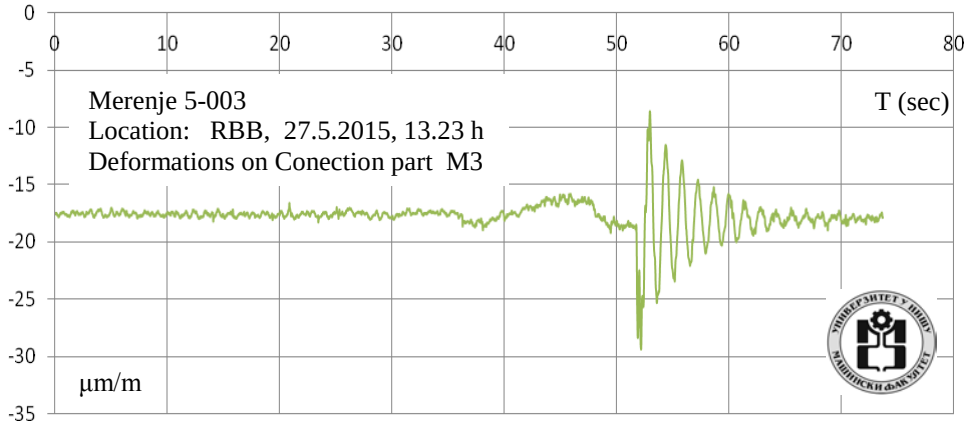
Merni Sistem-4 se koristi za merenje pritiska u hidrauličnoj instalaciji koja je stacionarna pored pogona izvozne mašine. Kompjuter-2 služi za merenje pritiska u kočionoj instalaciji koji daje hidraulični agregat stacioniran uz bubanj izvozne mašine.

Merni Sistem-5 se koristi za kontrolu homogenosti i neprekidnosti žica u užadima. Kontrola se obavlja mernim uređajem koji radi na principu magnetnog fluksa. Za kontrolu užadi, prema slici 2, koristi se kompjuter-3. Merni uređaji sa magnetnim fluksom koriste merne glave prema prečniku užeta koju ispituju. Ti uređaji imaju A/D konvertore kojima se digitalizuje merni signal i kao takav uvodi u merno-akvizicijski računar. Dalje, merni uređaji na principu magnetnog fluksa koriste softver za obradu i prikaz mernih signala. Stabilnost rada mernih sistema se obezbeđuje autonomno, električnim agregatom snage 2.5 kW i uređajima za neprekidno napajanje (UPS).

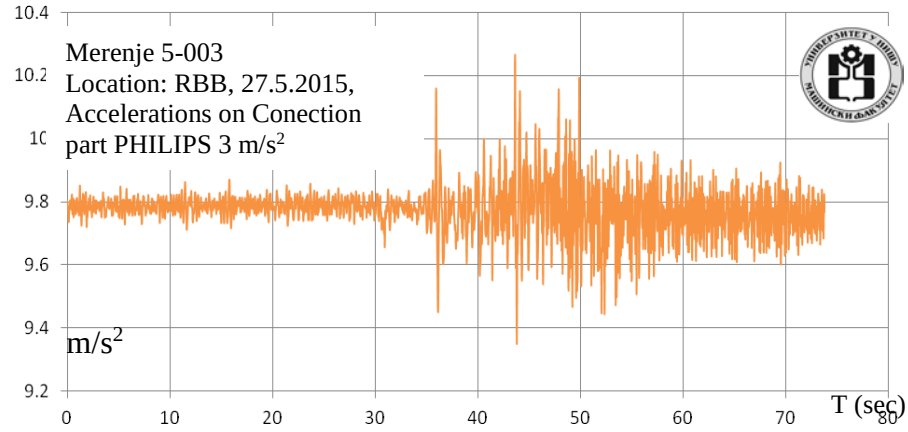
Merni Sistem-6 služi za komunikaciju dva računara. Kompjuter-1 ima komunikacionu jedinicu za bežično slanje signala prema Kompjuter-2. Koristi emiter i risiver. Time se povezuju merne veličine oba merna sistema, i vremenski sinhronizuju. Iz tako sinhronizovanih podataka moguće je videti kako osciluje koš u toku kočenja ili kretanja maksimalnom brzinom. Zatim moguće je videti koliko kasni oscilovanje koša od početka kočenja sistema, kako izgleda moment i rad kočenja. Moguće je registrovati kad nastaju prekomerne vibracije ili incident. Tako je moguće identifikovati trenutak kada je potrebna tehnička korekcija ili servis.



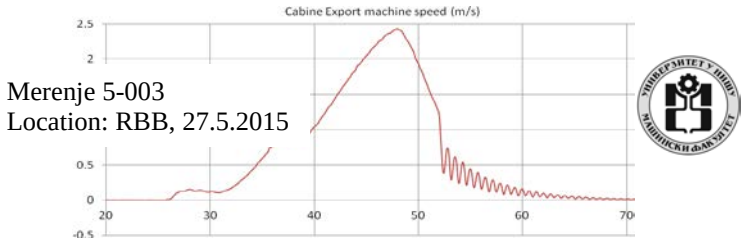
Slika 3. *Merna traka HBM LY 6/120 na prizmi spojnog pribora koša sa užadima*
Slika 4. Trokomponentni davač ubrzanja Philips L9369



Slika 5. *Dijagram 5-003.3, M3 – senzor deformacije spojnog pribora*



Slika 6. *Dijagram 5-003.5, A3 – senzor vertikalnih ubrzanja koša ASEA HSDE 2.5*

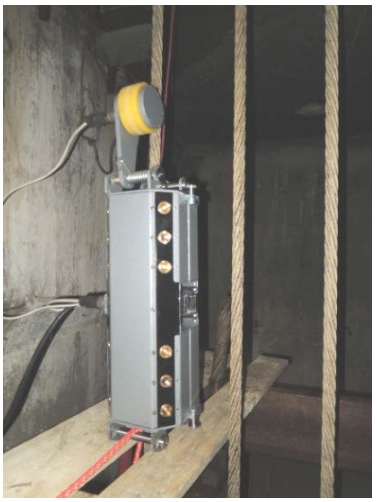


Slika 7. *Dijagram 5-003.6, brzina vertikalnog kretanja koša posle kočenja (oscilovanje)*

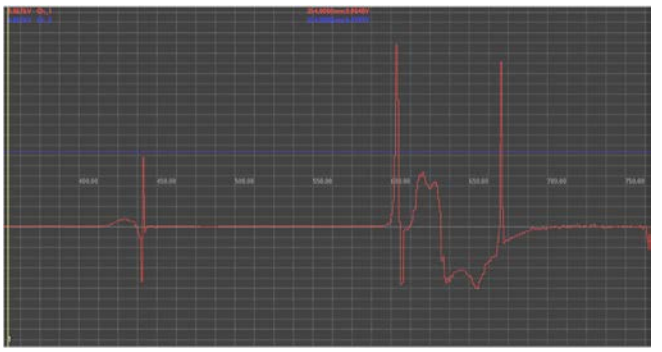
3 ISPITIVANJE UŽADI MAGNETNIM FLUKSOM

Periodična kontrola užadi na rudarskim izvoznim mašinama realizuje se na 6 meseci. Kontrola se organizuje prethodnim planom merenja. Za kontrolu kontinuiteta površine metalnog preseka užeta se koriste uređaji – TESTERI koji senzorima prate promenu magnetnog fluksa (pulsa) pri kretanju čeličnog užeta kroz nepomičnu mernu glavu. Slika 8. pokazuje mernu glavu pri testiranju užeta prečnika 27 mm, u RBB Bor [13]. Merenjem se registruju tri veličine: Položaj užeta u odnosu na mernu glavu, promena magnetnog fluksa i dubina defekta. Položaj merne lokacije na užetu se prati enkoderom. Magnetni fluks se prati sa dve merne glave, međusobno upravne. Tako se formiraju tri signala. Merni signali se digitalizuju i uvode u računar kojim se vrši monitoring. Svi signali se zapisuju i čine dokumentaciju. Nakon merenja vrši se analiza signala. Isti plan merenja se primenjuje u sledećim merenjima. Poređenjem starih i novih zapisa se utvrđuje promena na užadima.

Na slici 9 pokazani su rezultati zapisa veštački izazvane nehomogenosti užeta uzrokovane umetanjem čelične žice u užadnu pletenicu površine 5 mm^2. Na ovaj način, poznata je veličina promene poprečnog preseka užeta na mestu diskontinuiteta i odgovarajući merni signal.



Slika 8. *Uređaj NDT Zavada MDNV Data Logger*

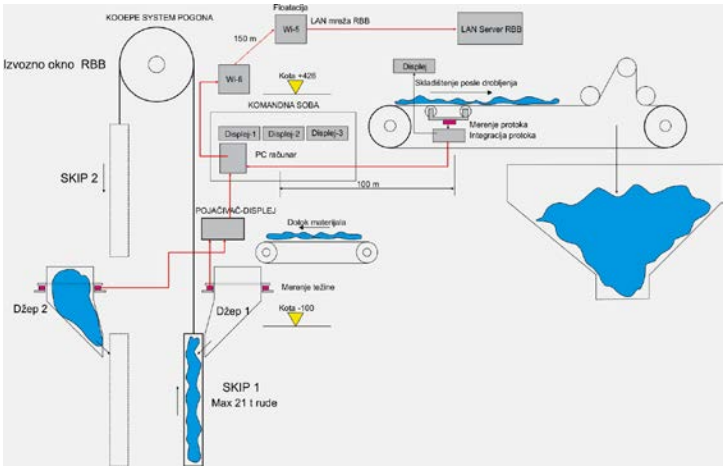


Test kretanja malom brzinom (ručnim okretanjem enkodera). Test sa umetnutom žicom od 5 mm^2. Datum 4.6.2015. Mesto: Servisno okno. Napon pojačivača: 2 mV/V. Primedba: vrlo mali šum. Horizontalna osa sa belim brojevima: merni položaj lokacije na užetu.

Slika 9. *TEST 1: Određivanje amplitude signala defekta*

4 SISTEM ZA MONITORING (IZVOZNOG) KAPACITETA JAMSKOG KOPA

U okviru projekta TR35049 (2014.), razvijeno je tehničko rešenje sistema za merenje težine izvezene rude bakra i monitoring procesa rada, praćenja performansi izvoznih transportnih mašina i opreme [14]. Merni-monitoring sistem omogućuje praćenje težina rude koja je izvoznom mašinom vertikalno transportovana iz jamskog rudarskog postrojenja, slika 10. Takođe, merni sistem prati i horizontalni transport ka bunkerima za skladištenje. Merni sistem prati dve tipične tehnologije transporta ruda: Vertikalni-prekidni, horizontalni-kontinualni. Koncepcija ovog sistema je postavljena na zahtev RTB za informatičkim praćenjem proizvodnje i registrovanje količine rudarskog iskopa. Pri tome se proverava jednakost izmerenog protoka na oba sistema.



Slika 10. *Merni, informatički i softverski sistem Projekta*

Glavni sistemi tehničkog rešenja za monitoring izvoza su: **Sistem-1** za tenzometrijsko merenje težine rude u džepu; **Sistem-2** za tenzometrijsko merenje težine rude na transportnoj traci, (Softver za protočnu obradu podataka sa mernih senzora, Softver za rad sa bazama podataka o izvozu rudarskog postrojenja); **Sistem-3** za mrežnu komunikaciju sa LAN RBB (Softver za monitoring izvoznog postrojenja). Projektovani sistem je delimično realizovan za kapacitet od 300 t/čas. Karakteriše se mernom brzinom od 200 uzorka/sec. Prati proces izvoza sa 10 ciklusa/čas, prosečnim kapacitetom skipa 15 t, broj skipova: 2, srednjom brzinom izvoza rude 5 m/s. Klasa tačnosti mernih senzora: 0.1/0.2 %. Brzina odgovora: 0.01 s. Sistem omogućava uvid u težine trenutnog, dnevnog, nedeljnog, mesečnog izvoza rude. Podaci o procesu se distribuiraju mrežnom komunikacijom u organizaciona sedišta rudnika. Ima tri sistema:

SISTEM-1 služi za merenje težine i monitoring utovara rude u dva džepa za punjenje skipova. Mehaničke veličine - sile i brzine (težine rude, protok na traci, brzina trake) se mere tenzometrijskim senzorima (Vinstonovim mostom) i optički (inkrementalnim enkoderom). Merenje se obavlja na koti punionice (-100), praćenje (monitoring) procesa se obavlja u komandnoj sobi Izvozne mašine (+410). Signali se kroz okno vode industrijskim kablom, protokolom RS485. Podaci dobijeni merenjima se preuzimaju PC industrijskom stanicom i uvode u LAN mrežu RTB. Slika 10. Na koti -100, je standardni vagarski terminal HBM WE2107M-SS1, sa certifikatima PTB, OIML, i certifikatom Direkcije za MDM Srbije. Ovim terminalom se obezbeđuju zapisi o doziranju, tariranju, presipu

materijala. Povezivanjem na PC računar, omogućuje nadzor i dijagnostiku čitavog mernog sistema.

SISTEM-2: Merenje protoka rude nakon izvoza i drobljenja i monitoring skladištenja, sl.10. Vaga na traci DT-4 služi za dinamičko merenje protoka rasutog materijala u proizvodnom procesu. Brzina kretanja trake/materijala se meri enkoderom. Opterećenje (metarska težina materijala) se meri mernim ćelijama proizvodnje HBM tip Z6FC3 montiranih na dva merna sloga valjaka. Podaci o izmerenoj težini materijal na trakastom transporteru se osrednjavaju, množe sa brzinom (izmerene enkoderom), te se tako dobijena informacija o trenutnom protoku prikazuje i šalje preko serijskog porta (Profibus DP, Ethernet ili RS485) na PC/PLC sistem koji prati (upravlja) postrojenjem. Uređaj za prikaz rezultata merenja protoka je Meoller/Microinovation XV102-E6-70. Nalazi se u kontrolnoj sobi Izvoznog okna, na posebno urađenoj tabli za monitoring. Softver za kontorlu rada protočne vage izračunava trenutni i kumulativni protok (t/h; t/8h; t/24h; t/7 dana, t/mesec), kalibriše vage, vrši upis i kontrolu pristupa bazi podataka, sinhronizuje komunikaciju sa ostalim komponentama.

SISTEM-3: To softverska windows aplikacija monitoringa i stavljanje podataka o proizvodnji (podaci sa mernih vaga) u LAN RTB.

5 REZULTATI PRIMENE

Prikazani merni sistemi su izrađeni i testirani industrijski. Merni sistem za monitoring izvoznog kapaciteta je izrađen delimično. Realizacija pokazanih tehničkih sistema kroz Projekat Ministarstva [3,7,14] su prvi veći informatički zahvat od izgradnje izvoznog postrojenja 1970. godine. Na bazi ispitivanja vibracija su uočeni nedostaci i izvršene su tehničke korekcije vođica koševa. Višegodišnje praćenje svih izvoznih mašina omogućilo je bolje poznavanje mega-mašina, efikasnije održavanje i bolju procenu preostalog veka eksploatacije.

6 ZAKLJUČCI

1. Tehnička rešenja, koja su testirana u RTB Bor, već su doveli do pravovremene zamene delova i produžene eksploatacije odgovorne opreme na izvoznim mašinama. Tehničko rešenje se zasniva na mernom lancu koji je integrisan informacionim sistemom za praćenje vitalnih parametara postrojenja. Oprema se može prilagoditi različitim kategorijama rudnika. Istraživanja u oblasti rudarskih mašina su značajna jer rudarstvo ima približno 80% vrednosti opreme u kategoriji transportne opreme.
2. Ponašanje sistema se periodično može meriti i upoređivati sa ranije izmerenim. Tako se mogu pratiti (periodično) promene u sigurnosti postrojenja.
3. Tehničko rešenje pokazano na slici 2 je realizovano je na naučnim osnovama teorijskih i eksperimentalnih metoda. Takođe, tehničko rešenje je originalno i potpuno novo u naučnom tehnološkom prostoru, pre svega kao komplet grupisanih tehnologija za kontrolu sigurnosti vitalnih sklopova izvoznih rudarskih postrojenja.
4. Tehničko rešenje na slici 2 omogućuje grupu eksperimentalnih provera tehničkih karakteristika izvoznih rudarskih mašina: graničnih (dozvoljenih) brzina i ubrzanja, dozvoljenih napona u spojnom priboru, proveru homogenosti i neprekidnosti žičane strukture rudarskih užadi, uravnoteženosti Koepe vučnog sistema, kontrolu unutrašnjih sila u spojnom priboru, kao dovoljnu meru za ocenu sigurnosti.
5. Predloženi koncept grupisanih metoda se može daljim istraživanjima proširiti novim kriterijumima kontrole [15].

ZAHVALNOST

Dinamička istraživanja realizovana su podrškom Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije, a u okviru projekta TR35049 u 2011-2018 godini. Ovaj rad je napisan u okviru Projekta Mašinskog fakulteta od 15.11.2018. Autori rada se zahvaljuju Rudniku bakra RTB Bor na kvalitetnoj saradnji.

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QUALITY, MANAGEMENT AND ORGANIZATION

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DESIGNING A LEARNING SPACE FOR MECHANICAL ENGINEERING EDUCATION

Robin Støckert[1] Vojislav Novakovic[2],Aleksandar Košarac[3]

Between 2010 and 2017, The Norwegian Ministry of Foreign Affairs was running a program of higher education, research and development (HERD) in the Western Balkans. Within the field of sustainable energy and environment, two projects was initiated by Professor Vojislav Novakovic at NTNU. First the SEE-WB (Sustainable Energy and Environment) and then QIMSEE (Quality Improvement Of Master Programs in Sustainable Energy And Environment). Both collaborative projects, aimed to contribute to educating a national workforce at WB countries that has adequate innovative qualifications in the energy sector by building the sustainable capacity of higher education institutions.
To enable and support communication and collaboration between the different partners in the projects, a set of software tools, equipment and related infrastructure was established and built on-site at each partner location. Hereafter defined as MFR (Multi-Functional Room). The MFR is a flexible space designed to facilitate a vast set of activities ranging from cross-campus collaboration and communication to new types of learning scenarios. In this paper we will describe the basic ideas behind the design, the use of the MFR and related training activities during the project and a glimpse into the classroom of the future.

Key words: Cross-Campus, Collaboration and Communication, Techology, Pedagogy

1 INTRODUCTION

QIMSEE builds on SEE-WB. The focus of the projects was aimed on a “green energy” dimensions in the region by (i) introducing new knowledge components in the engineering studies – new or modified curricula; (ii) providing upgrading of teachers’ skills through exchange visits; (iii) exposing faculties to new modes of teaching, (iv) providing study opportunities at NTNU for students preparing their Master’s theses; and (v) strengthening peer learning by supporting networks among the various engineering

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faculties at universities in the region. As stated in the Final report[1]:

Review of Norwegian Programmes in Higher Education, Research and Development (HERD) in the Western Balkans 2010-2015, the SEEWB project, which ended in 2014, contributed to five new internationally recognised MSc programmes in sustainable energy and environment being established at five universities in three states. QIMSEE has developed this further by having three more universities join the programme, and strengthening the regional network, where the University of Zagreb is playing a leading role despite no longer being eligible for Norwegian funding.

During the last three years of SEEWB – the period funded by HERD – over 200 MSc students were enrolled in these new programmes, of which almost one-third were female. About 170 had graduated by the time SEEWB ended, which was way above the initial ambition of 50-75 MSc students. 21 MSc students spent one semester at NTNU working on their theses.

One of the areas that has elicited the greatest interest is how engineering studies are organised at NTNU, which contains in particular two dimensions that WB universities are interested in adapting. The first is the close link to industry, so that theses and teaching are problem-solution oriented and less academically driven: the most effective learning is in applying new knowledge to real problems. The other dimension is working in teams where students learn to share and work together and the teacher is more a tutor-resource than a lecturer – information transmission is a lot more demand-driven. A workshop on team work was held at NTNU in January 2015 for faculty and students from the Western Balkans and was continuously referred to throughout the field work as a real eye-opener.

At the same time, QIMSEE was moving more and more towards regional learning and experience sharing. In June 2015 the first of two planned “summer schools” was held in Ohrid in Macedonia and the second workshop was held in Bar, Montenegro in 2016. The »summer schools« had students and faculty members from all eight universities, including some students from NTNU and EIT[2] facilitators. The focus was exactly on how to use team work to address engineering problems.

The possibilities for regional interaction and learning are being further strengthened through the establishment of multi-media learning centres, hereafter defined as Multi Functional Rooms(MFR) at the participating universities. This will allow for formal distance learning – using professors from the different universities in the region, from NTNU and elsewhere – but also host student workshops that will allow for joint projects across the region, something that is also generating excitement.

The extracted report summary above, indicates that the combination of a flexible and technology enhanced learning space(MFR), combined with related pedagogy and the knowledge of interdisiplinay teamwork skills (EiT)[4], creates excitement and facilitates more student active learning through collaboration and communication on many levels.

2 THE MULTIFUNCTIONAL ROOM

To support the goals of the projects, it was necessary to develop and establish a common technological platform and related standards for cooperation and communication. The MFR was set up on a dedicated campus location at each university, to support activities defined in the project synopsis. The local priorities and relevant

[4] Experts in Teamwork is a master’s degree course in which students develop their interdisciplinary teamwork skills. The course is compulsory for all students in master’s programmes and programmes of professional study at NTNU.

needs at each University resulted in an interesting variety of MFR enable a design which aligned with the campus context. Hence, we ended up with an interesting variety of solutions, ranging from flexible learning spaces (classrooms, meeting/production rooms), via mechanical/data labs to a full-scale conference room.



Figure 1. *MFR in East Sarajevo and Banja Luka*

2.1 Room design

There are several design principles/guides which may be used in the creation of contemporary learning spaces. (JISC, 2006)**[3]**, (FLEXspace)**[4]** and other relevant sources are often referring to different parts of the design and usage, which describes factors like flexibility, type of furniture, collaboration, futureproof, tools and technology, etc.

In the design phase of these rooms, we focused on the basic elements that makes a good room/workplace: Air, light, acoustics, colors, good flexible furniture. In other words, we choose to prioritize on environmental quality and atmosphere first, and then on the flexibility to utilize the room with a selection of learning scenarios. In addition we had to take into consideration that the rooms should facilitate videoconference and other types of AV-communication. This was handled by improving acoustics (sound quality), setting up lights for different videoconference settings and finally by using nice colours and materials to create a good visual atmosphere for users and videocameraes. All the factors mentioned are important and contributes to the multipurpose functionality of the room.**[5]**

2.2 Activities and scenarios

We needed to define user scenarios in accordance with the specific objectives of the project. During the project period, the different MFR were used in various ways.

- Ordninary teaching with use of interactive projector, which made all the lecture notes available on pdf immediately after the session was finished.
- Marketing of MFR and demoes for visitors.**[6]**
- Guests from other Universities or companies connected through videoconference(VC) to present at conferences or in ordinary lectures.
- Local and networked groupwork
- Production of multimedia teaching material like presentations, small instructional videos, audio, notes)
- Local and networked Project meetings where all member Universities could attend in the same meeting and share documents via videoconference.
- Meetings with publc/privat sector through videoconference.
- Local and networked conferences and workshops



Figure 2. *Local and distributed activities*

In addition, we had to make a flexible sustainable solution, which could be utilized after the project was finished. As user experiences are gathered, new user scenarios will be discovered and maybe implemented in the future.

The design, implementation and use of the MFR were presented at several workshops and international conferences by amongst others: Danijela Kardas, Bojan Knezevic, Vuk Adzic, Aleksandar Kosarac, Vojislav Novakovic and Robin Støckert. We got feedback and advice to bring back in the continuous process to optimize the MFR`s.



Figure 3. *Presentation at the Innodoct and Inted conference*

The goal was that the multifunctional rooms should accommodate a variety of teaching methods and usage scenarios – e.g. Active learning and teaching activities, meetings, conferences, presentations. Furthermore, development, adaption and production of teaching material/curriculum, become an arena for unified collaboration and communication**[7]**. In a bigger picture, the MFR should facilitate a vast selection of relevant local and distributed activities to accelerate the process of improving the mechanical engineering education and joining the universities, industry and the public sector.**[8]**

2.3 Infrastructure and technology

The Infrastructure model can be divided in different segments, starting from local cabling, network and switches in the MFR, via campus infrastructure and finally University to University, country to country.

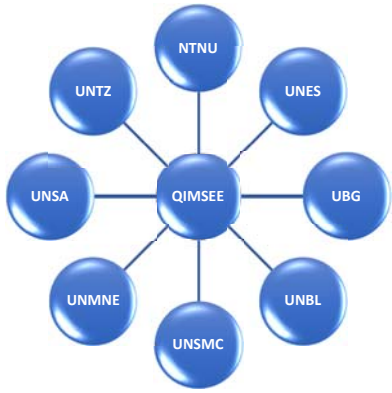


Figure 4: *Partners in the QIMSEE project*

We will focus on the infrastructure in the MFR due to the fact that the rest of the infrastructure(network) was not managed or controlled within the project. Hence, the connections between Universities used normal internet, without certain demands regarding »Quality of service« (QoS)[5]

First of all we needed to provide a wired network to connect the local equipment in the MFR, but in addition a wireless network to support the connection of any type of mobile devices (BYOD)[6] belonging to students, teachers or other visitors. The BYOD solution provides flexibility and easy connection to the features of the MFR. Up to 50 users can connect to a projector at the same time and the teacher can choose up to 4 user screens to be displayed side by side. The students may also use their mobile devices to connect to a common video-conference system for all MFR locations. Features like this, enhance group work and interaction between teacher and class, but it is up to the teacher to include these possibilities in a pedagogical approach.

A set of standard equipment was set for all the multifunctional rooms. The reason for this was that each node/MFR in the QIMSEE network should be able to help each other with technical issues. Furthermore, to ease implementation of needed defined standards for communication and collaboration into existing network infrastructure. This common platform of equipment and support services, are crucial to make the basic functions operative. It also makes it easier to have common technical/pedagogical training sessions and to develop and exchange experiences regarding the role of the MFR in the future.

The main components were pc, videoconference-systems with loudspeakers microphones and several types of cameras, interactive projector and document camera.

[5] The ability to provide different priority to different applications, users, or data flows, or to guarantee a certain level of performance in a IP-network.
[6] Bring Your Own Device.

Several software solutions for communication, collaboration and sharing of workspace and files, were introduced and installed at each location/node in the network. The software solutions represented a variety of tools/features that could be useful for several learning scenarios. They could improve and support new pedagogical approaches to obtain more student active learning like different types of teamwork such as Team Based Learning (TBL) and Case Based Leaning (CBL), supported by the knowledge on how to work in and as a cross-disciplinary group. (See chapter: Summer school). Furthemore, to aid the teacher in producing, presenting and delivering optimized learning and related resources locally and through the network of nodes.

3 TRAINING

The concept of connected multifunctional rooms contains several dimensions of user scenarios and related local and networked activities. The users might vary from technicians, students, teachers,professors, external public or company representatives, AV/IT-personel. All which have different goals, experience and motives to utilize the potensial of the MFR in a local or networked mode.

3.1 Training and usage

The following series of images illustrates some of the various activities that was done during the project. The main idea of these activities was to create a set of Super-users which could be a local motivator and know the basic functionality, Secondly to train the trainers in order to obtain a local user group at each MFR, which wil inspire and train more teachers and students users to take ownership of the room and its features.

Training of technical personel regarding use, maintenance, repair, support service for ordinary users and related local og networked activities, marketing of MFR and demoes for visitors (schools, public/private sector).



Figure 5*: Technical training for AV/IT personel from Partner Universities*

Training and inspirational local/networked seminars for teachers and project-members with topics like new pedagogical approach, technical possibilities, creating new teaching material, collaboration and communication.



Figure 6: *Example from Workshop held at MFR in Belgrade demonstrating collaboration and production of teaching material.*



Figure 7: *Online seminar with guest lectures, connecting several MFR-nodes in the network.*

Engage presenters from other Universities or companies to attend at conferences held in in MFR



Figure 8: Seminar in Banja Luka Closing conference at MFR in Sarajevo

3.2 Summer School

During the project, two summer schools was arranged for students from all participating Universities. The activities ranged from teambuilding, lectures, presentations and social interaction to develop Foundational literatcies, the competence of approaching complex challenges and a fast changing environment.



One major task during the summer schools was to examine and find a solution to a complex problem, by working in teams. The teams were especially trained in teamwork, based on a obligatory course developed at NTNU called Experts in Teamwork (EiT).

In EiT, students develop teamwork skills by reflecting on and learning from specific situations of cooperation in carrying out a project. Interdisciplinary teamwork is used as an opportunity to develop collaborative skills that make teamwork more productive and the results achieved by the teams are used to benefit internal and external partners.The learning method in EiT is experience-based. An important part of the learning process is the situations that arise as the team works together. Students develop skills in collaboration by reflecting on these situations throughout the project life cycle. Team members perform reflection activities together, stimulated by facilitation, writing down reflections, exercises in teamwork, and feedback.

The skills developed through EiT is valuable for all kinds of teamwork done locally in a MFR or in a group consisting of members from different Universities cooperating through several networked MFR in real time.

4 CONCLUSION

The challenges we face in the future is complex and to solve them, we need cross disiplinay teams with the ability and skills to work together on many levels. The 21st century skills defined by world economic forum claims that today's job candidates must be able to collaborate, communicate and solve problems – skills developed mainly through social and emotional learning (SEL). Combined with traditional skills, this social and emotional proficiency will equip students to succeed in the evolving digital economy.

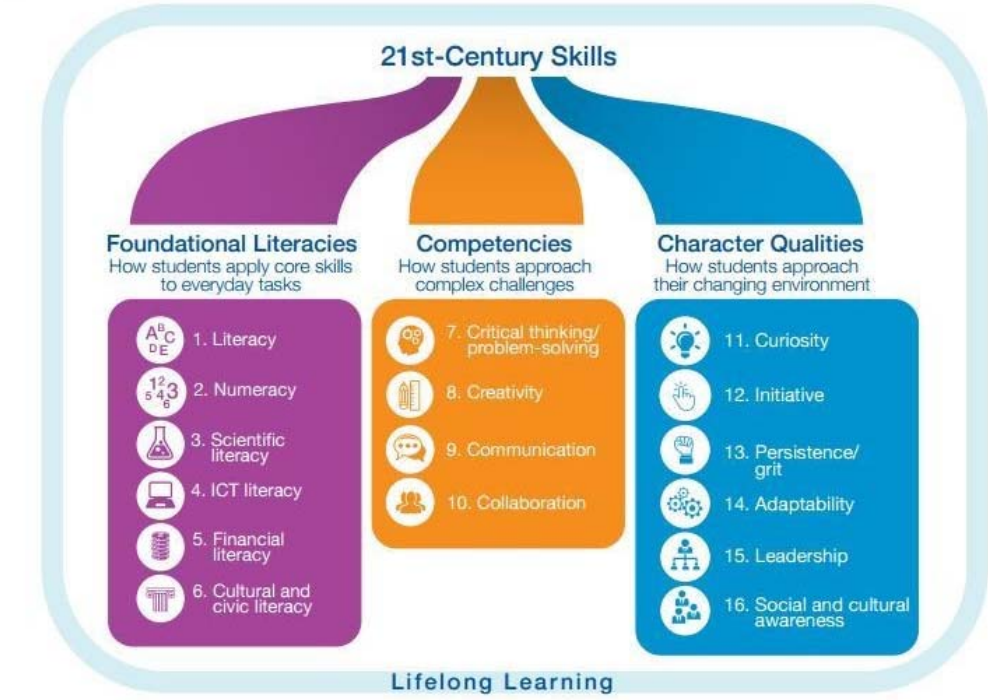
The 21st-century skill coincides with the basic pillars in QIMSEE project regarding developing the education by improving the foundational literacies by the development of internationally recognised MSc programmes. Furthemore to equip the

students with competencies in communication and collaboration and the tools (MFR) to work together. The character qualities are amongst others safeguarded by the activities in the EiT course/summer school.

The idea of the networked MFR in order to connect Universities together,was ahead of its time. If we look at the NMC Horizon report[9] for the last 3 years , the redesign or learning spaces and the Cross-Institution & cross-sector collaboration has been defined as key trends accelerating higher education technology adoption.

The SEE-WB and QIMSEE experience and infrastructure can be used to equip the future workforce with the 21st century skills. It is now up to the partner Universities to build on the experiences from the projects and to maximize the use of the established infrastructure and find new ways of utilizing and developing the Multi Functional Rooms.

Figure 9: World Economic Forum World Economic Forum. New Vision for Education (2015)



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KEY ENTREPRENEURIAL COMPETENCIES WITHIN THE CONTEXT OF MECHANICAL ENGINEERS EDUCATION IN BIH

B. Vučijak [1], T. Scholze[2]

Abstract: The paper summarizes the experience in addressing key entrepreneurial competencies and potentials and methods to develop them with mechanical engineering students. Paper presents achievements reached within the framework of the ERASMUS+ project REady for BUSiness (REBUS), underlining testing phase with the Study Visit at the University of Palermo, Italy. It presents existing impact of the REBUS project in revising curricula but also participation of different teaching tools and introducing blended learning concept in order to upgrade achieving entrepreneurial and intercultural competences in engineering studies.

Key words: entrepreneurial competences, intercultural communication competence, spotting the opportunity competence

1 INTRODUCTION

The REBUS project is initiated since it become visible that in transition countries (like Balkan countries or those that formerly belonged to USSR) young people are quite reluctant to create or even to be employed in the private sector, having high preference for employment at the public sector. They consider such employment safe in terms of salary payments and in terms of keeping the job, and even better paid as compared to private businesses. They do not consider own entrepreneurial capacities relevant, even when they are the most talented students within the generation. Even worse, if they get a public job, their potential often remain unused, since such jobs rarely request for innovative solutions or approaches and as such can hardly be fully validated for payment limitations in the sector [1] .

The REBUS project intends to contribute to change of such attitude and to enable higher potential for development of entrepreneurship at engineering and IT students in the partner universities and countries from South East Europe and Russia.

One of needed results was to assess to which set of the competencies is it about when speaking of building entrepreneurship competencies with students, so as how to

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achieve such result. The paper presents decided set and changes in curricula and teaching methods decided at Mechanical Engineering Faculty of University of Sarajevo.

2 KEY ENTREPRENEURSHIP COMPETENCIES

2.1 Basis for selection of key entrepreneurial competencies

In order to decide on key competencies to be developed, REBUS project decided to use the results of a survey among stakeholders on which competences are most relevant for building entrepreneurial competencies at engineering and IT studies. It also acknowledged that the European Commission identified Sense of Initiative and Entrepreneurship as one of the 8 key competences necessary for a knowledge-based society [2].

In 2016, on ten years anniversary of the above mentioned identification, Joint Research Centre, the European Commission's in-house science service, has prepared a report EntreComp: The Entrepreneurship Competence Framework, in order to support policy decisions. It was recognized that the development of the entrepreneurial competencies of Europeans is one of the key policy objectives for all EU Member States.

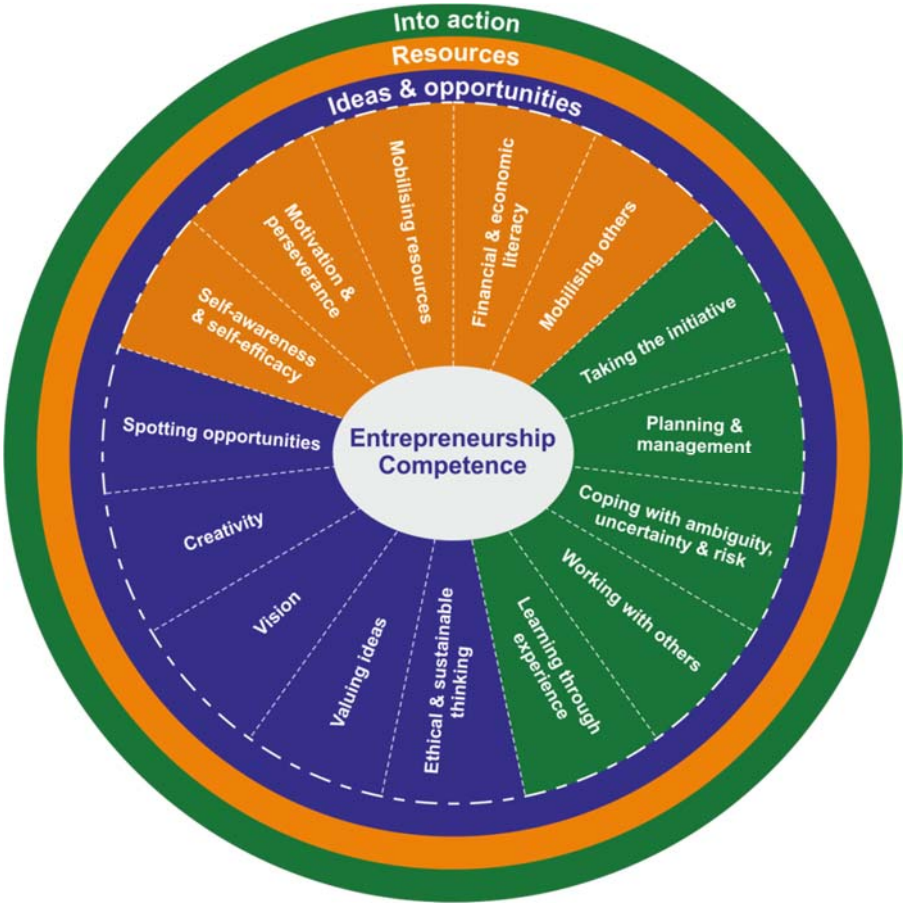


Figure 1. *Areas and competences of the EntreComp conceptual model [3]*

Entrepreneurship Competence Framework as presented in this report consists of three interconnected areas defined as 'Ideas and opportunities', 'Resources' and 'Into action', each of these three areas further consists of 5 competences. The framework also proposes a list of even 442 learning outcomes, aiming to be used as a basis for the development of learning activities creating entrepreneurship as competence [3].

EntreComp defines entrepreneurship as made up by the 3 competence areas and 15 competences, as presented at figure 1.

2.2 REBUS set of entrepreneurial competencies

REBUS competence framework was targeted at initial phase of the project implementation, already in June 2017 20 transversal competences belonging to the set "Sense of Initiative and Entrepreneurship" are selected as having particular relevance in the context of entrepreneurship education in Higher Education. The project decided to use the competence definition scaled to three different dimensions, to knowledge, skills and attitudes. Based on that related LEVEL5 reference systems were developed, creating the basis for the assessment and validation of the competences of students [4].

The EntreComp describes the 15 competences as in Figure 1, and the REBUS project team concluded that at most of the listed aspects correspond with the REBUS selected definition of the competence, that it is the ability to apply a synthesis of knowledge, skills and attitudes in in a particular situation and in a particular quality [5]. However, aspects mentioned in EntreComp like "Looking for opportunities" and "Visioning" can hardly be measured for validation purposes along a system of defined competence levels, what is the objective of the REBUS project. Thus the project decided to try to mix the EntreComp set of competencies with the LEVEL5 validation system ([4]) based on the above competence definition. The LEVEL5 system has been successfully applied in 25 European funded transnational projects and approximately 150 non-formal and informal learning projects with more than 2.000 learners, among them also entrepreneurial and service related competences ([5])

REBUS decided set of competences are also clustered to the Personal competences, Social competences, Organizational competences and Field competences (as example mechanical engineering), where only the last ones are traditionally subject of teaching programmes of the universities (Figure 2).

The finally decided REBUS competence set is described in details with descriptions of a competence summary and aspects what a learner should know (knowledge), be able to do (skills) and what attitudes show (attitude axis of a competence), so as with a reference system which clusters knowledge, skills and attitudes along 5 competence levels. That set, to be piloted with the students of participating universities, consists of 15 competences as follows [6]:

1. Field Competences
2. Entrepreneurship Competence as general concept
3. Problem solving
4. Leadership
5. Project Management
6. Planning and Resource Management
7. Intercultural Communication
8. Communication
9. Teamworking
10. Flexibility/Adaptability
11. Critical thinking

12. Networking
13. Creativity
14. Client orientation
15. Evaluating/Reflecting

REBUS set of entrepreneurial competences is an open catalogue of competences relevant for this education objective. Partners agreed that it is neither a closed repository nor a compulsory catalogue from which all items have to be selected.



Figure 2. *REBUS set of competences [6]*

2.3 Example of a competence summary and reference system

REBUS consortium is consisting of partners from quite a different cultural background, thus it was logical to use such environment to lecture and evaluate intercultural communication competency at partners' students.

For that purpose intercultural communication is defined as the competence to respectfully, constructively and effectively communicate with other people from different cultural backgrounds. The student should have knowledge about cultural diversity and how is it reflected in needed communication, and should be able to adapt to communication needs that result from different cultural backgrounds. He/she needs to have a positive attitude towards diversity and interacting with people from other cultures and is determined to avoid misunderstandings and resulting frustration. The student has to be aware of his own cultural identity and know how it affects his/her communication [6].

This means in terms of knowledge, skills and attitude that the student should have the following:

Knowledge: The student should

- have knowledge of ways to establish a relationship of trust and respect with others from different cultural backgrounds
- have knowledge of relevant intercultural communication techniques
- know the benefits of diversity
- have knowledge of variations of certain cultures and how cultural imprints may influence communication styles, including the own cultural background
- have knowledge how to address culture related conflicts/misunderstandings

Skills: The student should

- be able to communicate in a clear fashion with others from different cultural background
- be able to integrate with colleagues and learners of different cultures
- be able to reflect own cultural imprints in his/her communication
- be able to exchange knowledge and experiences with persons with different cultural backgrounds
- be able to give and receive feedback to and from learners, staff organizations of different cultural background
- be able to tolerate and overcome difficulty, stress and frustration, because of intercultural misunderstandings, so as to make him/herself understood
- be able to recognize culture based problems and misunderstandings and to adapt the own communication style accordingly

Attitudes: The student should

- value integrity
- respect others and their different cultural backgrounds
- have a positive attitude towards interacting with people from different cultures
- want to avoid culture based miscommunication
- want to support others

Similar competence summary and reference system is defined for all other selected competencies and used for the project purposes.

2.4 Building selected competences at higher education

It is clearly understood that the traditional higher education institution is focused to build knowledge at students, at some level and depending on practical students' engagement also to skills development. For these goals many teaching tools are available and practiced. But improving students' attitudes remains a complex task, where less methods are know and applicable.

Reviewing again the whole list of the selected competencies another question arise – how to integrate topics like formerly mentioned intercultural communication, networking, evaluating or leadership into the engineering or IT studies curricula?

Decision was to use blended learning concept, where teaching materials – presentations, videos, surveys and similar – are provided for the students for self-learning, combined with mentoring, practical project work orientation and teamwork, with supervised self-evaluation using LEVEL 5 system on achieved progress. In addition, topics like Problem solving, Project Management, Planning and Resource Management, Critical thinking or Creativity (with Innovation Management) are directly integrated into existing curricula of courses targeting similar competencies.

2.5 Piloting activities – students' study visit

Testing the blended learning system included targeted students' study visits to EU universities – during the two weeks period in September 2018 the 15 students of

Mechanical Engineering Faculty of University of Sarajevo joined their colleagues from University of Montenegro in Podgorica, later all of them were coupled with students of University of Elbasan from Albania on the road to Palermo for targeted training. The visits were a perfect opportunity to upgrade and later to evaluate progress in their multicultural communication competencies. Joint trip, short tours to success entrepreneurship stories in the vicinity of Palermo, group project work – where each of the groups consisted in 2 students per each of the three universities – provided good environment for upgrading their practical skills and their attitudes, initial low level of self-confidence was diminishing through time. Change in their communication competencies was visible to other students and to professor after being back at home university.

The same visit for good opportunity also to develop students' creativity and general entrepreneurship competencies, or spotting the opportunities as defined by EntreComp. Students' teams/groups participated in developing of entrepreneurship project development from idea creation, selection of the most promising one, its development into canvas and prototyping, also "marketing" the idea to other groups. This was found to be a very powerful teaching tool, decided to be more used for regular courses implementation.

3 CONCLUSION

In order to build up entrepreneurial competencies of IT and engineering students first task is to define which of such competencies are actually lacking and are essential to have. REBUS defined such a set of competencies, not being a closed repository. There will be reluctance to introduce some of them, like for example communication competencies, into the curricula, simply for the reason that they will not be considered as "sufficiently technical or engineering". Blended learning concept, combining availability of teaching materials with mentoring, supervised project development and self-evaluation, can be used to bridge this gap and still enable engineering and IT students to become leaders of innovation and entrepreneurship.

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PROCESS OF IMPROVING THE ENTREPRENEURIAL COMPETENCIES

Slaviša Moljević[1], Ranka Gojković[2], Snežana Nestić[3], Goran Orašanin[4], Dino Tihić[5]

Abstract: Entrepreneurship, through the creation of new jobs, increased innovation and poverty reduction, has been recognized as the main factor in economic and social development. In this paper, special attention is paid to the development of entrepreneurial knowledge, skills and attitudes through entrepreneurial education. There is an increasing awareness that entrepreneurial skills, knowledge and attitudes can be learned, leading to a more visible development of the entrepreneurial mindset and entrepreneurial culture in individuals and society as a whole. The paper presents the process of improvement of entrepreneurial competences among students of engineering disciplines. The process of improvement represents the approaches developed within Erasmus + REBUS projects.

Key words: Improvement, Entrepreneurship, Teamworking, Intercultural Communication

1 INTRODUCTION

European business sector pays an ever more increasing attention to competences such as sense of initiative and entrepreneurship. In 2006, the European Union proposed 8 key competences for lifelong learning, one of which is "a sense of initiative and entrepreneurship".[1]

The development of entrepreneurial capacities of European citizens and organizations is one of the key objectives of the EU and its member states. Western Balkans countries and Russia in general have a high level of resistance to private initiatives, business and entrepreneurship. [2]

The Erasmus + REBUS project is established with aim to enable strong support to address a challenge of bringing entrepreneurship into HEIs and establishing the

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interface between higher education and practical business context based on cooperation network of EU and Western Balkan countries. [3]

The project aims at developing, testing, validating and mainstreaming holistic and needs driven open learning modules to promote entrepreneurship competences of engineering graduates at the interface of academic education and learning in practice business contexts.

Based on different theoretical approaches to entrepreneurship, it is possible to identify a number of entrepreneurial competencies, that is, knowledge, skills, attitudes, abilities related to entrepreneurship and entrepreneurial behaviour. An entrepreneur has the capability to identify, analyse and use business opportunities, to hire the necessary business assets and to launch business ventures based on identified market opportunities. [4]

The REBUS project promotes the development of various training modules for entrepreneurship and their integration into existing or new curricula at higher education institutions. The project also promotes the creation and adoption of a system and the validation, implementation and evaluation of the training module and the competency validation system. [3]

Entrepreneurship education for college students has an important role in order to grow new entrepreneurs. [5] There is an increasing awareness that entrepreneurial skills, knowledge and attitudes can be learned, leading to a more visible development of the entrepreneurial mindset and entrepreneurial culture in individuals and society as a whole.

The University of East Sarajevo has implemented many activities aimed at raising the awareness of students about the importance of entrepreneurship. The paper presents the process of implementing Rebus's approach to entrepreneurial learning and the approach to assessing entrepreneurial competencies at the University of East Sarajevo.

2 IMPROVING ENTREPRENEURIAL COMPETENCIES OF STUDENTS AT THE UNIVERSITY OF EAST SARAJEO

Through the implementation of the REBUS project at the Faculty of Mechanical Engineering, the adaptation and improvement were made to curricula. Training for the 35 students in the field of entrepreneurship was realized.

The realization of the training of students is in line with the recommendations of the Rebus project in the following way:

- F2F (face to face)
- e-learning and
- learning projects

Through training, students were introduced to the basics of entrepreneurship and were trained for the independent development of business plans.

Students registered through project platform called Mahara (http://mahara.learningrebus.net). This platform supports the REBUS blended learning approach which provides the acquisition and validation of entrepreneurship competences. [6]

Each student created his own profile and was able to connect with other students through the system.

In addition, professors engaged in the project (trainers), trained by the EU partner, have created their own presentations that were put on the platform. Each registered student had access to all these presentations and their learning was enabled

through the Mahara system.
12 students were selected for 11 day training on entrepreneurship at the University of Duisburg-Essen. Students of the University of East Sarajevo attended training together with students from the Volga State University of Technology and the Universum College Pristina. The training was realized through multicultural teamwork realized in a way that each team had at least 2 members from each university. The aim of the training was to improve entrepreneurial competences, teamwork and intercultural communication.

3 VALIDATION OF COMPETENCIES

Validation of competencies was carried out using the LEVEL 5 competency validation system.

Students performed self-assessment of their own competencies before and after education and training conducted within the REBUS project.

Based on the outcomes of the evaluation instrument developed in this project, the coaching teacher can use feedback and dialogue to work with students, on an individual as well as group level basis, to determine which aspects they should be working on in order to become more competent.

Students of the University of East Sarajevo performed self-assessment for three groups of competencies:

- Entrepreneurship

Entrepreneurship refers to a learner's competence to turn ideas into action. It includes a number of sub-competences such as creativity, innovation and risk-taking, as well as the ability to plan and manage projects in order to achieve the objectives. The learner is competent to apply different entrepreneurial skills and strategies in order to develop, organize, and manage an encounter he/she wants to achieve, be it private, professional or a contribution to civic society. The learner is able to discover opportunities, to realize innovation, to exploit and use resources and to identify and bear risks. They know to judge and plan entrepreneurial activities in regard to the given economic conditions, and how to act and react in different professional/ business situations. The learner is able to assess and evaluate risks, to convince others of their vision and to work both individually and in a team. They are able to communicate in a goal-oriented way and to delegate tasks to others. The learner is ready to take over risks and responsibility and appreciates development and innovation. They value pro-active behaviour, collaboration and independence and comply to ethical standards for doing business. They are determined to take the necessary steps to achieve their vision.

- Teamworking

The learner is competent in interacting with others involved in the activities of the organisation and to collaborate to reach a common goal. The learner respects specific backgrounds, competences and skills of team/group members and has the ability to act as a team member. This involves communication skills like assertiveness, clarity and active listening, awareness of diversity in teams and potentials of teamwork. They have an attitude of appreciation for teamwork as efficient way of collaborating and source of creativity and are determined to contribute to the success of the entire team. They are aware of the roles and capabilities in the team and act accordingly. They put any kind of action that turns ideas into facts, taking risks, organising activities.

- Intercultural Communication

Intercultural communication is the competence to respectfully, effectively and constructively communicate with people from different cultural backgrounds. The learner

has knowledge about cultural diversity and how this is reflected in communication. They are competent in interacting with others and to establish a relation of trust and respect. They are able to adapt to different communication needs that result from different cultural backgrounds. They have a positive attitude towards diversity and interaction with people from other cultures and are determined to avoid misunderstandings and resulting frustration. The learner is aware of his own cultural identity and knows how it affects their communication. [7]

Entrepreneurial competencies include the knowledge, skills and attitudes needed to realize their own business. (Figure 1)

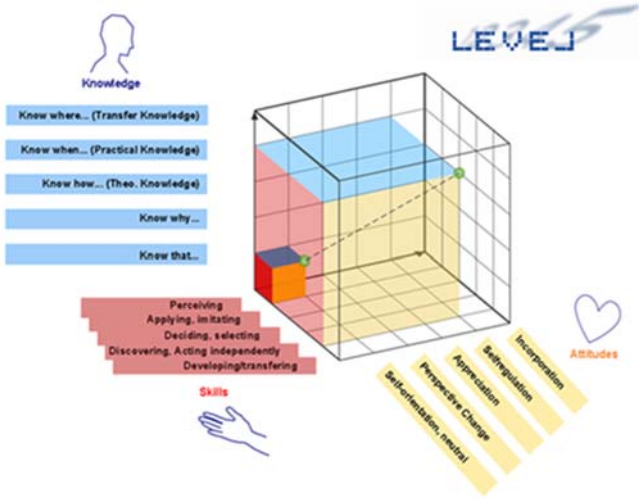


Figure 1. *Assessment of competences [7]*

Students evaluated knowledge, skills and attitudes with grades from 1 to 5. Levels of self-assessment are shown in Table 1. [7]

	KNOWLEDGE	SKILLS	ATTITUDES
L	Level Titles	Level Titles	Level Titles
5	Know where else...(Transfer knowledge)	Developing / Constructing Transferring	Incorporation (Internalizing)
4	Know when...(Practical knowledge)	Discovering / Acting independently	Affective self-regulation
3	Know how...(Theoretical knowledge)	Deciding / Selecting	Appreciation
2	Know why...(Factual knowledge	Applying / Imitating	Perspective taking
1	Know-that...(Basic knowledge)	Perceiving / Listening	Self orientation (Neutral)

4 RESULTS OF SELF - ASSESSMENT

Students performed self-assessment of their own competencies before and after education and training. After the self-assessment, the results showed significant progress and improvement of student competencies.

The results of the first and second self-assessment of entrepreneurial competencies are shown in Figure 2. The biggest improvement has been achieved in the field of attitudes.

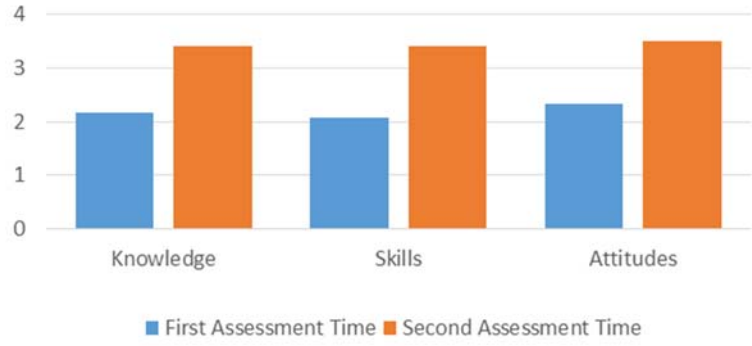


Figure 2. *Entrepreneurship*

Figure 3 shows the competencies of students in the field of teamworking. Improvements are also evident in this field.

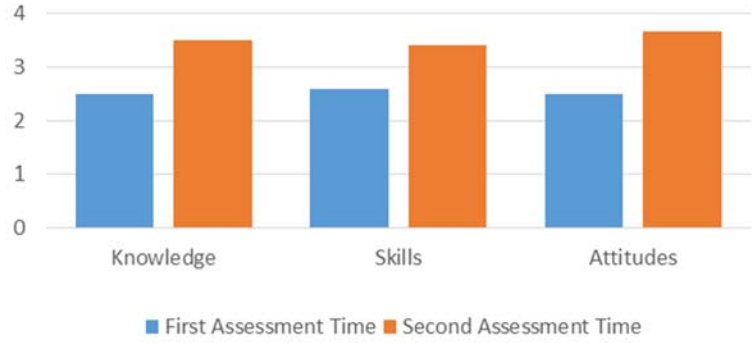


Figure 3. *Teamworking*

The level of knowledge, skills and attitudes regarding intercultural competences is shown in Figure 4.



Figure 4. *Intercultural Communication*

Percentage of improving knowledge, skills and attitudes of students before and after the training has increased by 31% to 64%. The largest improvements were

achieved in the field of entrepreneurial skills by 64%.

5 CONCLUSION

Students need knowledge, skills and attitudes that are flexible and relevant to demands of today's industry. To enter and make progress in the world of work and to keep abreast of changes in job descriptions, students need to also develop entrepreneurial competencies to increase their employability. The approach developed within the Rebus project has shown significant progress in improving these competencies among students. An intercultural training held at the University of Duisburg - Essen has had a significant impact on the improvement of entrepreneurial competencies. Intercultural training has gained prominence in recent years due to the fact that the need for communication skills in the context of international encounters has become more widely acknowledged. More than a work-related skill, intercultural communication can be envisioned as a life skill which allows one to function effectively in his or her day-to-day activities. [8]

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ORGANIZACIONA KULTURA I USPJEŠNOST MENADŽMENTA

Vlado Medaković[1], Bogdan Marić[2]

Rezime: U radu je prikazana organizaciona kultura kao jedna od ključnih varijabli organizacionog ponašanja i uspješnosti menadžmenta. Sa strategijom i vođenjem, kultura organizacije čini okosnicu njenog poslovnog uspjeha. Pojam kultura uopšte uključuje niz elemenata, kao što su: tradicija, običaji, navike, vrijednosni sistem, vjerovanja, stavovi, mjerila i norme ponašanja. Jasno je da menadžment organizacije treba nastojati da obezbjedi takvu atmosferu da svaki zaposleni mora osjećati da pripada datoj organizaciji, što je u direktnoj korelaciji sa uspješnošću menadžmenta.

Ključne riječi: Organizacija, menadžmet, organizaciona kultura

ORGANIZATIONAL CULTURE AND SUCCESS OF MANAGEMENT

Abstract: The paper presents organizational culture as one of the key variables of organizational behavior and management success. With strategy and leadership, the culture of the organization is the backbone of its business success. The notion of culture in general includes a number of elements, such as: tradition, customs, habits, value system, beliefs, attitudes, standards, and norms of behavior. It is clear that the management of the organization should strive to provide such an atmosphere that every employee must feel that he belongs to the given organization, which is in direct correlation with the management's success.

Key words: Organization, management, organizational culture

1 UVOD

Kultura potiče od latinske riječi (lat. cultus – gajenje, njegovanje, obrada polja) i govori o iskonskoj čovjekovoj vezanosti za prirodu, za obradu polja. Termin kultura je među prvima upotrijebio rimski filozof Ciceron. Kultura je sve ono što je čovjek stvorio svojim radom, a u svrhu održanja, poboljšanja i napredka ljudske vrste.

Prilikom definisanja organizacione kulture moramo istaći da ona predstavlja normativna očekivanja ponašanja u organizacijama, odnosno kontekst u okviru kojeg rade pojedinci i timovi. Preuzimanje rizika, eksperimentisanje, otvorenost, povjerenje i autonomija su dio organizacione podrške koja pruža osnovu za inovacije[4].

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Organizaciona kultura predstavlja sistem pretpostavki, vjerovanja, vrijednosti i normi koje su članovi organizacije usvojili ili razvili kroz zajedničko rješavanje problema i koji bitno utiču na njihovo mišljenje i ponašanje[1]. Ona predstavlja veoma moćno sredstvo oblikovanja ponašanja članova organizacije te je zato često predmet organizacionih promjena. Sadržaj organizacione kulture čine kognitivni i simbolički elementi[1].

U uslovima stalnih promjena na globalnom tržištu sve je teže osigurati posebnost. Lično zbunjujuće djeluju, na prvi pogled, sasvim suprotni procesi: 1) proces globalizacije omogućen informatizacijom i komunikacijom, 2) proces regionalizacije unatoč globalizaciji, utemeljen na zajedništvu interesa regija – kolektivna posebnost i 3) proces individualizacije, unatoč neumitnim procesima regionalizacije i globalizacije, koji se temelji na težnji očuvanja posebnosti. U tom košmaru istovremenih višesmjernih interakcija i nezaustavljivih sociooloških, kulturoloških, političkih i ekonomskih kretanja, posebnost je na cijeni.

Pripadati interesnoj grupaciji i u njoj imati značajnu ulogu, biti prisutan i djelovati na globalnom nivou, a istovremeno biti prepoznatljiv po posebnosti težnja je mnogih organizacija u borbi za opstanak na turbulentnom globalnom tržištu. U tom kontekstu kultura organizacije je pretpostavka i konstanta, a nivo kulture organizacije i kvaliteta njenih elemenata su varijable koje određuje posebnost.

Svaka organizacija ima svoju kulturu koja može biti manje ili više podsticajna za ostvarivanje uspjeha organizacije. Preduzeće može automatizovati rad, smanjiti zalihe, odstraniti sve što je nepotrebno u organizacionoj šemi, ali da uprkos tome nema pravih efekata. Razlog za to je organizaciona kultura. Organizaciona kultura je set vrijednosti i načina ponašanja koji su zajednički za određenu kompaniju.

U čemu je razlika između organizacione klime i kulture[6]? Važno je da naglasimo da su ova dva koncepta zapravo metafore pozajmljene iz različitih oblasti naučnih disciplina, tako da nije lako poreditи ih. Prvi termin je antropološki, a drugi meteorološki i oslanja se na perspektive članova organizacije o klimatskim uslovima. Klima se odnosi na percepciju i iskustva članova, dok kultura oblikuje i podrazumjeva često nesvjesne pretpostavke o ponašanju u organizaciji.

Odgovor na ubrzanje promjena, u sredini u kojoj preduzeća obavljaju svoju poslovnu i širu društvenu misiju, traže od menadžera da budu transformacioni lideri, tj. da imaju sposobnost kreiranja vizije, misije, ciljeva, politike i strategija i njihove implementacije, postižući pri tome značajno veću vrijednost za potrošače i krupne transformacione zaokrete u kratkom roku. Kompetentnost ovih organizacija proizilazi iz znanja koje posjeduju menadžeri i zaposleni u preduzeću, ali i iz tehničkih sistema i organizacione kulture koji podstiču na inovacije, krupne promjene i povećanje opštih vrijednosti za krajnje korisnike, kupce i klijente[6].

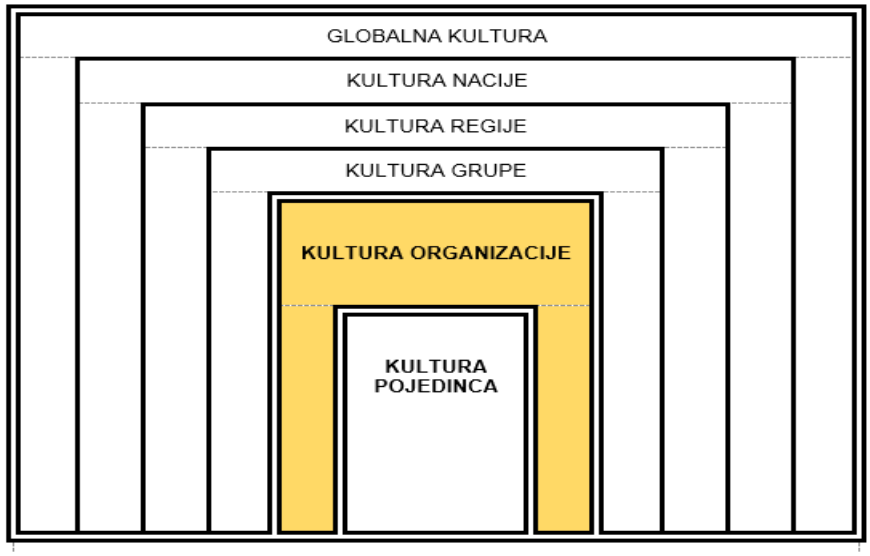
2 ORGANIZACIONA KULTURA

Koncept organizacione kulture pripada dvijema oblastima menadžmenta: organizacionom ponašanju (kroz ulogu koncepta organizacione kulture u objašnjenju ponašanja ljudi u organizacijama) i upravljanju ljudskim resursima (kroz ulogu koncepta organizacione kulture u upravljanju ljudskim resursima)[2]. Istraživanja[5] su pokazala da organizaciona kultura ima i interaktivni uticaj na performanse zajedno sa ostalim komponentama organizacije i menadžmenta. Naime, kada organizaciona kultura djeluje u istom pravcu sa još nekim menadžment sistemima ili praksama, njihov zajednički uticaj je jači nego što bi bio odvojeni uticaj svake od njih. Riječ je, dakle, o sinergetskom efektu uticaja kulture i drugih menadžment komponenti između kojih postoji visoka korelacija. To su obično one komponente preko kojih kultura vrši i indirektni uticaj na organizacione performanse. Identifikovano je nekoliko takvih

komponenti poput liderstva, prakse i politike upravljanja ljudskim resursima. Filozofiju kompanije oblikuju uzorne ličnosti. U početku je to osnivač kompanije, pojedinac ili grupa pojedinaca koji imaju kapital, ideje i sposobnost da vode kompaniju. Oni utvrđuju norme ponašanja i način komunikacije interno i eksterno - van kompanije. Utvrđuju standard koji govore kako poslove treba obavljati i kako se ponašati u poslovnim, radnim i tehnološkim procesima. Sa rastom i razvojem kompanije, uspostavljeni model poslovne filozofije postaje način mišljenja, komuniciranja i ponašanja. To je za datu kompaniju uzor i put koji se prenosi sa starijih na mlađe generacije zaposlenih, sa osnivača na svakog pojedinca, sa rukovodioca na vrhu na srednji menadžment i operativce. Nakon formiranja organizacione kulture, top menadžment kompanije nastoji da adekvatnim strategijama upravljanja održi tako uspostavljen i formiran pristup poslovanju. Može se reći da svaka organizacija ima svoju kulturu po kojoj se prepoznaje i razlikuje od drugih.

Bitne karakteristike kulture organizacije jeste da se ona stiče i naučena je, zajednička je za cijelu organizaciju, tokom vremena se akumulira, simbolička je, strukturirana je i adaptivna.

Organizaciona kultura predstavlja kompleksan obrazac vjerovanja, očekivanja, ideja, vrijednosti, stavova i ponašanja koje dijele članovi jedne organizacije. Kultura vodi jednu organizaciju i njene aktivnosti i predstavlja nešto kao „operativni sistem organizacije“. Ona pokazuje kako zaposleni razmišljaju, rade i kako se osjećaju. Organizaciona kultura utkana je u sve aktivnosti organizacije. Ona utiče na način organizovanja, vrstu strukture i stepen decentralizacije, primjenu autoriteta, vrstu moći, stepen formalizacije, standardizaciju postupaka, način kontrole, alokaciju resursa, upravljanje ljudskim resursima, način planiranja, strategiju i drugo. Organizaciona kultura utiče na ukupnu praksu i ponašanje organizacije. Treba naglasiti da između ponašanja i kulture postoji dvosmjerna veza u kojoj se kultura pojavljuje i kao uzrok i kao posljedica ponašanja. Organizaciona kultura je najznačajniji vrh magičnog trougla strategijskog razvoja organizacije. Ona ima mnoštvo različitih funkcija kroz koje pomaže rukovodiocima u upravljanju organizacijom i usmeravanju svih organizacijskih jedinica i zaposlenih prema ostvarivanju organizacione misije, strategije i ciljeva. Na slici 1. Prikazani su nivoi kulture organizacije kao i mjesto kulture organizacije.



Slika 1. *Nivoi kulture organizacije*

Menadžment organizacije imaju veoma značajnu ulogu u stvaranju organizacione kulture, pa je potrebno da znaju sljedeće[3]:

- kulturu stvaraju lideri organizacije;
- zaposleni se identifikuju sa liderima, načinom na koji se ponašaju i posmatraju ih kao modele;
- kultura se formira oko kritičnih događaja, iz kojih se uči koja ponašanja su poželjna, a koja ne;
- kultura se razvija iz potrebe da se održe efektivni radni odnosi između članova organizacije;
- kultura je pod uticajem okruženja koje je najčešće promjenjivo i dinamično.

3 ZAKLJUČCI

Kultura organizacije nastaje tokom rasta i razvoja organizacije, izgradnjom svojih unutrašnjih i spoljašnjih aspekata. Proces izgradnje kulture organizacije je dugotrajan proces. Menadžment koji ulaže u izgradnju i podizanje kulture organizacije na viši nivo, pokazuje obzirnost prema vlastitom poslovnom rezultatu. Koncept kulture organizacije u funkciji je dugoročne poslovne uspješnosti. Organizaciona kultura utiče na sadržaj i način funkcionisanja menadžmenta, ali sa druge strane i konstituisani menadžment utiče na sadržaj i način ispoljavanja organizacione kulture. Prednost menadžmenta preduzeća u nastajanju je što ne treba da se bavi zatečenim navikama, pravilima i obrascima ponašanja, već startuje od početka i uspostavlja svoja “pravila igre”. Naravno, postoje situacije kada je potrebno promjeniti organizacionu kulturu kompanije. Organizaciona kultura se mijenja ponekad i bez utvrđenih novih ciljeva samo iz razloga jer je došlo do dolaska novog menadžmenta. Nesaglasnost između kulturne tradicije kompanije i dominantnih vrednosti menadžmenta, koji dolazi kao nasljednik, često je uzrok mogućeg poslovnog posrtanja kompanija. Zato je nasleđivanje ili zamjena upravljačkog tima jedno od ključnih pitanja upravljanja organizacionom kulturom.

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FMEA ZA ISO 9001 – UPRAVLJANJE RIZIKOM

Zorana Tanasić[1], Goran Janjić[2], Biljana Vranješ [3], Miroslav Dragić[4], Borut Kocec[5]

Rezime: Standard ISO 9001:2015 je uključio razmišljanje zasnovano na riziku u zahtjevima za uspostavljanje, implementaciju, održavanje i kontinuirano poboljšanje sistema upravljanja kvalitetom. FMEA metoda i alati sa kojima je integrisana mogu biti osnova za upravljanje kvalitetom koji je zasnovan na riziku.
U radu je prezentovamo razmišljanje zasnovano na riziku koje omogućava organizaciji da utvrdi faktore koji mogu dovesti do toga da njegovi procesi i sistem upravljanja kvalitetom odstupaju od planiranih rezultata. Na osnovu toga se sprovode preventivne mjere kako bi se minimizirali negativni efekti njihovog nastanka ali i maksimalno iskoristile mogućnosti prilikom njihovog sprečavanja.
Ključne riječi: ISO standard, FMEA, kvalitet, rizik

FMEA FOR ISO 9001 – RISK MANAGEMENT

Abstract: Risk-based thinking is essential for achieving an effective quality management system. The ISO 9001: 2015 standard included risk-based thinking in the requirements for the establishment, implementation, maintenance and continuous improvement of quality management systems. The FMEA method and tools with which it is integrated can be the basis for risk-based quality management.
Risk-based thinking enables an organization to determine the factors that could cause its processes and its quality management system to deviate from the planned results, to put in place preventive controls to minimize negative effects and to make maximum use of opportunities as they arise.
Key words: ISO standard, FMEA, Quality, Risk

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1 UVOD

Standardi serije ISO 9000 zahtijevaju da se u organizacijama definišu standardni postupci rada, mjerljivi ciljevi poslovanja i upravljački postupci koji vode prema utvrđenim ciljevima. Standardizacija postupaka rada se rješava projektovanjem, implementacijom, održavanjem i kontinuiranim poboljšavanjem sistema upravljanja kvalitetom, koji kao rezultat treba dati standardan kvalitet proizvoda i/ili usluge.

Savremene organizacije zahtijevaju sistemsko upravljanje kvalitetom i rizicima u svim procesima i aktivnostima koje čine mreže procesa u preduzeću. Kontinuirani PDCA ciklus stalnih poboljšavanja, na kome je zasnovan QMS, omogućava postizanje efikasnosti procesa u svim aktivnostima za stvaranje kvalitetnog proizvoda. Poboljšavanje kvaliteta proizvoda ili usluga je direktno uslovljeno sa upravljanjem rizikom a što je direktno u vezi sa kontekstom organizacije. Strateški pristup upravljanja rizikom u organizacijama omogućava da se primjene i unaprijede najbolje poslovne prakse.

2 ISO 9001:2015 I UPRAVLJANJE RIZIKOM

U 21. vijeku, u turbulentnom okruženju, organizacije se suočavaju sa odlukama koje su direktno povezane sa pojavom određenog rizika. Rizik podrazumijeva ishod donesene odluke, koji može biti pozitivan ali veoma često i negativan. Razmišljanje na osnovu rizika i procjena rizika danas se zahtijeva od svake organizacije. Značaj procjene rizika potvrđena je u reviziji standarda ISO 9001:2015 gdje se uvode zahtjevi za uvođenje razmišljanja temeljenog na riziku. Svrha upravljanja rizikom kao rezultat neizvjesnosti kod ostvarivanja ciljeva, jeste povećanje vjerojatnosti da organizacija ostvari svoje ciljeve kroz smanjivanje grešaka i nepovoljnih situacija.

2.1 ISO standardi

Standard ISO 9001 je prošao kroz pet revizija, pri čemu je peta revizija donijela mnoge značajne promjene u svijetu poimanja kvaliteta. Pored uvođenja konteksta organizacije, pojma dokumentovanih informacija, liderstva, znanja organizacije i sl., najveće promjene i nove izazove je donio koncept razmišljanja zasnovan na riziku. Jedan od ciljeva standarda bio je da se istaknu mogućnosti i prilike koje rizik može da stvori za organizaciju. U standardu ISO 9000:2015 (Osnove i riječnik) rizik se definiše kao „posljedica neizvesnosti“ i „odstupanje od očekivanog", bilo da je ono pozitivno ili negativno. Nova verzija međunarodnog standarda kroz definisane zahtjeve želi da organizacija analizira i shvati kontekst svoje organizacije ali i da na osnovu utvrđenih rizika planira svoje buduće aktivnosti uz dodatni oprez. Ove aktivnosti mogu uključivati specifične vrste kontrole, testiranja, procedura kvaliteta, izbora različitih komponenti i materijala, ograničavanja opsega radnih parametara, redizajn proizvoda i procesa, preventivno održavanje mašina i sl.. Takođe, za svaku definisanu mjeru određuje se lice odgovorno za njeno sprovođenje i krajnji rok sprovođenja mjere.Od organizacija se traži da utvrdi rizike i mogućnosti koje treba da riješi kako bi obezbjedila da QMS postigne svoje namjeravane rezultate, spreči ili smanji neželjene efekte i kontinuirano unapređuje svoje poslovanje [5].

Novi koncept razmišljanja zasnovanog na riziku isključuje preventivne mjere jer zahtjevi u standard ISO 9001:2015 koji se odnose na rizike i prilike treba da djeluju kao preventivni alat [2].

U Tabeli 1 navedene su tačke u standardu ISO 9001:2015 u kojima se spominju rizici i prilike.

Tabela 1. Tačke standard ISO 9001:2015 na koje se odnosi rizik

Tačka	Naziv	Objašnjenje
0.3.3	Razmišljanje zasnovano na riziku	Koncept razmišljanja zasnovan na riziku i principi rizika (ISO 31 000:2015)
4.1	Razumijevanje organizacije i njenog konteksta	Od organizacije se zahtijeva da odredi sve rizike koji mogu uticati na poslovanje organizacije i njene ciljeve.
5.1.1	Liderstvo	Rukovodstvo predstavlja liderstvo i neophodno je da osigura da svi rizici i prilike budu definisani i praćeni i da promoviše razmišljanje zasnovano na riziku
6.1	Mjere koje se odnose na rizike i prilike	Od organizacije se zahtijeva da preduzme mjere za identifikovanje rizika i prilika i da planira na koji način će ih pratiti.
7.	Resursi	Ne spominje se rizik
8.5.1	Upravljanje proizvodnjom i pružanje usluga	Od organizacije se zahtijeva da planira, implementira i kontroliše procese kako bi prepoznala i identifikovala rizike i prilike.
9.3	Preispitivanje od strane rukovodstva	Od organizacije se traži da: prati, mjeri, analizira i evaluira rizike i prilike, na osnovu činjenica vrši preispitivanje
10.2	Neusaglašenost i korektivne mjere	Traži se sprovođenje stalnog poboljšanja kroz odgovaranje na promjene uzrokovane rizicima.

2.2 Sistem za upravljanje rizicima

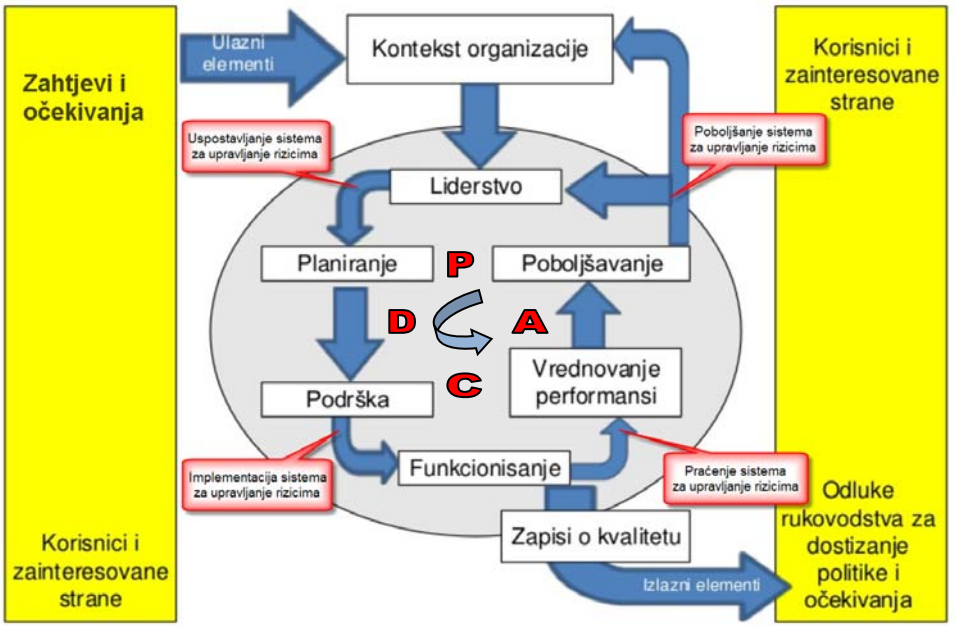
Organizacije treba da stalno utvrđuje rizike i prilike koje mogu da utiču na njeno poslovanje i sposobnost da ostvaruje predviđene rezultate QMS-a ali i da daje analizu kroz procjenu rizika. Takođe, organizacija treba da odredi potrebne mjere koje se odnose na identifikovane rizike i prilike i preispita efikasnost definisanih mjera kroz kontinuirana preispitivanja od strane rukovodstva.

Treba naglasiti da se identifikacija rizika ne zaustavlja samo na utvrđivanju rizika prije početka izvođenja aktivnosti u organizaciji dok kontrola i praćenje rizika se odnosi na identifikaciju novih i praćenje identifikovanih rizika kako ne bi došlo do njihovog ponavljanja i pojavljivanja. Na osnovu svega navedenog upravljanje rizikom je veoma važan segment pri uspostavljanu QMS-a u preduzeću. Na prvom mjestu je identifikacija uzroka koji mogu dovesti do neželjenih posljedica kao i njihovo praćenje sa uvođenjem mjera za eliminaciju ili poboljšanje ako se radi o prilikama identifikovanih rizika [5].

Upravljanje rizikom, kao i upravljanje kvalitetom je put koji vodi prema kontinuiranom poboljšanju procesa poslovanja, od nastanka pojma kvaliteta pa sve do danas. Može se zaključiti da se sistem za upravljane rizikom, izložen u ovom radu, pored razmišljanja zasnovanog na riziku, oslanja na još jedan princip upravljanja kvaliteta, a to je PDCA (Plan – Do – Check – Act) ciklus. Na taj način se obezbeđuje povezanost zahtjeva standarda sa njegovim principima i stvara osnova za jedan funkcionalan i efikasan sistem koji omogućava stalna poboljšanja poslovanja organizacije [2,5].

Procesni pristup uspostavljanja QMS-a, definisan međunarodnim standardom ISO 9001, je zasnovan na PDCA ciklusu i na razmišljanju na bazi rizika uz stalna praćenja, mjerenja, analize i poboljšanja svih procesa koji čine mrežu procesa poslovanja. To je uslov da se na sistematičan i sveobuhvatan način kontinuirano upravlja rizikom i stalno poboljšava kvalitet proizvoda i usluga. Na Slici 2 prikazana je

jedna od predloženih varijanti za grafički prikaz modela ISO 9001:2015 sa sistemom za upravljanje rizicima.



Slika 2. *Sistem upravljanja kvalitetom i sistem upravljanja rizicima*

U mnogim standardima menadžmenta obuhvaćeni su zahtjevi za rizik, npr. standard ISO 31000:2015 daje osnovne principe i smjernice za sistemsko upravljanje rizicima. Oblast rizika će uvijek biti aktuelna, jer organizacija ne može da bude analizira I obuhvati sve neizvesnosti I rizike koje nosi njeno poslovanje.

3 FMEA METODA

Analiza načina otkaza i njihovih posljedica (FMEA – Failure Mode and Effects Analysis) je alat kojim se pronalaze i analiziraju svi mogući načini otkazivanja komponenti sistema ili procesa, posljedica koje ti otkazi, ako se dogode, imaju na sistem i mogućnost izbegavanja otkazivanja ili smanjivanja uticaja otkazivanja na sistem ili proces. Kratkoročno, FMEA daje analizu potencijalnih otkaza, identifikuje ozbiljnost njihovih efekata i određuje prioritet za izvođenje korektivnih mjera. Dugoročno, FMEA razvija kriterijume za planiranje i projektovanje sistema, obezbjeđuje dokumentaciju za buduće analize pouzdanosti u slučaju izmjene sistema, ispunjava zahtjeve standarda ISO 9001:2015 koje se odnose na rizike ali i daje osnovu za planiranje održavanja i analizu pouzdanosti procesa i Sistema [6].

FMEA je iterativna metoda koja od inženjera, ili odgovorne osobe za neki proces, zahtijeva da odgovore na sljedeća pitanja:

- Šta se može pogriješiti na proizvodu ili u procesu?
- Koliko se može pogriješiti?
- Šta je potrebno preduzeti da se izbjegnu greške?

FMEA je važna tehnika u programu osiguravanja pouzdanosti koja se može koristiti za riješavanje raznih problema. Cilj primjene FMEA analize je:

- procijeniti efekte i posljedice događaja, prouzrokovanih bilo kakvim greškama koje čine sastavni dio sistema ili procesa,
- odrediti važnost ili kritičnost svakog oblika greške s obzirom na pravilno funkcionisanje sistema i njegov uticaj na pouzdanost i/ili sigurnost postupka,
- distribucija identifikovanih načina otkaza u skladu s mogućnošću njihovog otkrivanja, dijagnoze, testiranja, zamjenljivosti dijelova i
- procjena sprovođenja potrebnih mjera.

Jedan od najznačajnijih faktora za uspješnu primjenu FMEA analize je ažurnost i uključenost tima za sprovođenje i praćenje grešaka kroz primjenu FMEA obrasca.. FMEA je osmišljena kao preventivna mjera a ne metoda kojom se analiziraju činjenice. Na osnovu FMEA analize treba da se greške konstrukcije ili procesa prepoznaju prije ugradnje u proizvod. Neophodno je uvođenje FMEA analize u što ranijoj fazi, kada je proizvod ili proces još jednostavan i jeftin, kako bi se sprečile izmjene proizvoda ili procesa u kasnijoj fazi, kada su izmjene mnogo teže i skuplje.

Jedan od pristupa za određivanje prioritetnih akcija je upotreba faktora rizika RPN (Risk Priority Number) u zavisnosti od S, O i D.

RPN = Ozbiljnost (S) x Pojavljivanje (O) x Detekcija (D)

Faktor rizika predstavlja proizvod vrijednosti: ozbiljnosti oblika greške, vrijednosti pojavljivanja greške i vrijednosti detekcije greške. U okviru pojedinačnih FMEA analiza ova vijrednost može se kretati između 1 i 10. U ovom koraku se ispoljava kreativnost i sposobnost tima u organizaciji da prepoznaju preventivne mjere za identifikovane rizike i pravovremeno reaguju kako bi održale ali i unaprijedili svoje poslovanje. Kao pomoć za donošenje odluke o upotrebi FMEA analize mogu se koristiti parametri kvaliteta proizvoda ili procesa proizvodnje koji se mjere. Mjerenje parametara kvaliteta proizvoda ili procesa proizvodnje se izvodi pomoću nekoliko različitih metoda, a u okviru ovog rada korišćene su dvije metode i to:

- FTQ (First Time Quality) i
- KPI (Key Performance Indicator).

FTQ se izražava brojem izdvojenih dijelova na milion izrađenih dijelova (ppm). Može se mjeriti na bilo kojem koraku u procesu proizvodnje, gde se dijelovi izdvajaju. FTQ se izračunava na sljedeći način (Slika 3):

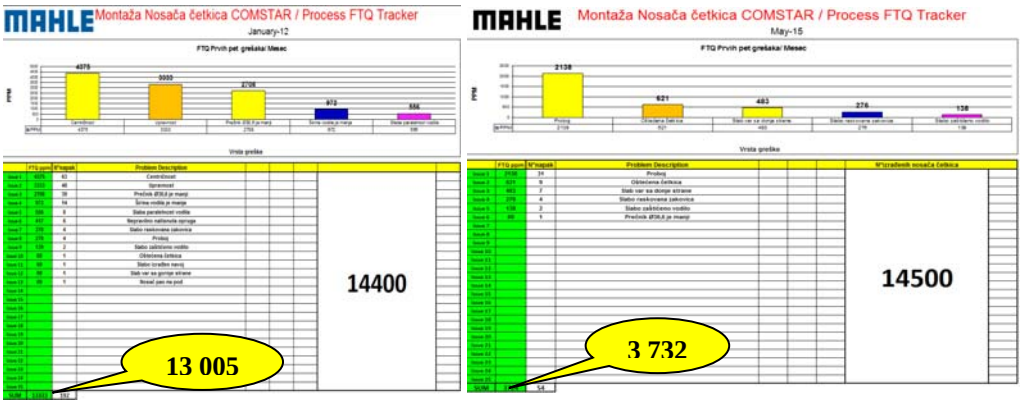
FTQ(PPM) = ((S+R)/N) x 1000000

Gdje je: S – broj otpisanih proizvoda,
R – broj popravljenih proizvoda,
N – ukupan broj proizvoda koji se pokušaju izraditi.

KPI ocjenjuje uspjeh preduzeća ili određene aktivnosti odnosno procesa koja se izvodi. Ukupna učinkovitost procesa je skup široko prihvaćenih mjerenja koji odražavaju proizvodni uspjeh:

OEE = dostupnost x učinak x kvalitet

Za potencijalne greške koje imaju visok broj prioriteta rizika (RPN) definišu se odgovarajuće preventivne mjere za smanjenje njegove vrijednosti. Ovim mjerama teži se uticati na uzroke pojave greške i po mogućnosti njihovo potpuno otklanjanje.



Slika 3. *FTQ – prvih pet grešaka*

4 ZAKLJUČAK

Model poslovne izvrsnosti sadrži kriterijume održivog razvoja, kao i humane dimenzije kvaliteta za ostvarivanje ciljeva kvaliteta življenja sadašnjih i budućih generacija, odnosno teži se ka društveno odgovornom poslovanju. Bogatstvo raspoloživih alata za procjenu i upravljanje rizikom pokazuje da je upravljanje rizicima značajna disciplina. Organizacije koje žele ostvariti svoje ciljeve, moraju veliku pažnju posvetiti upravljanju rizicima koji utiču na njihovo poslovanje.

Osnova FMEA metode je analiza rizika. Ova metoda predstavlja sistemski i strukturiran pristup rizicima i na taj način pomaže dizajnerima sistema da razumiju moguće greške i prioritete prije završetka analize rizika. Uz kombinovanje sa drugim korisnim alatima za identifikaciju, upravljanje, kontrolu i preispitivanje rizika, FMEA može da pruži sveobuhvatno rješenje za zahtjeve koji obuhvata standard ISO 9001:2015.

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PRIMJENA FMEA METODE KAO UNIVERZALNE METODE ZA PROCJENU GUBITAKA ELEKTRIČNE ENERGIJE U DISTRIBUTIVNIM PREDUZEĆIMA

Zdravko Krivokapić[1], Slaviša Moljević[2], Budimirka Marinović [3], Jelena Lojović[4],

Menadžment rizicima predstavlja važan aspekt dobrog vođenja uspješnih organizacija. Zbog toga je potrebno da se u organizaciji uspostavi proces upravljanja rizikom integrisan u cjelokupno poslovanje organizacije i da istovremeno bude integralni dio svih organizacionih procesa. U kontekstu razmatranja rizika i u skladu sa konstantnim nastojanjima da se isti svedu na najmanju moguću mjeru u ovom radu je prikazana FMEA (Failure mode and effects analysis) metoda kao univerzalna metoda za procjenu rizika na primjeru gubitaka električne energije u distributivnim preduzećima. Poslovni proces koji će biti obuhvaćen metodom je proces kontrola, servis i baždarenje električnih mjerila iz razloga što ovaj poslovni proces u svojoj realizaciji ima najveći uticaj na gubitke električne energije.
Ključne riječi: FMEA, gubici električne energije, upravljanje zasnovano na riziku.

APPLICATION OF FMEA METHOD AS A UNIVERSAL METHOD FOR ESTIMATE ELECTRICITY LOSS IN DISTRIBUTION COMPANIES

Risk management is an important aspect of good management of successful organizations. Therefore, it is necessary for the organization to establish a risk management process integrated into the entire operation of the organization and at the same time enabling that process to be an integral part of all organizational procedures. In the context of risk considerations and consistent with permanent efforts to minimize it, FMEA (Failure mode and effects analysis) method is presented as a universal risk assessment method using the example of electricity losses in power distribution companies. The business process that will be encompassed by this method is the process of control, service and calibration of electrical measuring instruments, because this business process has the greatest impact on the losses of electricity during its realization.
Key words: FMEA method, losses of electricity, risk-based management

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1 UVOD

Jedna od osnovnih namjena sistema upravljanja kvalitetom jeste da se djeluje u preventivnom pravcu, odnosno da su „razmišljanja zasnovana na riziku“. Naime rizik predstavlja neodvojivi dio savremenog poslovanja, pa stoga upravljanje rizikom postaje i sastavni dio upravljanja preduzećem.

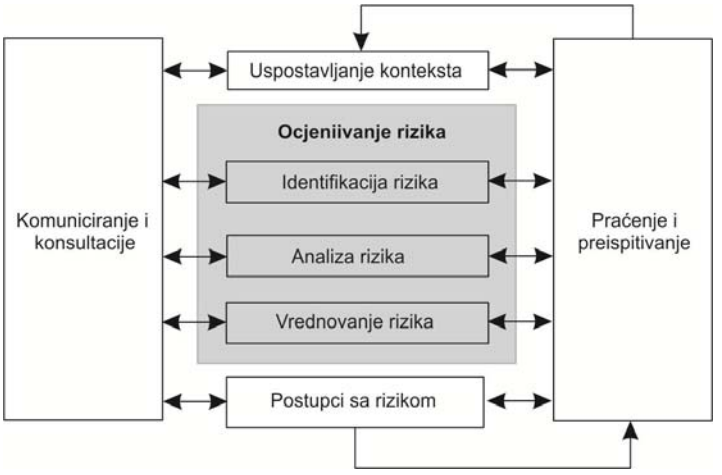
U kontekstu razmatranja rizika i u cilju konstantnog nastojanjem da se isti svedu na najmanji mogući nivo u ovom radu je predstavljena FMEA metoda kao univerzalna metoda za procjenu rizika na primjeru gubitaka električne energije u distributivnim preduzećima. Kroz primjenu FMEA metode se otkrivaju svi opasni događaji, posljedice svih takvih događaja, kako dolazi do nastanka opasnog događaja, kako možemo izbjeći opasan događaj, a samim tim i kako smanjiti posljedice. Za uspješno provođenje FMEA metode potreban je dijagram toka posmatranog poslovnog procesa, definisati parametre koji utiču na ishod aktivnosti i uvrstiti iskustvene podatke, ukoliko postoje, kako bi postupak ocjenjivanja bio relevantniji.

2 RAZMIŠLJANJE NA BAZI RIZIKA

Pojam rizika se definiše na razne načine, a zajedničko za sve definicije je da se rizik vezuje za neizvjesnost i gubitak. Tako Marović et al. definišu rizik kao neizvjesnot u vezi ishoda događaja i mogućnosti da ishod bude nepovoljan što dovodi do intuitivnog pojma rizika koji obuhvata nedostatak znanja o budućnosti i mogućnosti neke nepovoljne posljedice [1]. U standardu ISO 31000:2009 rizik se definiše kao „efekat neizvjesnosti na ciljeve“ [2]. Dakle, iako ne postoji opšta definicija rizika, postoje zajednički elementi u svim definicijama, a to su neizvjesnost i gubitak.

Kod procesa upravljanja rizikom, izuzetno je važno da organizacija procjeni vlastite kapacitete, ali i da je svjesna opasnosti u svom poslovanju. Zbog toga identifikacija rizika i njegova procjena su posebno važni da bi se rizik izbjegao ili smanjio. Kroz identifikaciju rizika se formira lista rizika, definiše uzrok i definišu događaji koji mogu uticati na ostvarenje ciljeva.

ISO 31000:2015 definiše principe upravljanja rizikom (slika 1), okvir za upravljanje rizikom i proces upravljanja rizikom. Naime, potrebno je da upravljanje rizikom bude integrisano u cjelokupno poslovanje i da je istovremeno integralni dio svih organizacionih procesa. Za identifikaciju rizika izuzetno su važne informacije.



Slika 1. *Proces upravljanja rizikom ISO 31000:2015*

U procesu upravljanja rizikom analiza rizika predstavlja zahtjevan postupak koji podrazumijeva obradu identifikovanih rizika, analizu postojećeg sistema i definisanje dodatnih mjera za upravljanje identifikovanih rizika.

Vrednovanje rizika je postupak upoređivanja nivoa rizika koji je otkriven u procesu analize rizika sa kriterijumima rizika definisanim u postupku utvrđivanja konteksta upravljanja rizikom. Ako rizik koji se javlja u procesu zadovoljava određene kriterijume smatra se prihvatljiv. Međutim, ako je suprotno, neophodno je utvrditi listu prioriteta rizika i definisati načine postupanja sa ovim rizicima. Naime, upravljanje rizikom obuhvata klimu, kulturu i poslovnu filozofiju organizacije.

U kontekstu prethodno navedenog u nastavku se primjenjuje FMEA metoda kao metoda za procjenu rizika. Tačka 8.5.3 standarda ISO 9001 koja se odnosi na preventivne mjere možda najdirektnije oslikava potrebu za primjenom adekvatne metode za menadžment rizicima, jer zahtjeva [3]:

- utvrđivanje potencijalnih neusaglašenosti i njihovih uzroka;
- vrednovanje potrebe za eventualnim mjerama, da bi se sprječilo pojavljivanje neusaglašenosti;
- utvrđivanje i primjenu potrebnih mjera;
- zapise o rezultatima preduzetih mjera i
- preispitivanje preduzetih preventivnih mjera.

3 PRIMJENA FMEA KAO UNIVERZALNE METODE ZA PROCJENU RIZIKA DISTRIBUTIVNIH PREDUZEĆA

U poslovanju distributivnih preduzeća postoje određeni rizici, međutim, oni koji se izdvajaju kao najvažniji i čiji uticaji imaju posljedice koje su od suštinske važnosti za preduzeće su:

- realizacija potraživanja za isporučenu električnu energiju krajnjim kupcima – nameće i kao jedan od osnovnih ciljeva, ali i kao rizik poslovanja
- smanjenje nivoa gubitaka električne energije – gubici predstavljaju veliki rizik u poslovanju, jer isporučena, a neočitana energija je čist gubitak u poslovanju preduzeća.
- kontinuitet u isporuci električne energije - predstavlja uslov kvalitetnog poslovanja i smanjenja gubitaka.
- bezbjednost zaposlenih i potrošača - s obzirom da se po zakonu preduzeća koja obavljaju djelatnost distribucije električne energije tretiraju kao „imaoci opasne stvari“, potrebno je posebnu pažnju posvetiti bezbjednosti radnika i potrošača.

Osnovni rezultat nakon sprovođenja FMEA metode je procjena visine rizika, što se kvantifikovano izražava RPN (Risk Priority Number) brojem. Ocenjivanje rizika od odstupanja, relativni rizik od nastanka odstupanja, određuje se na osnovu tri faktora [4]:

- Ozbiljnost posljedica - potencijalne posljedice odstupanja,
- Vjerovatnoća pojave - vjerovatnoća da će doći do odstupanja ili učestalost njegovog ponavljanja
- Mogućnost otkrivanja - vjerovatnoća da će odstupanja biti otkrivena prije nego što se ispolje njene posljedice

Množenjem tri faktora koji su gore pomenuti određuje se numerički prioritet rizika (RPN) za svaku pojedinačnu vrstu odstupanja i njegove posljedice. RPN se koristi u cilju rangiranja korektivnih mjera da bi se eliminisao nastanak potencijalnih

odstupanja. Prvo je potrebno obratiti pažnju na odstupanja sa najvećim RPN brojem. Isto tako, posebna pažnja se mora posvetiti odstupanjima koji imaju visoku ozbiljnost posljedica bez obzira na vrijednost RPN broja. Poslije sprovođenja korektivne mjere pristupa se određivanju novog RPN broja. Unaprjeđivanje se nastavlja dok rezultirajući RPN broj ne bude zadovoljavajući, odnosno unutar dozvoljenih granica.

Prema IEC 60812:2006, svaki FMEA postupak sastoji se od sljedećih deset koraka [5]:

- Preispitivanje procesa ili proizvoda
- Ustanovljavanje potencijalnih odstupanja uz pomoć Brainstorming metode
- Formiranje liste potencijalnih efekata svakog odstupanja
- Ocjenjivanje ozbiljnosti posljedica
- Ocjenjivanje vjerovatnoće pojave odstupanja
- Ocjenjivanje mogućnosti otkrivanja odstupanja
- Proračun RPN broja za svaki mogući efekat
- Određivanje prioriteta za odstupanja koje zahtjevaju primjenu određenih mjera
- Sprovođenje mjera u cilju eliminacije ili smanjivanja odstupanja sa visokim nivoom rizika
- Proračun preostalog rizika nakon sprovođenja predviđenih mjera.

3.1 Primjena FMEA metode na konkretnom primjeru

Već je navedeno da se u okviru poslovanja ZP „Elektro-Hercegovina“ a.d. Trebinje odvija 6 poslovnih procesa. Poslovni proces koji će se analizirati primjenom FMEA metode je kontrola, servis i baždarenje električnih mjerila. Ovaj poslovni proces u svojoj realizaciji ima najveći uticaj na gubitke električne energije koji su tema ovoga rada. Kroz realizaciju ovog procesa obuhvaćena je kontrola mjernih mjesta i otkrivanje neovlaštene potrošnje kao ključni faktori koji utiču na gubitke koji su jedan od najvećih rizika poslovanja preduzeća. Ovaj poslovni proces je u zvaničnoj dokumentaciji preduzeća opisan kroz pripadajući priručnik o procesu i kroz dvije operativne procedure, a to su: kontrola priključka i mjernog mjesta krajnjeg kupca i servisiranje i baždarenje mjernih uređaja (MU).

Uspješna primjena FMEA metode kod procjene rizika podrazumjeva određena prilagođavanja samom procesu koji se analizira. U konkretnom slučaju će se, takođe, izvršiti prilagođavanje generičkih skala konkretnom postupku analize procesa kontrole, servisa i baždarenja električnih mjerila.

U tabelama 1 i 2 su date generičke skale za ocjenjivanje ozbiljnosti posljedica, ocjenjivanje vjerovatnoće pojave i ocjenjivanje mogućnosti otkrivanja odstupanja za posmatrani process. Ako ne postoje realni podaci iz procesa, tim za ocjenjivanje mora da procjeni koliko često može da se pojavi svaka vrsta odstupanja. Članovi tima mogu bolje da procjene vjerovatnoću i učestanost pojave za svaku vrstu odstupanja ukoliko su im poznati mogući uzroci odstupanja. Kada se potencijalni uzroci identifikuju za sve vrste odstupanja, ocjenjivanje vjerovatnoće može se izvršiti čak i ako ne postoje podaci o ranijim odstupanjima u procesu.

Tabela 1. *Skala za ocjenjivanje ozbiljnosti posljedica i mogućih učestalosti odstupanja*

Ocjena	Efekat	Ozbiljnost posljedice	Moguća učestanost odstupanja
10	Ekstremno visok	Pojava odstupanja može da dovede do prekida važnih operativnih funkcija i ugrožavanja interesa organizacije kupaca el. energije.	Više od jedne pojave dnevno, odnosno preko 3 pojave u 10 slučajeva.
9	Opasno visok	Pojava odstupanja može da dovede do nenadoknadivih gubitaka kod organizacije ili kod zainteresovanih strana.	Jedna pojava svaka 3 do 4 dana, odnosno 3 pojave u 10 slučajeva.
8	Veoma visok	Pojava odstupanja može da izazove veoma visok uticaj na organizaciju i zainteresovane strane čije se posljedice mogu nadoknaditi samo djelimično.	Jedna pojava nedeljno ili 5 pojava u 100 slučajeva.
7	Visok	Pojava odstupanja može da dovede do velikog nezadovoljstva zainteresovanih strana sa neizbježnim posljedicama po organizaciju. Očekuje se nastanak gubitaka električne energije energije.	Jedna pojava mesečno ili 1 pojava u 100 slučajeva.
6	Srednji	Pojava odstupanja može da dovede do velike neusaglašenosti u procesu rada uz opravdane žalbe zainteresovanih strana.	Jedna pojava svaka tri meseca ili 3 pojave u 1.000 slučajeva.
5	Mali	Pojava odstupanja može da dovede do značajnog pada performansi procesa, što bi prouzrokovalo žalbe kupaca električne energije.	Jedna pojava svakih šest meseci do godinu dana ili 5 pojava u 10.000 slučajeva.
4	Veoma mali	Odstupanje može da dovede do velikog broja neusaglašenosti, ali se može izvršiti korekcija.	Jedna pojava godišnje ili 6 pojava u 100.000 slučajeva.
3	Neznatan	Pojava neusaglašenosti može da izazove mali uticaj na organizaciju i kupce električne energije, ali ih organizacija može prevazići bez gubitka performansi.	Jedna pojava u 3 godine ili 6 pojava u 10 miliona slučajeva.
2	Zanemarljiv	Odstupanja ne moraju imati očigledan uticaj na organizaciju i kupce električne energije iako postoje neznatni poremećaji performansi procesa.	Jedna pojava svakih 3 do 5 godina ili 2 pojave u 1 milijardi slučajeva.
1	Nepostojeći	Odstupanja imaju neprimjetan uticaj na organizaciju i kupce električne energije i ne utiču na performanse procesa.	Jedna pojava u više od 5 godina ili manje od 2 pojave u 1 milijardi slučajeva.

Zbog prirode samog procesa koji se analizira i zbog olakšavanja primjene FMEA metode, a prateći iskustvo [6] skala za ocjenjivanje mogućnosti otkrivanja odstupanja je oformljena tako da se kreće u rasponu od 1 do 3, što se daje u tabeli 2.

Tabela 2. *Skala za ocjenjivanje mogućnosti otkrivanja odstupanja*

Ocjena	Vjerovatnoća otkrivanja odstupanja	Opis
3	Veoma mala	Proces se teško kontroliše ili se efekat odstupanja teško može otkriti.
2	Srednja	Vrši se vizuelna procesna kontrola od strane neposrednih izvršilaca ili se vrše povremena mjerenja numeričkih veličina.
1	Veoma visoka	Otkrivanje uzroka odstupanja vrši se kontrolom koja sprečava nastanak odstupanja.

Korišćenjem dijagrama toka za prikaz posmatranog procesa upotrebom FMEA metode za procjenu rizika izvršeno je identifikovanje rizika za sve aktivnosti u posmatranom procesu. U tabeli 3 su prikazani dobijeni rezultati.

Tabela 3. *Modifikovana FMEA matrica primjenjena na posmatranom procesu*

Aktivnost	Moguće posljedice odstupanja	Ozbiljnost posljedica	Mogući uzroci odstupanja	Vjerovatnoća pojave	Mjere za otkrivanje/eliminaciju odstupanja	Mogućnost otkrivanja	RPN
Kontrola mjernog mjesta	Moguće netačno mjerenje (gubici električne energije)	4	Nepotpun mjesečni ili godišnji plan kontrole	3	Potpunija i detaljnija izrada Plana kontrole MU od strane radnih jedinica	3	36
Utvrđivanje neovlaštene potrošnje	Gubici električne energije	4	Nemoguć pristup mjernom mjestu	2	Izmještanja mjernih mjesta u cilju obezbjeđenja dostupnosti mjernog mjesta	2	16
Zamjena MU	Gubici električne energije	4	Propusti kontrolora/ očitača prilikom kontrole/ očitanja mjernog mjesta	1	Veću pažnju posvetiti analizi logičke potrošnje i primjeni Opštih uslova za isporuku električne energije	3	12
Obrada kontrole	Nepotpuni pregledi podataka i izvještaji ERS-u	1	Greške u obradi podataka	4	Pojačati kontrolu zapisnika od nivoa Radnih jedinica do nivoa Rukovodioca sektora mjerenja	3	12
Prijem MU	Nije primljen predviđeni broj MU	2	Neusaglašeni plan i termini prijema MU	2	Usaglašavanje plana sa terminom prijema MU	1	4
Priprema za baždarenje i provjera ispravnosti MU	Nepotpuna priprema za baždarenje	3	Nepotpun postupak pripreme	2	Postupak pripreme (vizuelna kontrola, kontrola plombi) uraditi u skladu sa procedurom	2	12
Servisiranje MU	Moguća neispravnost mjernog uređaja	3	Odstupanje od postupka servisiranja	1	Postupak servisiranja provoditi u skladu sa propisanom procedurom	1	3
Baždarenje	Moguć gubitak	4	Neispravni	1	Baždarenje i etaloniranje	2	8

MU	električne energije		uređaji za baždarenje i nepoštovanje protokola		MU mora biti usklađeno sa propisima i rokovima		
Ovjera MU	Neovjeren mjerni uređaj	2	Neblagovremeno prikupljanje MU	3	Blagovremeno prikupljanje i slanje zahtjeva za ovjeru MU	2	12
Vraćanje MU	Nije izvršeno blagovremeno vraćanje MU	1	Nepotpuna provjera	1	Usklađivanje stvarnog stanja sa stanjem na spisku	1	1
Verifikacija KMS	Neverifikovan KMS	2	Nedostavljen zahtjev za kontrolu i verifikaciju	3	U radnim procedurama propisati kao obavezno dostavljanje zahtjeva u pisanoj formi	2	12
Izvještavanje	Nepostojanje mjesečnog izvještaja baždarenih i otpisanih MU	1	Nedostupnost podataka o izvršenim kontrolama MU	3	Pooštriti obavezu evidencije o broju baždarenih, iskontrolisanih i plombiranih mjernih mjesta od strane RJ	1	3
Otpis MU	Neblagovremeno otpisivanje MU	1	Nepoštovanje propisa predviđenih za rad komisije	2	Dodatnu pažnju posvetiti praćenju propisa i imenovanju članova komisije	1	2

Na osnovu izvršenog ocjenjivanja i dobijenih rezultata u prethodnoj matrici se vrši rangiranje samog rizika.

Za aktivnost za koje, na osnovu ocjenjivanja, utvrđeni RPN brojevi imaju vrijednosti od 1 do 8 nije potrebno preduzimati značajnije mjere. Naime, greške u provođenju aktivnosti koje su u ovom rasponu nisu značajnije, odnosno ne proizvode značajnije rizike u samom procesu. U ovom dijelu, od suštinskog je značaja dodatno obratiti pažnju na strožije poštovanje propisanih procedura i upustava za rad.

Za raspon RPN brojeva 8 – 16 postoje dvije grupe aktivnosti. Tako, aktivnosti koje se odnose na obradu podataka, ovjeru mjernih uređaja, verifikovanje KMS-a i priprema za baždarenja nose sa sobom mnogo manji rizik, a samim tim i posljedice za organizaciju. Tu su najčešće u pitanju rutinski propusti u radu kod navedenih aktivnosti i svi ti propusti se lako otklanjaju bez značajnijih posljedica, praktično većom radnom disciplinom i odgovornošću. Aktivnosti koje u svojoj realizaciji kao odstupanje mogu proizvesti nastanak gubitaka električne energije, zahtjevaju znatno ozbiljniji tretman. U ovom djelu, u cilju smanjenja rizika navode se sljedeće mjere:

- posvećivanje dodatne pažnje analizi logičke potrošnje i u tom dijelu dodatno pojačati učestalost periodičnih procjena logičke potrošnje;
- Kod teško dostupnih mjernih mjesta, a to je obično slučaj u domaćinstvima u kojima se ne živi tokom godine i koja se posjećuju u kraćim vremenskim periodima, uložiti dodatne napore u cilju stupanja u kontakt sa vlasnicima kuća ili stanova u cilju izmještanja mjernih mjesta.

Aktivnosti za koje je raspon RPN brojeva 16 – 36 su najbitnije za poslovanje preduzeća. Odstupanja koja se mogu javiti u ovom dijelu proizvode gubitke koji su jedan od primarnijih rizika poslovanja preduzeća. U cilju smanjenja ovoga rizika neophodno je strogo popunjavanje i detaljnija izrada mjesečnih i godišnjih planova kontrole i strogo poštovanje istih.

4 ZAKLJUČCI

Ključni princip sistema kvaliteta je donošenje odluka na osnovu činjenica, pri čemu se do istih dolazi prikupljanjem, obradom i analizom podataka i opažanja. U cilju uočavanja faktora koji utiču na krajnji kvalitet proizvoda i usluga i za potrebe djelovanja na te faktore koriste se alati, metode i tehnike kvaliteta.

Posmatranje gubitaka električne energije u radu distributivnih preduzeća ima za cilj definisanje svih parametara koji utiču na gubitke elekrične energije kao jedan od najznačajnijih rizika distributivnih preduzeća, ali i procjenu inteziteta njihovog uticaja. Na ovaj način se omogućava sagledavanje gubitaka kao jednog od značajnijih rizika poslovanja preduzeća.

Posmatranje gubitaka kao rizik ima za cilj i definisanje i implementaciju niza mjera u cilju eliminisanja ili umanjenja istih. Primjenom FMEA metode u radu je izvršena procjena nivoa rizika za proces koji ima najveći uticaj na gubitke električne energije: kontrola, servis i baždarenje električnih mjerila. Postupak FMEA metode, dat prema IEC 60812:2006, je prilagođen konkretnom primjeru, izvršeno je prilagođavanje tabelarnih pregleda za postupak ocjenjivanja. Primjenom ove metode izvršeno je ocjenjivanje svih aktivnosti iz posmatranog procesa na osnovu modifikovanih tabela za ocjenjivanje, nakon čega su propisane neophodne mjere sa ciljem da se utiče na glavne rizike poslovanja.

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APPROACH OF THE ENTREPRENEURSHIP DEVELOPMENT AT THE UNIVERSITY OF MONTENEGRO

Jelena Jovanovic [1], Zdavko Krivokapic[2], Aleksandar Vujović[3]

Abstract: In the Western Balkan countries, young generation prefer "safe" employment at public enterprises much more than establishing their own business. The Erasmus plus REBUS project is established with the aim to provide strong support for addressing the challenge of bringing entrepreneurship into HEIs and establishing a interface between high education and practical business context based on the network of EU and Western Balkan countries. The paper is focused on the Rebus approach of entrepreneurship learning at the University of Montenegro. REBUS project promotes the development of various entrepreneurship training modules and their integration into existing or new curricula of the teaching courses at the HEIs. The project also promotes the creation and adoption of a validation system, the implementation and evaluation of the training modules and the competence validation system. According that, the University of Montenegro realized many activities aimed at raising the awareness of students about the importance of creating their own business and learning about entrepreneurship. The paper presents the process of implementation of Rebus approach about entrepreneurship learning and approach of evaluation of entrepreneurial competences at the University of Montenegro.

Key words: entrepreneurship, validation, competence, *business*

1 INTRODUCTION

The history of entrepreneurship has its roots in 17th and 18th centuries the greater emphasis of entrepreneurship in theoretical sense is found in the period of the end of 19th century[1]. The entrepreneurship is related to the process of implementing a new business arrangement and there is an extraordinary fact is that 75% of jobs in the world are created through entrepreneurial ventures.

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There is dilemma about the level of correlation between academic education and success in entrepreneurship. Based on literature sources [2] the entrepreneurship is based on three pillars:

- Excellent knowledge of the needs of customers, markets, technology, technics etc.,
- Experience, passion to the work and persistence, as well as the investment of enormous work,
- Ideas and objectives, finding and striving to the unused market conditions.

The Erasmus REBUS project is established with aim to enable strong support to address a challenge of bringing entrepreneurship into HEIs and establishing the interface between higher education and practical business context based on cooperation network of EU and Western Balkan countries. The project developed a concept to support the development of key competences for employability that will guarantee more flexibility in the labor force and allow for faster adaptation to constant changes in a more interconnected world [3].

The project is predominantly focused on developing entrepreneurial competences among students of technical and ICT studies because these students are considered to have the greatest capacity and creativity for developing their own business.

2 ACTIVITIES OF THE UNIVERSITY OF MONTENEGRO PROJECT TEAM ON THE REBUS PROJECT IMPLEMENTATION

University of Montenegro successfully realizes the Rebus project through the following key activities:

- Adaptation of existing ECTS course catalogs
- cooperation with enterprises in order to realize practical teaching of students in business real environment
- Education of students about entrepreneurship

The Faculty of Mechanical Engineering at the University of Montenegro, as the main participant in the realization of the Erasmus plus Rebus project, determined the need to change the following teaching courses at different levels of studies according to the training that teachers passed in the field of Entrepreneurship in Essen Germany. That is shown on figure 1.

Title of the course	New or Upgraded	Level of Study:	Completion level	Upgrade or development covers area of:
Marketing in traffic	Upgraded	Bachelor	10%	Development of fisibility analysis
Industrial engineering	Upgraded	Bachelor	10%	Enterpreneurship. Development of new products and services
Organization and management in traffic	Upgraded	Master	10%	Risk management
Entrepreneurship and innovation	Upgraded	Master	10%	Personal competences. Intercultural competences
Organization and management	Upgraded	Master	10%	Risk management
Innovation and competitiveness	New	Bachelor	100%	Innovation and competitiveness

Figure 1: *Modification of ECTS teaching courses*

We made changes up to 10% for 5 teaching courses. These changes can be realized without re-accreditation. The reorganization at the University of Montenegro enabled the creation of a completely new teaching course called: Innovation and Competitiveness on Bachelor study program called "Traffic road" at the Faculty of Mechanical Engineering Podgorica. The course is mostly designed on the basis of information available through the application of the Rebus project and working on the Rebus project. The ECTS catalog of the course, created on that way, was entered into

the accreditation of all study programs at the University of Montenegro, completed in 2017. Professor who created the ECTS catalogue is a member of the working team at the Rebus project. Lectures according teaching course Innovation and competitiveness is started in winter semester of school year 2018/19.

Three professors from the Faculty of Mechanical Engineering passed training in the field of enterprenurship at the University of Essen, after which they were obliged to transfer their knowledge to students. Consequently, in accordance with the objectives of the Rebus project, 30 students were selected who needed to become familiar with the topic of entrepreneurship and with methods and techniques that are in correlation with the development of innovation and entrepreneurship.

3 STUDENT'S ACTIVITIES IN THE FIELD OF ENTREPRENEURSHIP

Selected students, mainly from the Faculty of Mechanical Engineering, are registered through project site called Mahara (http://mahara.learningrebus.net/). Each student is created his own profile and was able to connect with other students through the system.

The project site which available transparency of learning material for e-learning under the name Mahara was created by the EU partner. The site has provided key presentations by the EU partners on the most important topics in this field:

- Personal comptences
- Intercultural competencies and
- Entrepreneurship

In addition, professors engaged in the project (trainers) trained by the EU partner have created their own presentations that were put on the same site. Each registered student has access to all these presentations and his / her learning is enabled through the Mahara system.

The realization of the training of selected students is in line with the recommendations of the Rebus project on following way:

- F2F (face to face)
- e-learning and
- learning projects

The students were from different study years and different study programs, and according that, their initial knowledge of entrepreneurship was very diverse. Consequently, professors who passed the Essen training give F2F-type lectures on entrepreneurship. Each student studied different methods and techniques, which are in relation with entrepreneurship, through various courses they, according to their knowledge, made presentations on certain topics. They put presentations on their profiles in Mahara system. By this approach is fully respected the Rebus approaches of F2F training and e-learning.

The students created teams in order to develop projects of new services or products or projects of some improvements and research that can be realized in some business environments. For these projects they planned to use scientific methods and techniques.

In order to achieve all of Rebus objectives, there were developed a pathway to guide trip through preparation of student's project. It is a step-by-step procedure [3]:

1. PLAN - At the beginning of the practical learning student should describe the project that he wants to realize. Already at this phase student can reflect on the competences that he may acquire during his project and fill in a first questionnaire about them.

2. DO - During his practical learning phase he can keep a logbook in which he can record his experiences (he is invited to collect the proofs of his work also in his personal e-portfolio; he can create pages and collections and publish them in his section on Mahara site).
3. CHECK - At the end of his learning project he will be invited to assess himself on the development of his entrepreneurial competences. He will do that with the help of the LEVEL5 validation system, an easy to use validation tool. At this stage he will warmly invited to discuss his findings with his mentor.

After conducting the training provided by Rebus, the testing of students from the field of entrepreneurship was conducted. A well-done test of entrepreneurship was one of the criteria for selecting students who were educated at the University of Palermo. Criteria for selecting students for training at the University of Palermo are defined in the following way:

- Passed a test of Entrepreneurship with more than 50%
- Average mark at studies
- Knowledge of English
- Prepared presentation in the field of entrepreneurship
- A project in the field of entrepreneurship

Based on defined criteria, 14 students were selected for 11 day training on entrepreneurship at the University of Palermo. Students of the University of Montenegro attended training together with students from the Faculty of Mechanical Engineering in Sarajevo and the University of Elbasan. The training was realized through team work multicutural based in a way that each team had at least 2 members from each university.

4 VALIDATION OF COMPETENCIES

According to the Rebus project a competence is define as ability to apply a synthesis of

- Knowledge,
- Skills and
- Attitudes

as it is shown on figure 2 [3,4].

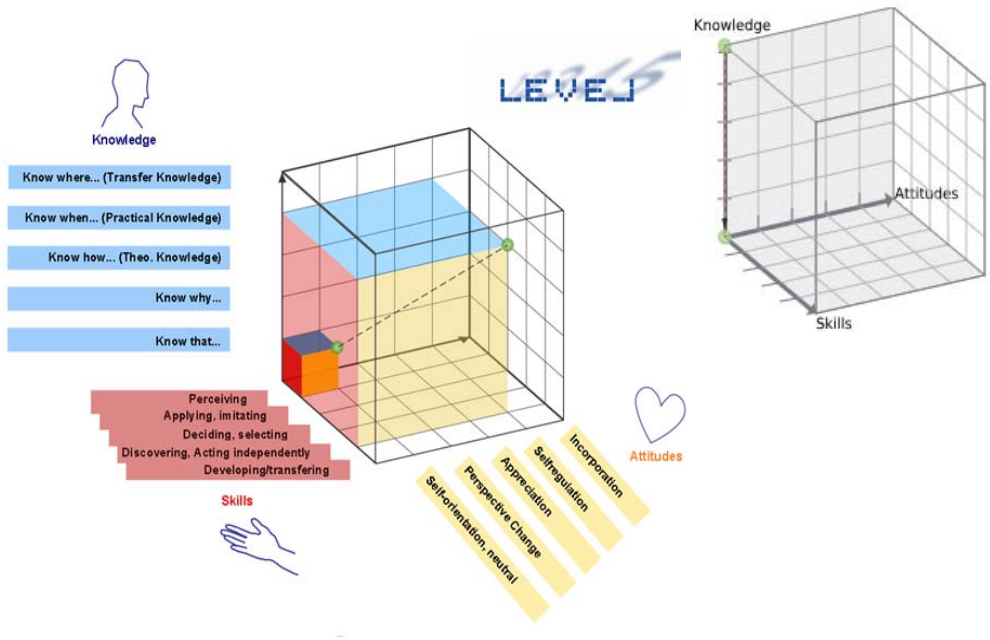


Figure 2. Assesment of competences

Knowledge is defined as theoretical and practical knowledge of the application of various tools and strategies such as project management, marketing, leadership, economic principles ....

Skills are defined as the ability to apply different tools and strategies in accordance with the situation and goals to be met, the ability to assess and analyze opportunities and risks, take responsibility for realized activities and the ability to promote their ideas.

Attitudes include proactivity, motivation to take initiative, willingness to take risks, all in order to achieve the set goal.

Students carry out self-assessment of all these categories through 5 levels of grades as it shown in Table 1 [3,4].

Table 1: Levels of self-assessment

LEVEL	KNOWLEDGE	SKILLS Capabilities	ATTITUDES Emotions/Values
5	Know where else…	Transfering	Incorporation
4	Know when…	Discovering	Commitment
3	Know how…	Deciding	Appreciation
2	Know why…	Imitating	Perspective taking
1	Know-that…	Perceiving	Neutral

Students of the University of Montenegro have been tested according 2 competencies:

- Enterpreneurship
- Intecultural communication

The appearance of the form for self-assessment of students is shown in Figure 3. By choosing the grade for each category of knowledge of the chosen competence, an additional window opens where they have to fill a description which confirms the assessment [5].

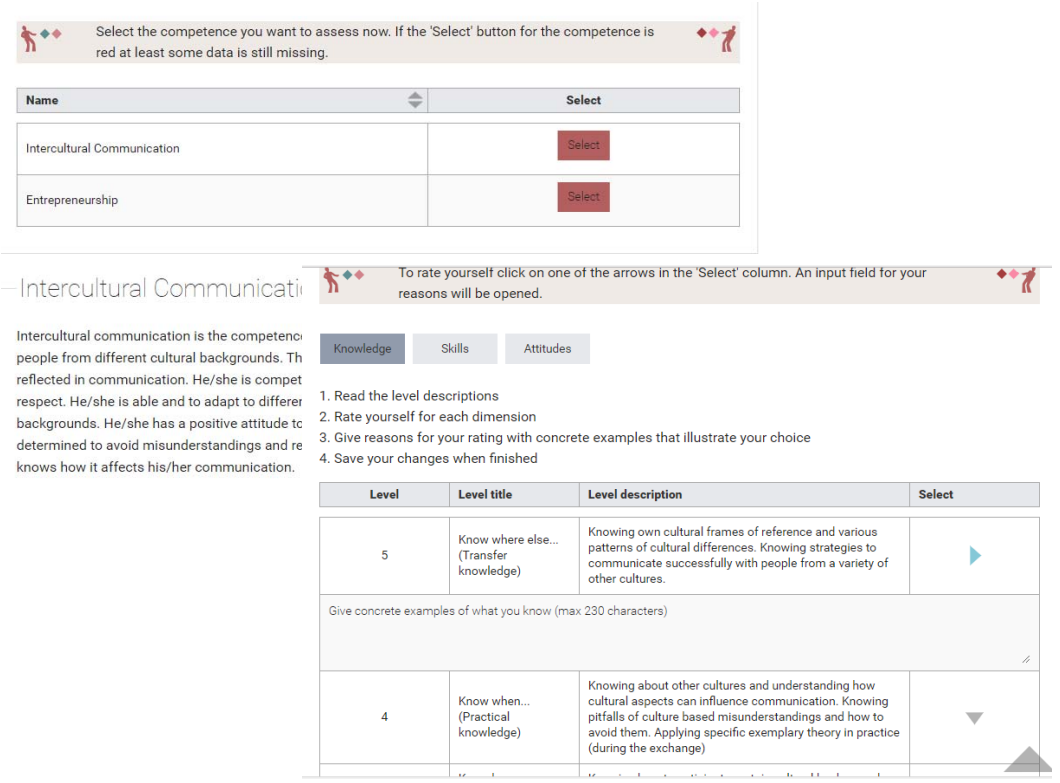


Figure 3. *Window for self-assessment of students*

After conducting the assessment by all students, the issuance of certificates will be enabled.

Students who have had training in Palermo will have the opportunity to conduct the second self evaluation in order to obtain the certificate of the competence level which they have finally acquired. The double assessment will also indicate the level of advancing students' education through the Rebus project.

During the training in Palermo, students had obligation to define and work on their own team's projects. There were performed competition between team's projects with the following criteria:

- the best documentation
- the best teamwork
- the smartest and most promising idea

Students will have obigation to develop projects that were initially defined within the national teams and set up on the Mahara system after gaining competencies on the Rebus project.

5 CONCLUSION

Rebus project highlights the importance of the development of entrepreneurial competences among students, mainly ICT and technical studies, which are expected to independently create sophisticated businesses and contribute to the most innovative activities in organizations where they are employed.

In this paper is presented the Rebus approach of development and evaluation of entrepreneurial competence, appled at the University of Montenegro. Students of UOM passed F2F and online education under the mentorship of UOM professors who were previously trained by mentors from the EU Universities. After such education, 14 of them who met the prescribed criteria, passed the training about entrepreneurship at the University of Palermo.

A special contribution of the project is in establishing a system for validating competencies, called Level 5, which enables students to realize self-evaluation under supervision and obtaining certificates of acquired entrepreneurial competencies. According that, students performed first self-evaluation for 2 competences (entrepreneurship and multicultural communication) before training in Palermo and second self-evaluation after the training. Comparative analysis of these two evaluations shows that students had very good education through the Rebus project, especially through training in Palermo, which will certainly contribute to their entrepreneurial competencies.

Most of them are very interested about establishing their own business. All of them, definitelly plan to learn more about entrepreneurship and achieve higher level of enterpreneural compteneces. However, Rebus project will have very well impact on development of enterprenural compteneces among students at the University of Montenegro, especially at the Faculty of Mechanical Engineering.

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5S KAO ALAT LEAN KONCEPTA U PROCESU MAŠINSKE OBRADE PLOČASTIH MATERIJALA

Bogdan Marić[1], Željko Batinić[2], Vlado Medaković[3]

Rezime: U radu je istraživana mogućnost primjene alata Lean koncepta 5S sa ciljem da se: (1) uspostavi kontrola prostornog raspoređivanja opreme, materijala i zaliha; (2) otkriju i otklone gubici, i spriječi njihovo ponovno pojavljivanje u budućnosti koji su nastali kao posljedica "nekontrolisanih" procesa u procesu mašinske obrade pločastih materijala. Istraživanja su pokazala da se primjenom alata Lean koncepta 5S može doći do dobro organizovanog radnog mjesta (čisto, uređeno, sigurno i organizovano), čime se povezuju ljudi i procesi, kao ključnog pokretača postizanja visokog kvaliteta, niske cijene i brze isporuke u proizvodnom sistemu mašinske obrade pločastih materijala.

Ključne riječi: Alat, Lean, Lean koncept proizvodnje, 5S

5S AS A TOOL OF LEAN CONCEPT IN THE MACHINE PROCESSING OF PLATE MATERIALS

Abstract: The paper explores the possibility of applying the tools of Lean concept 5S in order to: (1) establish control over the spatial distribution of equipment, materials and supplies; (2) discover and eliminate losses, and prevent their re-emergence in the future that arose as a result of "uncontrolled" processes in the machine processing of plate materials. Research has shown that using the tools of Lean concept 5S can provide a well-organized workplace (clean, well-organized, secure and organized), connecting people and processes as a key driver for achieving high quality, low cost and fast delivery in the production system of the machine processing of plate materials.

Keywords: Tool, Lean, Lean production concept, 5S

1 UVOD

Savremeni tržišni uslovi rada zahtijevaju od proizvodnih sistema mašinske obrade pločastih materijala (proizvodnja namještaja od pločastih materijala) povišenu efikasnost procesa rada na putu od zahtjeva za proizvodom ili uslugom do njegove realizacije. U tom cilju smanjenju ciklusnih vremena, efikasno i efektivno upotrijebljenom radnom snagom, uređenju radnog okruženja, tokova materijala i informacija kroz

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proizvodni sistem pridaje se sve veći značaj. Iz navedenog se može zaključiti da se i u procesima rada proizvodnih sistema mašinske obrade pločastih materijala moraju postavljati ciljevi za uspostavljanje funkcionalne organizacije, to jest uređenost datih procesa rada koja će obezbijediti visok stepen fleksibilnosti u organizaciji i upravljanju orijentisanom prema kupcu.

Projektovanje funkcionalne organizacije mjerene efektivnošću i efikasnošću procesa rada uključuje i organizacijsko uređivanje niza međusobno zavisnih grupa uticajnih faktora od čijeg intenziteta i dejstva zavisi uspješan rezultat svakog rada. Krajnji cilj je da se uz što manje uloženih sredstava postignu što veći efekti, odnosno da troškovi po jedinici proizvoda budu što manji. Na taj način su menadžeri koji vode proizvodnju primorani da stalno odstranjuju aktivnosti koje stvaraju gubitke za preduzeće koristeći istovremeno efikasne menadžmentske metode, postupke i alate. Pored toga, minimiziranja se prenose i na pojedinačne elemente organizacione strukture zadržavajući pritom tržišnu moć i poziciju. Pristup u izgradnji ovakvog okruženja u preduzećima okarakterisan je kao Lean proizvodnja, Lean doktrina ili Lean koncept [2].

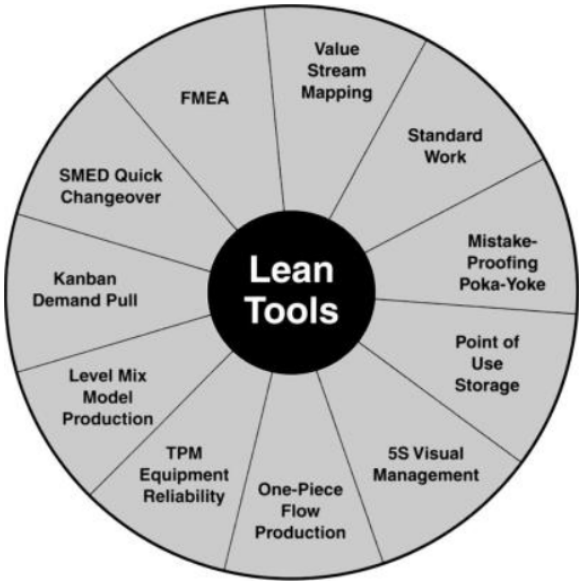
Cilj Lean koncepta je da eliminiše izvore gubitaka ili "slobodne prostore", a to su u suštini beskorisna vremena i gubici zbog prijevremenog ulaganja u proizvodnju. Eliminisanje zaliha najveći je problem, jer zahtijeva sinhronizaciju veoma bliskih procesa, onih koji povezuju različite funkcije unutar preduzeća. Ovaj koncept uključuje stalnu organizacionu i menadžmentsku modernizaciju. Riječ je o aktivnosti na smanjenju troškova proizvodnje smanjenjem svih pojavnih oblika gubitaka, izraženih u fabričkim tokovima materijala (engl. *factory flow*), gubicima u zastojima na sredstvima rada, u informacijama, energiji, zalihama (engl. *inventory management*), projektovanju i slično. Na taj način se stvara sistem koji će eliminisati gubitke u procesu rada organizacionih sistema, uzimajući ono što je osnovno za reprodukciju, proizvodnju i što utiče na povećanje cijene proizvodnje (oprema, materijal, radna snaga, vrijeme i dr.).

Sistemska i konstantna traganja za beskorisnim aktivnostima na svim nivoima procesa rada i njihovim eliminisanjem ili smanjivanjem posredno se utiče na kvalitet i troškove u preduzeću. Nove metode u obučavanju zaposlenih – alati i razvijena informaciona tehnologija omogućavaju da se ubrzaju istraživanja i omogući kontinuirano smanjivanje troškova i unapređivanje kvaliteta proizvoda po želji kupaca u svim elementima radnog odnosno poslovnog ciklusa.

Krajnji ishod Lean koncepta je oblikovanje fleksibilnih, odnosno Lean proizvodnih sistema koji mogu u najkraćem vremenu da odgovore na zahtjev svakog pojedinačnog kupca a da pri tom ne dođe do zastoja u proizvodnji i nagomilavanja nezavršenih proizvoda.

2 ALATI LEAN KONCEPTA

Primjenom različitih alata Lean koncepta (Sl. 1) želi se standardizovati, a zatim permanentno poboljšavati kvalitet procesa rada u preduzećima. Razloge za to treba tražiti u činjenici da standardni procesi rada obezbjeđuju standardan kvalitet proizvoda. Njih su tokom višegodišnjeg istraživanja razvila uspješna preduzeća u visokorazvijenim zemljama u cilju zadovoljenja korisnika proizvoda i usluga i drugih zainteresovanih strana. Ukoliko se primjenjuju korektno, alati Lean koncepta pomažu u identifikaciji i stalnoj eliminaciji otpada, poboljšanju kvaliteta, smanjenju vremena proizvodnje i smanjenju troškova. Zato danas mnoga preduzeća ulažu ogromna finansijska sredstva u razvoj i implementaciju alata Lean koncepta koji će im omogućiti sposobnost kontinuiranog i brzog prilagođavanja uslovima poslovanja koji se stalno mijenjaju.



Slika 1. *Alati Lean koncepta [8]*

Dosadašnja istraživanja [2,6,9] su pokazala da se Lean koncept, osim automobilske industrije koja je inicirala razvoj ovoga koncepta, postepeno prihvata i u drugim proizvodnim, uslužnim i administrativnim organizacijama, a rezultati su izazovni. Stoga se postavlja pitanje:

U kojoj mjeri se razvijeni alati Lean koncepta mogu primijeniti na procese rada u proizvodnim organizacijama koje se bave mašinskom obradom pločastih materijala i sa kakvim uspjehom?

Na osnovu traženja odgovora na ovo pitanje proizašla je i osnovna hipoteza u ovom radu:

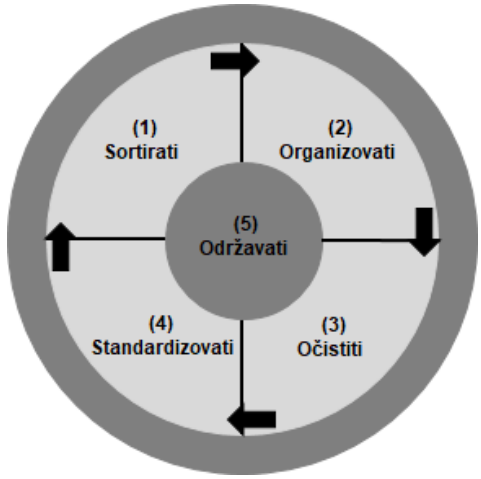
Primjenom alata Lean koncepta 5S u proizvodnom sistemu mašinske obrade pločastih materijala moguće je povećati efikasnost radnog okruženja.

2.1 Alat Lean koncepta 5S

Kada se govori o kontinuiranom poboljšanju, jedan od najefikasnijih i najprepoznatljivijih alata Lean koncepta je 5S [1,5] (u daljem tekstu 5S alat). Prema Osada [7], 5S alat predstavlja metodu pomoću koje se smanjuje višak materijala, energije, napora, itd. a dok se sa druge strane kvalitet i produktivnost podižu na optimalan nivo kroz održavanje i sređeno radno okruženje. Moriones [1] naglašava da je 5S alat jedan od prvih koja se implementira u proizvodne i uslužne sisteme kada sistemi prihvate organizacione promjene i započnu implementaciju Lean filozofije. Cilj 5S alata je da se na već postojećoj konfiguraciji, odnosno Layout-u sistema, uveća vrijednost organizovanosti, standardizacije, dicipline, čistoće u radno okruženje. Naziv 5S dobio je po pet riječi koje na Japanskom jeziku počinju sa slovom S: (1) Seiri *(Sortiranje)*, (2) Seiton *(Organizovanje)*, (3) Seiso *(Čistoća)*, (4) Seiketsu *(Standardizacija)* i (5) Shitsuke *(Održavanje)*.

Primjenom 5S alata u organizovanju radnog okruženja najlakše se svim zaposlenima objašnjava čitava Lean filozofija eliminacije gubitaka u proizvodnom sistemu.

Na Slici 2 prikazan je 5S ciklus unapređenja radnog okruženja.



Slika 2. *5S ciklus unapređenja radnog okruženja*

Sistematizacija filozofije i metodologije 5S alata data je u Tabeli 1.

Tabela 1. *Sistematizacija filozofije i metodologije 5S alata*

A - Osnova za poboljšanje		**B - Mislite Lean**	
1.	Neposredno radno okruženje je značajano kao ključni pokretač postizanja visokog kvaliteta, niske cijene i brze isporuke.	1.	5S, vizuelno upravljanje – prvi alat Lean transformacije!
2.	Mogu li poboljšanja proizvoda doći do izražaja u neurednom i prljavom pogonu, odnosno radnoj sredini?	2.	Ako ne znate gdje da započnete "Lean", gdje bi to trebalo da bude? Započnite sa 5S!
3.	Možemo li očekivati da ljudi u sumornom okruženju maksimalno iskažu svoje potencijale?	3.	To je način da promovišete timski rad i da brzo ostvarite napredak (rezultat je vidljiv "golim okom")
4.	Može li slobodan um, pun svežih ideja, da funkcioniše u pretrpanom radnom prostoru?	4.	5S može biti više od početne tačke, to je zapravo kritični dio cjelokupnog procesa transformacije
C - Šta je ta je 5S?		**D - Zašto 5S?**	
1.	5S je sistematičan pristup za poboljšanje efikasnosti radnog mjesta kroz organizaciju	1.	Da bi se eliminisali gubici koji su nastalikao posljedica "nekontrolisanih" procesa
2.	Cilj je smanjiti gužvu, otkriti i otkloniti gubitke, i spriječiti njihovo ponovno pojavljivanje u budućnosti	2.	Da se uspostavi kontrola prostornog raspoređivanja opreme, materijala i zaliha
3.	Poboljšati urednost radnog mjesta – nalazeći posebno mjesto za sve i ostavljajući sve na svom mjestu	3.	Da se obezbijediti čisto, uredno, bezbjedno i produktivno radno mjesto
4.	5S se odnosi na organizaciju radnog mjesta i predstavlja osnovu Lean proizvodnje		
E - 5S Elementi		**F - Dobro – Nakon 5S**	
1.	Sort – Sortirati (Osloboditi se svega što nije potrebno)	1.	Bojom kodirane oblasti
2.	Set – Organizovati, urediti (Pravilno razmjestiti potrebne stvari, ograničiti zalihe)	2.	Čisti prolazi
3.	Shine – Očistiti (Očistiti sve spolja i iznutra)	3.	Povećana uočljivost neusaglašenosti
4.	Standardize – Standardizovati (Definisati pravila za održavanje prva 3S)		
5.	Sustain – Održavati (Obezbijediti poštovanje pravila)		

Aktivnosti i smjernice za implementaciju 5S alata date su u tabelama 2 i 3.

Tabela 2. *Aktivnosti i smjernice za implementaciju 5S alata*

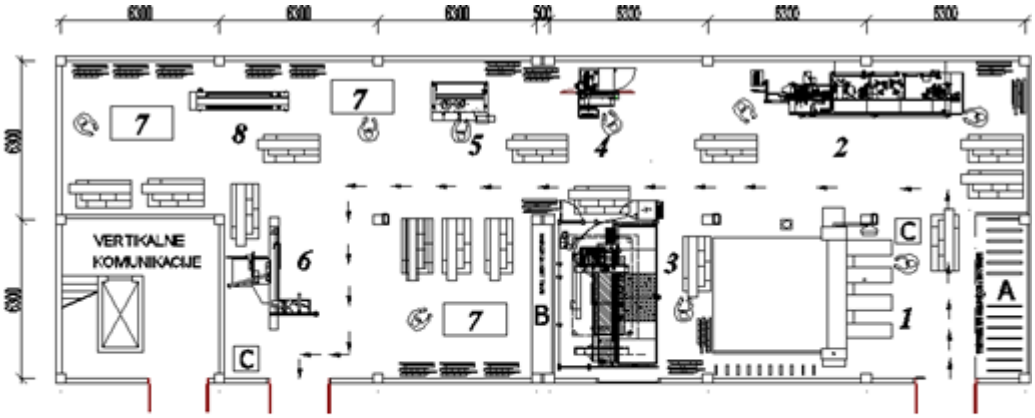
1. Sortirati (Sort, Seiri)		**Crvene etikete (Red Tag)**	
1.	Identifikovati i ukloniti gužvu	1.	Jednokratna aktivnost uklanjanja ili premještanja nepotrebnih stvari: - Identifikovati nepotrebne stvari, opremu koja se ne koristi, itd. - Popuniti i okačiti crvenu etiketu. - Unijeti u dnevnik crvenih etiketa. - Stvari označene crvenom etiketom moraju se ukloniti ili premjestiti u roku od 30 dana.
2.	Klasifikovati stvari na osnovu učestalosti korišćenja		
3.	Izbaciti sve što se ne koristi (vježba sa crvenom etiketom)		
2. Organizovati (Set in Order, Seiton):		**3. Očistiti (Shine, Seisou):**	
1.	Definisati standard za prva 3Sa.	1.	Eliminisati sve vrste zagađenja: nečistoća, prašina, tečnost i dr.
2.	Proslijediti informacije članovima tima, tako da ne dođe do konfuzije ili grešaka koje se tiču: - Lokacija (alata, prolaza) - Isporuka - Destinacija - Količina - Rasporeda (čišćenja) - Zastoja (održavanje) - Procedura i standarda	2.	Čišćenje je provjeravanje!
		3.	Provjeriti nepravilnosti i pronaći uzroke
		4.	Fizički očistiti i vizuelno "pročešljati" (tražeći sve što se ne nalazi na svom mjestu)
		5.	Da se poboljšaju: bezbjednost, kvalitet proizvoda i radno okruženje
3.	Učiniti da svi budu upoznati sa standardima (vizelno)		
4. Standardizovati (Standardize, Seiketsu):		**5. Održavati (Sustain, Shitsuke):**	
1.	Eliminisati sve vrste zagađenja: nečistoća, prašina, tečnost i dr.	1.	Održavati rutinu! Dnevno pet minuta za 5S aktivnosti
2.	Čišćenje je provjeravanje!	2.	Svako dugoročno učestvuje u 5S (obuka)
3.	Provjeriti nepravilnosti i pronaći uzroke	3.	Podsticati i prepoznavati dostignuća
4.	Fizički očistiti i vizuelno "pročešljati" (tražeći sve što se ne nalazi na svom mjestu)	4.	Redovno sprovoditi nadgledanje i reviziju
5.	Da se poboljšaju: bezbjednost, kvalitet proizvoda i radno okruženje		

Tabela 3. *Smjernice za implementaciju 5S elementa "Sortirati"*

Kriterijum sortiranja	
Učestalost korišćenja	**Aktivnost**
Nikada (nepotrebno) Jednom godišnje Jednom mjesečno Jednom nedjeljno Jednom dnevno ili češće	Odbaciti Smjestiti u skladište Smjestiti u fabriku ili kancelariju Smjestiti u najbliže radno okruženje Smjestiti na radno mjesto
Pitanja koja treba postaviti:	
Čemu služi? Koliko je često potrebno? Da li je potrebno da bude na ovoj lokaciji? A na nekoj drugoj lokaciji? Koliko toga je potrebno? Ko to koristi? Postoji li neki drugi razlog zbog kojeg bi to trebalo da bude ovdje?	

3 IMPLEMENTACIJA LEAN ALATA 5S U POSMATRANOM PROIZVODNOM SISTEMU MAŠINSKE OBRADE PLOČASTIH MATERIJALA

Implementacija 5S alata u posmatranom proizvodnom sistemu mašinske obrade pločastih materijala (Sl. 3) izvršena je prema aktivnostima i smjernicama datim u tabelama 2 i 3, na način prikazan na slikama 4, 5 i 6.



1. Raskrojač HOLZMA 43
2. Kantarica HOMAG KAL 310
3. Obradni centar VENTURE 1M
4. Tiplerica BHX 050
5. Tiplerica ABD 60
6. Raskrojač P45
7. Montaža korpusa
8. Korpusna presa

A. Magacin pločastog materijala
B. Magacin za kant trake
C. Kutije za otpad

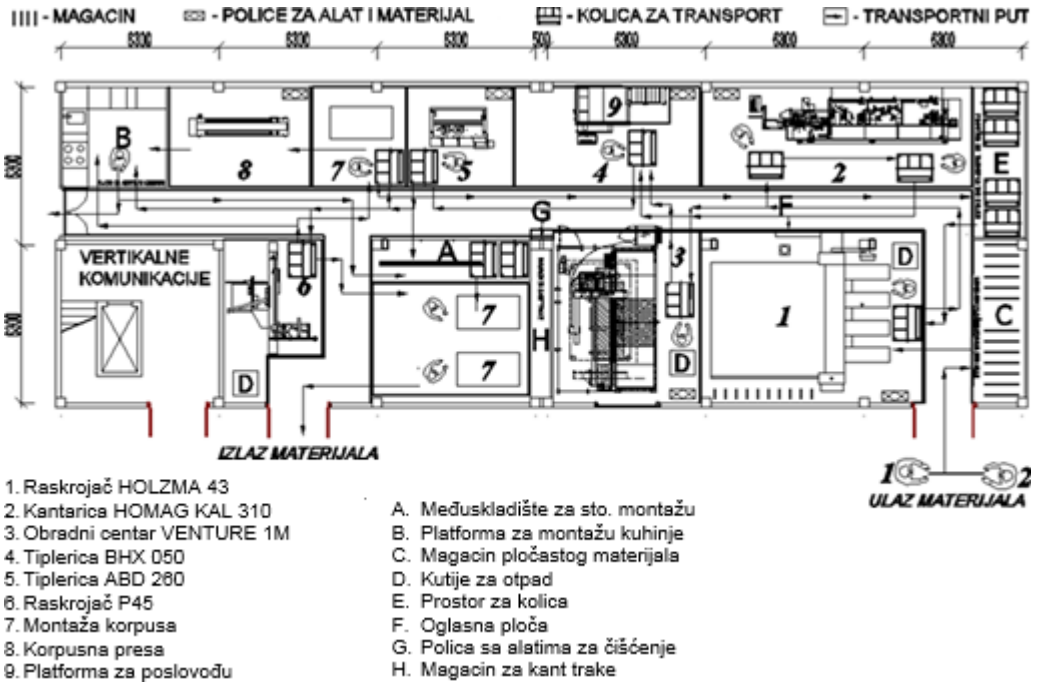
Slika 3. *Proizvodni sistem mašinske obrade – početno stanje*



Slika 4. *Početno stanje u objektu*



Slika 5. *Završno stanje u objektu*



Slika 6. *Proizvodni sistem mašinske obrade – završno stanje*

Sa Slike 6 se vidi da je cijelokupan prostor u proizvodnom sistemu označen kao radni prostor, transportni put i magacin ili međuskladište, čime se stvara uslov da se mogu podijeliti radne obaveze za čišćenje prostora proizvodnog sistema, a da ne ostane slobodan prostor.

Troškovi implementacije 5S alata u posmatranom proizvodnom sistemu mašinske obrade pločastih materijala prikazani su u Tabeli 4.

Tabela 4. *Tabelarni pregled ulaganja u proizvodni sistem mašinske obrade*

Vrsta ulaganja		Ulaganje
Nabavka i postavljanje žutih ljepljivih traka		76,00 KM
Nabavka i postavljanje upozoravajućih traka		50,00 KM
Nabavka i postavljanje traka za magacin i međuskladište		26,00 KM
Sprej lak u dvije boje		20,00 KM
Nabavka alata za čišćenje		90,00 KM
Oglasna tabla sa radnim stolom za poslovođu (Varijanta 1)		180,00 KM
Izrada platforme za poslovođu (Varijanta 2)		850,00 KM
Univerzalna transportna kolica (10 komada)		1640,00 KM
Transportna kolica za kuhinjske elemente		180,00 KM
Izrada pada na ulaznim i izlaznim vratima u sektor za mašinsku obradu		200,00 KM
Izrada ormara (6 kom)		720,00 KM
Izrada polica i nabavka opreme za montažu korupsa		150,00 KM
Primarna ulaganja	**Varijanta 1**	**3352,00 KM**
	Varijanta 2	**4072,00 KM**

- **Varijanta 1** – Mjesto za poslovođu nalazi na podu, nema potpunu preglednost i nije zaštićen od uticaja prašine.
- **Varijanta 2** – Mjesto za poslovođu nalazi se iznad poda na visini 2m, ima potpunu preglednost, ne zauzima prostor i poslovođa će biti u kabini koja je zaštićena od uticaja prašine.

4 ZAKLJUČCI

Kada se govori o kontinuiranom poboljšanju, jedan od najefikasnijih alata Lean koncepta je 5S. Predstavlja metodu pomoću koje se smanjuje višak materijala, energije, napora, itd. a dok se sa druge strane kvalitet i produktivnost podižu na optimalan nivo kroz održavanje i sređeno radno okruženje.

5S alat je jedan od prvih koji se implementira u proizvodne i uslužne sisteme kada sistemi prihvate organizacione promene i započnu implementaciju Lean filozofije. Cilj 5S alata je da se na već postojećoj konfiguraciji, odnosno Layout-u sistema, uveća vrednost organizovanosti, standardizacije, dicipline, čistoće u radno okruženje.

Implementacijom 5S alata u posmatranom proizvodnom sistemu mašinske obrade pločastih materijala došlo se, upravo, do povećane efikasnosti radnog okruženja kao posljedica dobro organizovanog radnog okruženja (prostora za rad), koje je rezultiralo, prije svega, dobijanjem u prostoru, odnosno, značajnim smanjenjem materijala i prostora potrebnih za postojeće aktivnosti i operacije.

Takođe, na osnovu dosadašnjih istraživanja primjene 5S alata u drugim proizvodnim i uslužnim djelatnostima prezentovanih u [1,2,3,5,7,9] za očekivati je da će se implementacijom 5S alata u posmatranom proizvodnom sistemu mašinske obrade pločastih materijala:

- smanjiti defekti,
- minimizovati vrijeme ćišćenja,
- smanjiti zalihe,
- poboljšati održavanje,
- povećati bezbjednost,
- povećati efikasnost radnika.

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POBOLJŠANJE LOGISTIČKE FUNKCIJE ALATNICE I EFIKASNIJE IZMJENE ALATA ZA OBLIKOVANJE LIMA

Darko Petković[1], Ibrahim Plančić[2], Merima Ramić[3]

Rezime: Logistika predstavlja cjelokupan proces planiranja, obezbjeđenja, kontrole i evidencije snabdjevanja i zbrinjavanja materijalnim sredstvima. U savremenim uslovima se najčešće koristi za označavanje poslovne funkcije i naučne discipline koja se bavi koordinacijom svih kretanja materijala i proizvoda u fizičkom, informacijskom i organizacijskom pogledu. U svijetu izražene konkurencije zahtjeva se razvijanje metoda koje će povećati obim i kvalitet proizvodnje i to je doprinjelo razvijanju logistike. Mann-Hummel BA obavlja razvoj i finalnu proizvodnju različitih vrsta filtera, između ostalih i filtera za autoindustriju. U ovom istraživanju i radu je predstavljeno logističko pozicioniranje alatnice u Mann-Hummel BA te dat prijedlog mogućeg unaprijeđenja rada alatnice kako bi ona bila što bolja podrška proizvodnji. S obzirom na ograničenost obima rada dati su samo prijedlozi boljeg povezivanja alatnice i proizvodnje uključujući i odabir transportnih i manipulativnih sredstava.

Ključne riječi : alatnica, logistika, Mann-Hummel, re-inženjering, menadžment.

THE LOGISTIC FUNCTIONS IMPROVENT OF THE TOOLROOM AND EFFECTIVE CHANGE SHEET FORMING TOOLS

Abstract: Logistics is the total process of planning, security, control and record the supply and disposal of material assets. In the modern conditions is most commonly used to refer to business functions and disciplines dealing with the coordination of the movement of materials and products in the physical, informational and organizational terms. In the world of stiff competition is required the development of methods to increase the volume and quality of production, and this has to led to the development of logistics. Mann – Hummel BA performs development and final production of various types of filters, including the filters for the automotive industry. For this reason, in this paper will consider the logistical positioning toolroom in Mann – Hummel BA and give sugestions of possible improvement work of toolroom to make it the best possible

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support to production. Also, it is given an example of better connectivity toolroom and production and choice of transportation and manipulation resources.

Key words : toolroom, logistics, Mann-Hummel, re-engineering, management.

1 UVOD

Osim proizvodnih jedinica (tehnološki sistemi) koji izvode neposrednu transformaciju predmeta rada u proizvodnom sistemu, mogu se uočiti i podisistemi koji izvode aktivnosti koji omogućavaju i olakšavaju rad proizvodnih jedinica. To su sistemi podrške tehnološkim sistemima. Osnovni sistemi podrške u proizvodnom sistemu, koji su predmet posebnog posmatranja pri projektovanju proizvodnih sistema, su :

- skladišta,
- unutrašnji transport,
- alatnica,
- snabdijevanje energijom,
- održavanje.

Alatnica je podsistem proizvodog sistema, koji snabdijeva tehnološke sisteme - proizvodne jedinice potrebnim alatom, priborom, pristrojem i pomagalima. To je kompleksan podsistem s obzirom na njegov zadatak: skladištenje, izdavanje alata, održavanje alata, izrada alata.

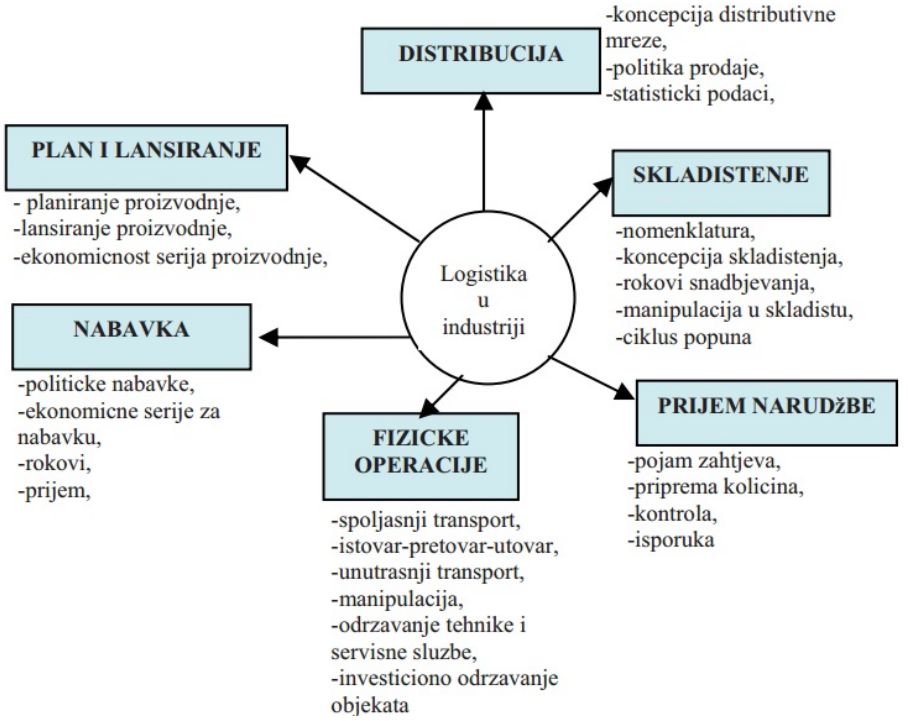
Specifičnosti alatnica u proizvodnim sistemima presovanja limova dubokim izvlačenjem leže u činjenici da se alati formiraju na modularnom principu i da mogu da teže i do 1-2 tone što pred funkciju logistike i formiranja (izrade) svakog posebnog alata postavlja posebne zahtijeve. Pri tome se projektovanje skladištenja alata vrši isto kao i za skladištenje materijala, a održavanje i izrada alata kao i za tehnološke sisteme proizvodne jedinice.

Alatnica Mann-Hummel BA u Tešnju je bila interesantna za razmatranje zbog svoje specifičnosti u odnosu na druge alatnice. Ova alatnice se veoma razlikuje od alatnica kompanija u kojima je npr. zastupljena obrada rezanjem. Kako je rečeno alati su specifični jer su velikih dimenzija (npr. min. 200x200x300 mm do max. 800x1000x1200 mm) i velikih masa od cca min. 200 kg pa do više od 1000 kg. Sastavljeni su od velikog broja dijelova, sklopova i podsklopova npr. i do 1000 dijelova urađenih različitim konstruktivnim principima itd.

2 LOGISTIKA KAO NAUKA

Pojam „logistika“ u literaturi se upotrebljava u različitim značenjima i ima širok opus primjene. Po jednima, riječ logistika je francuskog porijekla (loger – nastaviti), po drugima nastala je od riječi logistikos – mislilac tj. čovjek koji ispravno procjenjuje i brzo odlučuje. U savremenom smislu termin "logistika" upotrebljava se od II svjetskog rata u SAD-u, ali u zvanična vojna pravila ulazi tek od 1949. godine. Logistika je interdisciplinarna oblast sistema nauka koja obuhvata organizaciona rješenja, infrastrukturu, resurse, procese i ekonomsku podršku, radi realizacije zadatih ciljeva, kroz cjelokupni životni ciklus proizvoda. Logistika je povezana sa obavljanjem niza fizičko-distributivnih aktivnosti kao što su transportovanje, skladištenje, držanje određenih zaliha, manipulisanje rezervama, pakovanje i sličnim aktvnostima koje su u funkciji fizičkog transfera od proizvođača do potrošača. Značenje logistika može se interpretirati kao uspješnost dostavljanja materijala i proizvoda i održavanje stabilnosti i

kontinuiteta tog dostavljanja. U ekonomiji, termin logistika pokriva sve one aktivnosti koje su usmjerene na savladavanje prostorne i vremenske nepodudarnosti izmedju proizvodnje i potrošnje. Pojam industrijska logistika (slika 1.) predstavlja, po nekim autorima, "funkcionalni most preko koga se ostvaruje fizičko kretanje (i koordinacija) roba", što u izvjesnom smislu odgovara kombinaciji koncepta fizičke distribucije i koncepta rukovanja materijalom.



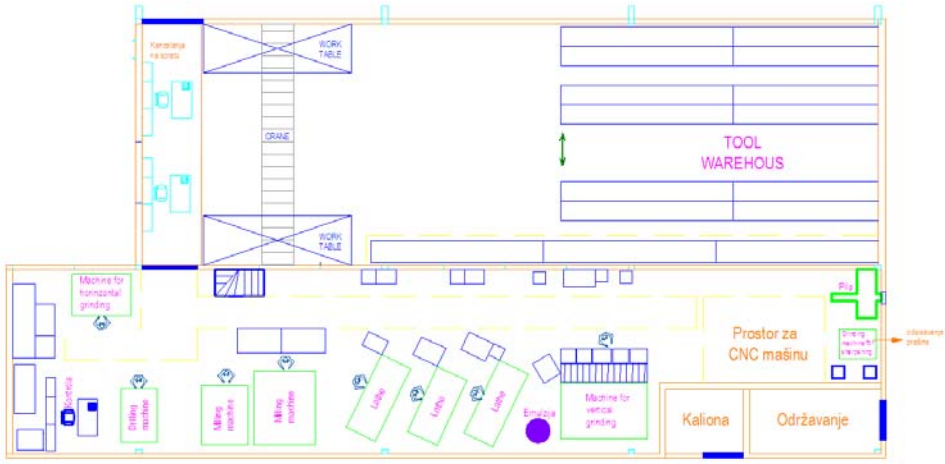
Slika 1. *Industrijska logistika*
Izvor : http://www.ingkomora.me/ikcg_sajt/cms/public/image/publikacije/2255.pdf

3 KOMPANIJA MANN-HUMMEL BA

MANN+HUMMEL grupacija djeluje globalno i zapošljava preko 11.500 radnika u preko 41 lokaciji u svijetu. Inovativna snaga ogleda se kroz 1.300 patenata širom svijeta. To pridonosi vodećoj poziciji razvojnog partnera i serijskog dobavljača za međunarodnu automobilsku i mehaničku industriju.

MANN+HUMMEL grupacija razvija, proizvodi i prodaje tehnički kompleksne sisteme i komponente kao što su sistemi za filtriranje zraka, usisne sisteme, filtere kabine za automobilsku industriju kao i filter elemente za servisiranje i opravku vozila. Proizvodi za opšti inženjering, razvojni inženjering i sektor industrijske proizvodnje, obuhvaćeni su paletom industrijskih filtera, sistema za filtriranje i sistema za manipulaciju materijalima odvojenih pri filtriranju. Preduzeće UNICO FILTER d.d. Tešanj integrirano je u grupaciju MANN+HUMMEL u 2005. godini tako da danas preduzeće nosi ime MANN+HUMMEL BA d.d. Tešanj. Preduzeće MANN+HUMMEL BA locirano je u Bosni i Hercegovini i proizvodi filtere i komponente za automobilsku industriju od 1974. godine.

MANN-HUMMEL je kompanija sa cca 600 zaposlenih. Kao što je ranije rečeno firma se bavi proizvodnjom filtera koji su veće ili manje složenosti konstrukcije. Međutim, alati za proizvodnju su veoma složeni i masivni, tako da rukovanje i skladištenje tim alatima nije nimalo jednostavan posao. Kompanija je opremljena sa velikim brojem automatskih i poluautomatskih mašina visoke preciznosti, tako da posjeduje i sopstvenu alatnicu. Na slici 2. predstavljena je funkcionalna šema rekonstruisane alatnice.



Slika 2. *Novi izgled alatnice*

Površina alatnice je 592 m^2. Prostor za skladištenje alata je cca 520 m. Alatnica se sastoji iz dva dijela. Prvi dio je dio u kome se skladište svi alati i u tom dijelu se također vrši spremanje alata za proizvodnju. Taj dio alatnice je rekonstruisan tako da je površina alatnice povećana sa 495 na 592 m^2, a prostor za skladištenje alata povećan sa 120 na 520 m. Alatnica je automatizovana i uvedene su pokretne stalaže koje omogućavaju mnogo bolju iskoristivost prostora. Jedna stalaža je postavljena uz zid dubine 500 mm, dužine 20 m. Radni prostor za skidanje alata viljuškarom je 3,5 m. Visina stalaža je 5170 mm, a ukupno 396 dužnih metara pokretnih stalaža služi za odlaganje alata. Kretanje radnika je maksimalno osigurano i proces je automatiziran.

4 PRAKTIČNI DIO ISTRAŽIVANJA

U ovom dijelu rada razmotrena su neka izvedbena riješenja alatnice, unutrašnji transport u alatnici i veza sa proizvodnjom, integracija funkcija alatnice u SAP sistem. Alatnica MHBA je bila u fazi rekonstrukcije i cilj je bio naći što bolja rješenja navedenih problema kako bi ona predstavljala što bolju podršku proizvodnji. Svi sektori u ovoj kompaniji su uvezani u SAP sistem i cilj je u najkraćem roku uvezati i alatnicu u taj sistem jer bi to doprinjelo boljoj produktivnosti kompanije. Potrebno je bilo razviti sistem šifriranja alata prema datom sistemu kako bi oni mogli biti pohranjeni. Alati su, kako je i ranije navedeno veoma masivni i rukovanje sa njima je otežano, tako da je potrebno naći što bolje rješenje manipulacije alatima prema odjeljenjima proizvodnje kao i sistem instaliranja alata na radnu mašinu, ali i poboljšanja radnih uslova jer se u ovoj kompaniji veoma vodi računa o zaštiti radnika i bjezbjednosti na radnom mjestu.

MHBA trenutno ima SAP korisnike koji se svakodnevno koriste sistemom SAP R/3 6.0. SAP bazirani podsistemi su glavni alati kojima su pokriveni gotovo svi poslovni procesi kompanije.

Kompanije MHBA, nakon dugogodišnjeg iskustva u korištenju ERP sistema, a pogotovo SAP – a, teško može zamisliti svoje efikasno poslovanje bez ERP rješenja. Bezbroj je benefita koje donosi primjena ovakvog sistema, tako da ih nema smisla ni nabrajati. Dobra praksa je da za svaki modul postoji ključni korisnik (Key-user) koji posjeduje veća znanja i vještine od krajnjih korisnika i koji istim služi kao lokalna podrška.

U MHBA kompaniji, prvenstveno na bazi svog iskustva s dosadašnjim korištenjem ERP sistema, pa i SAP – a, ukazuju na slijedeće nedostatke pomenutih velikih ERP sistema:

- visoki troškovi impelementacije i održavanja za naše standarde,
- potrebna hardverska infrastruktura i
- potrebna posebna znanja i edukacije.

Kao prijedlog što boljeg funkcionisanja SAP sistema i integracije alatnice u isti, dat je prijedlog implementacije PLM modula u SAP sistem. Na taj način bi svi odjeli i svi procesi unutar kompanije bili uvezani u jedinstven sistem, i to bi olakšalo i ubrzalo sve procese unutar organizacije.

Povezivanje proizvodnje i alatnice je veoma bitno. Nakon sveobuhvatnog sagledavanja postojećih sistema rada predloženo je da se transport alata između alatnice i proizvodnje olakša na taj način što će se nabaviti ručna kolica sa rolerima, a koja imaju automatsko upravljanje. Kolica mogu imati hidraulični sistem podizanja-spuštanja ili lančani. Na taj način će i rukovanje alatom (alati težine cca 500 kg) biti u velikoj mjeri olašano, ali će i bezbjednost radnika biti osigurana. Green Valley Manufacturing je kompanija koja dizajnira sredstva za manipulaciju alatima za duboko izvlačenje. Uvođenjem ovog rješenja bi se riješili duži zastoji, smanjio bi se broj radnika koji učestvuje u transferu alata, a kapacitet proizvodnje bi bio u značajnoj mjeri unaprijeđen. Planirani alat za dnevne potrebe bi se skladištio na pomoćnoj stalaži ispred alatnice, i na taj način bi zastoji i čekanja na alat bili svedeni na minimum. Na slici 3. su prikazani tipovi ručnih kolica sa rolerima.



Prvi tip kolica



Drugi tip kolica



Treći tip kolica

Slika 3. *Tipovi kolica sa rolerima*

Prva varijanta kolica

- cijena koštanja cca 10.000 ∈
- baterijsko napajanje
- posjeduje push/pull sistem (sistema vučenja ili guranja)
- prednosti: veoma efikasan rad, baterijsko punjenje i olakšano rukovanje

- nedostaci : visoka cijena koštanja
- izbor MHBA: veoma stabilna i postojana kolica, omogućavaju olakšan trasport alata malih i velikih težina.

Druga varijanta kolica

- cijena koštanja cca 8.000 ∈
- napajanje strujom
- izrađena specijalno za alate za duboko izvlačenje
- prednosti : napajanje strujom- baterijsko punjenje, olakšano rukovanje
- nedostaci : visoka cijena koštanja
- izbor MHBA: stabilna kolica koja omogućavaju olakšan transport alata, ali ograničena nosivost za alate cca 500 kg

Treća varijanta kolica

- Cijena koštanja cca 4.000 ∈
- hidraulični sistem podizanja
- prednosti : relativno niska cijena koštanja, hidraulični sistem sa instaliranim hidrauličnim akumulatorima, omogućava uštede u napajanju električnom energijom
- nedostaci : mala nosivost
- izbor MHBA: ekonomski veoma prihvatljiva, ali mala nosivost omogućava manipulaciju samo alatima manje težine

4.1. Rješenje procesa postavljanja alata na mašinu

Posmatrajući otežan proces postavljanja i montiranja alata za duboko izvlačenje koji su velikih težina, predloženo je da se na mašine koje koriste masivne alate postave pred – roleri koji bi taj proces dosta ubrzali i olakšali.

Da bi se olakšao i ubrzao proces postavljanja alata na mašinu mogu se koristiti pomoćni roleri koji se po potrebi montiraju na mašinu (za alate do 300 kg) . Za pravilno funkcionisanje alata u eksploataciji primarni značaj ima ispravan način montaže alata na mašinu. Na sljedećoj, slici 4. prikazan je fazni proces montiranja alata pomoću rolera.

Za alate velike težine (preko 300 kg) predlaže se rješenje ugradnje fiksnih rolera na proizvodnu mašinu. Za pravilno funkcionisanje alata, pored navedenog, od velike važnosti predstavlja i tačnost geometrije mašine.

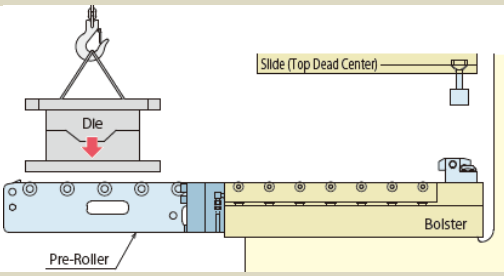
5 OCJENA IZVEDENOG RJEŠENJA (TEHNIČKA, EKONOMSKA)

SAP PLM pojednostavljuje i automatizira sve potrebne aktivnosti kako bi implementirani poslovni procesi bili sigurni, učinkoviti, te u skladu sa zakonima i propisima. Rezultat je smanjenje troškova i minimizirani rizik, kao i poboljšana slika kompanije i tržišne pozicije.

Sve navedene funkcionalnosti SAP PLM-a u potpunosti su prilagodljive specifičnim zahtjevima korisnika čime je moguće ostvariti maksimalnu fleksibilnost i upotrebljivost.

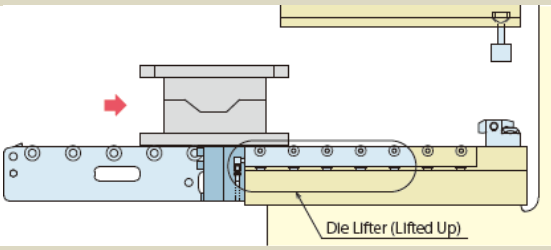
1. UBACIVANJE ALATA

Alat se prenese pomoću dizalice kolica ili viljuškara. Pred-valjci omogućavaju jednostavan utovar.



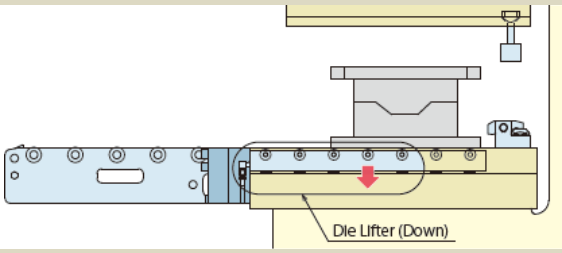
2. PRIJENOS ALATA

Sa pred-rolerima i podizačima potrebna je minimalna sila za prijenos.



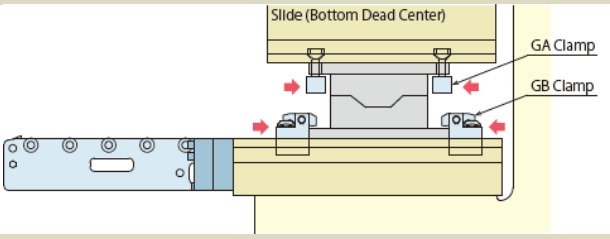
3. POSTAVLJANJE ALATA NA PODIZAČE

Kada podizači i alat ostvare kontakt, tada se podizači spuste pod djelovanjem pritiska.



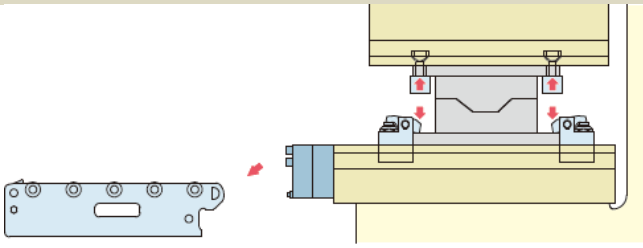
4. AUTOMATSKO POSTAVLJANJE STEZALJKI

Kada alat dođe na svoje mjesto, stezaljkama se automatski uglavljuje.



5. ZAKLJUČAVANJE ALATA

Pritiskom na dugme stezaljke se automatski zaključaju i pred-roleri se mogu maketi.



Slika 4. *Proces postavljanja pred-rolera*

Poboljšavanje uslova rada je veoma bitno, a tome bi uveliko doprinjela upotreba prethodno navedenih kolica sa rolerima. Iako bi to za kompaniju značilo novo ulaganje i dodatni trošak, mislim da bi to dugorčno bilo isplativo jer bi se olakšao i ubrzao transport alata, a samim time i omogućila bolja povezanost alatnice i proizvodnje. Kolica bi se mogla iskoristiti i za transport u proizvodnoj hali svih težih dijelova, i na taj način bi se smanjila mogućnost potencijalnih povreda na radu jer bi se olakšala manipulacija masivnim dijelovima.

Navedena sredstva su jednostavna za upotrebu i održavanje, a također su prilagođena uskim transportnim putevima. Upotreba pred- rolera pri montaži je također veoma dobro rješenje pri montaži teških alata.

6 ZAKLJUČAK

Polazni cilj navedenog rada je poboljšanje funkcije i organizacije alatnice kako bi kao potporni proces poslovanja dala punu podršku drugim proizvodnim procesima u kompaniji. Primarni značaj predstavlja aktivnost što skorijeg uvođenja SAP sistema u alatnicu što bi omogućilo povezivanje funkcije alatnice sa svim drugim poslovnim procesima i znatno povećalu produktivnost i kvalitet organizacije cjelokupne kompanije.

U radu je dat prijedlog uvođenja SAP PLM modula koji bi dodatno unaprijedio kvalitet rada informacionog sistema sa čime bi sve elektronske poslovne informacije u kompaniji bile uvezane u jedinstven ERP sistem. U cilju optimiranja funkcije alatnice prema drugim proizvodnim procesima dati su prijedlozi upotrebe kolica za transport alata sa rolerima i fiksnih rolera za mašine kojim bi se u velikoj mjeri olakšala manipulacija i transport veoma masivnih alata koji su specifični za ovu kompaniju.

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POVIŠENJE KVALITETA PROMENOM I ZAMENOM ALATA

Branko Popović[1]

Rezime: Povišenje kvaliteta rezultata procesa (poluproizvoda, proizvoda, dokumentacije, usluge) zahteva izmenu izvesne karakteristike kvaliteta. Kvalitet je nivo rezultata procesa koji je zahtevan, ugovoren ili očekivan od strane korisnika. Proveravanje kvaliteta se uvek vrši merenjem, kontrolisanjem ili ispitivanjem karakteristike kvaliteta.Karakteristike kvaliteta rezultata procesa su njegove bitne funkcionalne veličine, varijabilne (merljive, kvantitativne) ili atributivne (ocenjive, kvalitativne), sa neprekidnim (kontinualnim) i prekidnim (diskretnim) vrednostima. U izradi proizvoda bitne funkcionalne veličine su kritične dimenzije, koje ostvaruju alati a kod obrade proizvoda su obično to dimenzije otvora, dobijene rotacionim alatima (burgije, proširivači, upuštači, razvrtači, ureznici, profilni alati, itd.). U ovom saopštenju se analiziraju sva moguća povišenja kvaliteta proizvoda, primenom: periodične promene alata, zamene boljeg alata kao i dužim intervalom kontrolisanja.

Ključne reči: Kvalitet proizvoda.Povišenje kvaliteta. Promena i zamena alata.

INCREASING QUALITY WITH CHANGES AND TOOL REPLACEMENT

Abstract: Increasing the quality of process results (semi-products, products, documentation, services) requires the change of a certain quality characteristic. Quality is the level of the results of a process that is required, contracted or expected by the user. Quality checking is always done by measuring, controlling or testing the quality characteristics. Characteristics of the quality of the results of the process are its essential functional variables, variable (measurable, quantitative) or attributive (evaluative, qualitative), with continuous (continuous) and discontinuous (discrete) values. In the production of products, important functional sizes are critical dimensions, which are realized by tools, and in the processing of products, they are usually the dimensions of the holes, obtained by rotary tools (drills, expanders, absorbers, gutters, cutters, profile tools, etc.). This release analyzes all possible product quality improvements, using: periodic tool changes, replacement of a better tool, and a longer control interval.

Keywords: Product quality. Quality enhancement. Change the tool

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1. UVOD

Povišenje kvaliteta rezultata procesa (poluproizvoda, proizvoda, dokumentacije, usluge) uvek zahteva promenu postojeće karakteristike kvaliteta. Rezultat procesa je planirani izlaz poslovnog sistema, koji može biti: poluproizvod, proizvod, dokumentacija i usluga, materijalne ili nematerijalne prirode, kao i njihova kombinacija. Poluproizvodi su materijali ili količine sa karakteristikom kontinualnosti ili neprebrojivosti. Proizvodi su takođe materijalne prirode ali sa karakteristikom diskontinualnosti ili prebrojivosti. Dokumentacija je kombinacija nematerijalne i materijalne prirode, intelektualno ostvarenje, sa informacijama u obliku izrađenih računarskih programa i dokumenata. Usluge su nematerijalne prirode, koje proizvođači pružaju ili poručuju korisnicima Npr. rezultati procesa na primeru automobila za prodaju su: motorno ulje, motor, vozačev priručnik i prodavčeve upute [11].

Kvalitet je nivo do kojeg skup postojećih karakteristika kvaliteta ispunjava zahteve rezultata procesa.Kontrolisanje kvaliteta proverava planirani ili željeni kvalitet rezultata procesa, preko karakteristika kvaliteta, izvesnih bitnih ili zahtevanih obeležja rezultata procesa u postizanju kvaliteta. Razvoj kontrolisanja kvaliteta prema shemi na slici 1. započeo je oko 1920. širom primenom teorijskih raspodela, otkrivanjem statističkog kontrolisanja kvaliteta, prihvatanjem teorije sveukupnog kvaliteta proizvoda, uvođenjem kontrolisanja procesa, kontrolisanjem kvaliteta rezultata procesa, razumevanjem upravljanja kvalitetom, primenom Sistema šest sigma, sve do 1989. i kontrolisanja troškova kvaliteta [3], [8], [14].

Kod nas se kontrolisanje kvaliteta još uvek vrši proverama procenta neispravnosti rezultata proizvoda, neposredno posle neposrednog utvrđivanja ispravnosti a ponekad posredno posle merenja ili ispitivanja karakteristika kvaliteta.Međutim, u Americi se stalno primenjuje kontrolisanje troškova kvaliteta, koje obuhvata proračun troškova ubitaka kvaliteta u svim etapama proizvodnje, u: istraživanju tržišnih potreba, planiranju rezultata procesa, projektovanju, proizvodnji, kontrolisanju, pakovanju, prodaji, servisiranju i održavanju. Zato je veoma bitno da se kod nas, umesto lošeg kontrolisanje kvaliteta proveravanjem procenta neispravnosti rezultata proizvoda uvede bolje kontrolisanje kvalitea rezultata procesa preko troškova kvaliteta.

U ovom saopštenju se zato analiziraju troškovi kontrolisanja kvaliteta rezultata procesa preko troškova kvaliteta u procesu obrade predmeta: bez promene alata, sa periodičnom zamenomalata, primenom boljeg alatai primenom boljeg alata sa dužim intervalom [1], [2], [9], [11].

2. KARAKTERISTIKE KVALITETA

Karakteristike kvaliteta su bitne funkcionalne veličine proizvoda, kvantitativne (quantity) ili kvalitativne (quality), sa neprekidnim (continual) ili prekidnim (discrete) vrednostima. Karakteristike poluproizvoda, proizvoda i dokumentacije su uočljivije jer imaju varijabilne i kontinualne vrednosti, koje se mogu meriti, kontrolisati i ispitivati. Karakteristike usluga se teže uočavaju jer imaju atributivne i diskretne vrednosti, koje se ne mogu meriti, već samo kontrolisati i ispitivati [9],[10]. Opšte karakteristike kvaliteta, su najčešće troškovi neispravnosti, troškovi garancija, indeksi preciznosti i tačnosti procesa kao i procenat neispravnosti, prema shemi u tabeli 2.[6],[15].

1920. god.	Quality control and inspection	(Gauss, J. C. F).
1930. god.	Statistical quality control (SQC)	Shewhart, W.A.
1956. god.	Total quality control (TQC)	Feigenbaum, A. V.
1960. god.	Statistical process control (SPC)	Western Electric Company
1968. god.	Company-wide quality control (CWQC)	Ishikawa, K.
1985. god.	Total Quality Management(TQM)	Evans, J. R. Lindsay, W. M.
1986. god.	Six Sigma 6σ	Motorola
1989. god.	Overall quality system (OQS)	Taguchi, G.

Slika 1. *Razvoj kontrolisanja kvaliteta*

Karakteristike procesa su veličine odstupanja, linearnosti i stabilnosti procesa. Stabilan proces ima varijabilnosti slučajnog karaktera koje nastaju od uobičajenih uzroka pa takav proces treba samo povremeno kontrolisati. Nestabilan procesima varijabilnosti sistematskog karaktera od izvanrednih uzroka pa takav proces treba odmah identifikovati, otkloniti uočene uzroke izmenom elemenata procesa, pratiti i po potrebi kontrolisati. Karakteristike sistema su efektivnost i efikasnost sistema. Efektivnost je nivo realizacije planiranih aktivnosti i postignutih rezultata dok je efikasnost odnos ostvarenih rezultata i korišćenih sredstava.

Opšte karakteristike kvaliteta		
Troškovi neispravnosti	prosečni troškovi neispravnosti, *UMC* [$/kom]	
Troškovi garancija	prosečni troškovi garancija [$/kom]	
Indeksi preciznosti i tačnosti	*PPC=1, PPC=1, PPC>1,*	*PPP=1, PPP=1, PPP>1,*
Neispravnost proizvoda	nepopravljiva i popravljiva neispravnost %	

Karakteristike kvaliteta poluproizvoda, proizvoda i dokumentacije		
Korisnost (Availability)	Zamenjivost (Interchangeability)	Osetljivost (Susceptibility)
Spoljašnost (Appearance)	Održavanje (Maintainability)	Odloživost (Storability)
Prilagodljivost (Adaptability)	Mirisnost (Odour)	Otpornost (Strength)
Savršenost (Cleanliness)	Praktičnost (Operability)	Ukusnost (Taste)
Potrošivost (Consumption)	Prenosivost (Portability)	Ispitljivost (Testability)
Postojanost (Durability)	Proizvodnost (Producibility)	Poreklo (Traceability)
Raspoloživost (Disposability)	Pouzdanost (Reliability)	Otrovnost (Toxicity)
Istaknutost (Emittance)	Popravljivost (Reparability)	Prenosivost (Transportability)
Zapaljivost (Flammability)	Bezbednost (Safety)	Ranjivost (Vulnerability)
Elastičnost (Flexibility)	Sigurnost (Security)	Masivnost (Weight)

Karakteristike kvaliteta usluga		
Pristupačnost (Accessibility)	Uverljivost (Credibility)	Vernost (Honesty)
Tačnost (Accuracy)	Zavisnost (Dependability)	Spremnost (Promptness)
Učtivost (Courtesy)	Efikasnost (Efficiency)	Odgovornost (Responsiveness)
Udobnost (Comfort)	Efektivnost (Effectiveness)	Pouzdanost (Reliability)
Nadležnost (Competence)	Prilagodljivost (Flexibility)	Sigurnost (Security)

Slika 2. *Karakteristike kvaliteta rezultata procesa*

U izradi i obradi proizvoda bitne funkcionalne veličine su kritične dimenzije, koje ostvaruju alati, obično dimenzije otvora, dobijene rotacionim reznim alatima (burgije, proširivači, upuštači, razvrtači, ureznici, profilni alati, itd.).Proveravanje karakteristika kvaliteta vrši se merenjem (mernim instrumentom), kontrolisanjem (kontrolnikom) ili ispitivanjem (po izvesnom postupku). U Americi se najčešće prate i izračunavaju prosečni troškovi neispravnosti jer oni smatraju da je procenat neispravnosti loš pokazatelj kvaliteta i da to nije kvalitet za korisnika već trošak isporučioca. Osim toga oni tvrde da su indeks preciznosti *PPC* i tačnosti procesa *PPP*

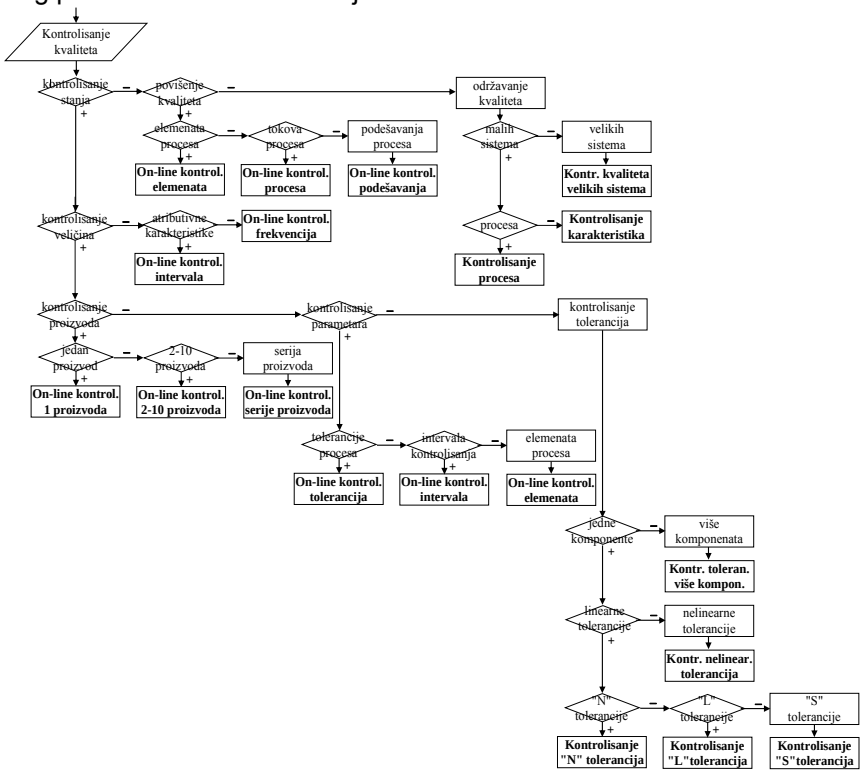
neprikladni i teško razumljivi za primenu. Pored toga troškovi garancija se kasno utvrđuju i dok se oni promene izgubi se tržište.

3. TROŠKOVI KVALITETA

Kod nas se kontrolisanje kvalitetaobavlja pasivno, preko uzoraka ili bez uzoraka (100 %), pri čemu su oba neprikladna jer se vrše kasno, kada su proizvodi već izrađeni. Kada se utvrdi neispravnost tek tada se proces prekida, vrši analiziranje i neophodno podešavanje procesa, zamenom nekog elementa proizvodnog procesa, pri čemu se pojavljuju nepopravljivi i popravljivi primerci.

U Americi se danas primenjuje kontrolisanje ukupnog kvaliteta (overall quality system, OQS), koji obuhvata proračun gubitaka kvaliteta u svim etapama proizvodnje, u: istraživanju tržišnih potreba, planiranju rezultata procesa, projektovanju, proizvodnji, kontrolisanju, pakovanju, prodaji, servisiranju i održavanju [2],[9]. Primenjuje se automatsko (on-line) kontrolisanje,kontrolisanje stanja kvaliteta, kontrolisanja veličina i kontrolisanja proizvoda, prema shemi na slici 3, sa aktivnim, trenutnim merenjem ili kontrolisanjem veličine karakteristika kvaliteta, sa: povratnim informacijama (feedback control) u toku samog procesa proizvodnje, podešavanjem (feed-forward control) i stabilisanjem procesa (calibration) [4],[10],[13].

Podešavanje procesa uključuje neophodnu promenu parametara procesa, radi sprečavanja pojava dalje meispravnosti. Naravno, primena automatskog kontrolisanja je skupa, zbog potrebnih elektronskih senzora i računara, pa treba utvrditi ekonomučnost njegovog uvođenja.Stabilisanje procesa omogućava održavanje podešenog procesa u stabilnom stanju.



Slika 3. *Postupci automatskog kontrolisanja kvaliteta*

Kontrolisanje stanja kvaliteta sadrži proveravanje povišenja kvaliteta, na elemenatima procesa, u tokovima procesa i u podešavanju parametara procesa. Kontrolisanje veličina obuhvata varijabilne i atributivne karakteristike. Kontrolisanje veličina sa atributivnim karakteristikama omogućava određivanje intervala (broj ispravnih proizvoda do popravke procesa) ili frekvencije kontrolisanja (broj proizvoda između uzastopnih kontrolisanja). Kontrolisanje veličina sa varijabilnim karakteristikama omogućava proveravanje ispravnosti proizvoda, parametara procesa i proveravanje tolerancija. Kontrolisanje ukupnog kvaliteta proizvodnje se zasniva na proračunu troškova kontrolisanja i popravki C_T (total cost of diagnosis and adjustment). Kontrolisanje ukupnog kvaliteta sa varijabilnim karakteristikama je lakše jer se gubici kvaliteta dobijaju na osnovu odstupanja od granica tolerancije [1],[7].

Izračunavanje prosečnih troškova kvaliteta omogućava povišenje kvaliteta putem promene ili zamene alata, primenom determinističkih ili stohastičkih postupaka. Deterministički postupci pretpostavljaju da je sa sigurnošću poznato vreme za promenu alata (zbog pohabanosti) ili za zamenu alata (zbog loma ili zamene s drugim dugovečnijim alatom.Stohastički postupci pretpostavljaju da vreme zamene alata zavisi od verovatnoće, koja se može odrediti pomoću statističke raspodele slučajne promenljive otkaza. Iako postoje realne mogućnosti za utvrđivanje raspodela otkaza, ovde će se razmatratisamo deterministički postupak.

4. TROŠKOVI KVALITETA OBRADE BEZ PROMENE ALATA

Troškove kvaliteta u svim etapama proizvodnje (u istraživanju tržišnih potreba, planiranju rezultata procesa, projektovanju, proizvodnji, kontrolisanju, pakovanju, prodaji, servisiranju i održavanju)određuju sledeći troškovi[1]:

- c_C(cost of checking and recovering), prosečni troškovi kontrolisanja sa ukupnim troškovima kontrolisanja (C_C) i intervalom uzastopnih kontrolisanja (n),
- c_D(cost of downgrading or discarding), prosečni troškovi neispravnih proizvoda sa prosečnim brojem neispravnih $(n+1)/2$, ukupnim troškovima neispravnih proizvoda (C_D) i brojem proizvoda između podešavanja (n_A),
- c_A(cost of adjusting, repairing and reworking), prosečni troškovi podešavanja procesa sa ukupnim troškovima podešavanja (C_A) i brojem proizvoda (n_A), kao i
- c_L(cost of lose caused by time lag), prosečni troškovi zbog propuštenih proizvoda u kontrolisanju sa brojem propuštenih proizvoda (n_L), ukupnim troškovima (C_D) i brojem proizvoda (n_A).

Optimalni interval kontrolisanja kod viših troškova neispravnosti, kada su $c_D >> c_A/n_A$ odnosno $n_L \leq n_A$, iznosi:

$$n_{OPT} = \sqrt{\frac{2c_C(n_A+n_L)}{c_D-\frac{c_A}{n_A}}} \text{kom} . \quad (1)$$

Ukupna suma svih prosečnih troškova kontrolisanja, bez promene alata u toku procesa, sa optimalnim intervalom kontrolisanja,omogućava izračunavanje sledećih optimalnih troškova kontrolisanja proizvoda, za karakteristiku kvaliteta (x)[7]:

$$c(\bar{x}) = \frac{c_C}{n_{OPT}} + \frac{n_{OPT}+1}{2}\frac{c_D}{n_A} + \frac{c_A}{n_A} + \frac{n_L \cdot c_D}{n_A} . \quad (2)$$

Npr. posmatrajmo obradu razvrtanja otvora na blokovima motora, u količini od 3.000 kom mesečno, sa troškovima intervalnih kontrolisanja od 4 $/kom,troškovima podešavanja 150 $, prosečnim brojem proizvoda 2.500 kom između sukcesivnih

podešavanja kada se menjaju svi alati.sa brojem propuštenih proizvoda 1 kom tokom vremena kontrolisanja i troškovi neispravnog neispravnog bloka motora od 60 $/kom, koji uzrokuje samo jedan neispravno obrađen otvor. Koristeći date vrednosti: N= 3.000 kom/mes, c_C= 4 $/kom, c_A= 150 $, n_A= 2.500 kom, n_L= 1 kom i c_D= 60 $/kom, prema formulama (1) i (2) dobijajaju se: optimalni interval kontrolisanja, kod (60>>(150/2.500); (1≤ 2.500) i troškovi kontrolisanja:

$$n_{OPT}=\sqrt{\frac{2\cdot4\cdot(2.500+1)^2}{60-\frac{150}{2.500}}}=18{,}27\approx 18\ \text{kom},$$

$$o(x)=\frac{4}{18}+\frac{18+1}{2}\cdot\frac{60}{2.500}+\frac{150}{2.500}+\frac{1\cdot60}{2.500}=0{,}534\$/\text{kom},$$

pa su ukupni mesečni troškovi kontrolisanja: 0,534$/kom 3.000kom/mesečno=1602$/mesečno.

5. TROŠKOVI KVALITETA OBRADE SA PERIODIČNOM PROMENOM ALATA

Periodična promena alata, u kraćim intervalima kontrolisanja, omogućava smanjenje prosečnog broja otkaza ali istovremeno povećava: prosečne troškove kontrolisanja, prosečne troškove alata, prosečne troškove radnika i prosečne troškove zbog češćeg prekida procesa.Ako se uvede periodična promena alata, u kraćim intervalima kontrolisanja, na svakih (n'_A) proizvoda, onda će se dobiti i manji broj neispravnih proizvoda sa verovatnoćom (p). Tada se može izračunati broj sukcesivnih podešavanja prema sledećoj formuli[1]:

$$n_A=\frac{n'_A}{p}. \qquad (3)$$

Npr. u posmatranju obrade razvrtanja otvora na blokovima motora, u količini od 3.000 kom mesečno, sa prosečnim brojem proizvoda od 1.500 kom, zbog periodične promene alata između sukcesivnih podešavanja, umesto ranijih 2.500 kom. Sada će se postići smanjenje prosečnog broja neispravnih proizvoda, sa verovatnoćom 0,02 pa će sedobitii veći prosečan interval između otkaza.Koristeći date vrednosti: N= 3.000 kom/mes, c_C= 4 $/kom, c_A= 150 $, n'_A= 1.500 kom, p= 0,02, n_L= 1 kom,c_D= 60 $/kom i p= 0,02, sada se dobijaju: broj proizvoda između podešavanja, optimalni interval kontrolisanja proizvoda kod (60)>>(150/2.500); (1≤ 2.500) kao i prosečni troškovi kontrolisanja, prema formulama (3), (1) i (2):

$$n_A=\frac{1.500}{0{,}02}=75.000\ \text{kom},$$

$$n_{OPT}=\sqrt{\frac{2\cdot4\cdot(75.000+1)^2}{60-\frac{150}{75.000}}}\approx100\ \text{kom},$$

$$o(x)=\frac{150}{1.500}+\frac{4}{100}\cdot\frac{100+1}{2}+\frac{60}{75.000}+\frac{1\cdot60}{75.000}=0{,}183\$/\text{kom},$$

pa se sada dobijaju daleko manji ukupni mesečni troškovi kontrolisanja: 0,183 $/kom 3.000 kom/mes= 549$/mes, sa uštedom od 1.602549= 1.053 $. Dakle, može se zaključiti, radi povišenja kvaliteta proizvoda,da umesto procesa bez promene alata, treba primeniti periodičnu promenu alata[5],[17].

6. TROŠKOVI KVALITETA OBRADE PRIMENOM BOLJEG ALATA

Ako se primenjuje bolji alat, drugačije konstrukcije alat ili materijala, sa dužom postojanošću, onda se postižu manji troškovi.

Npr. posmatrajmo obradu proizvoda u količini od 8.500 kom mesečno, s nabavnom cenom boljeg alata od 1.200 $, s troškovima intervalnih kontrolisanja od 1,5 $/kom i troškovima podešavanja od 250 $/kom, uz 2 podešavanja mesečno, s troškovima podešavanja alata od 980 $, s prosečnim brojem proizvoda između sukcesivnih podešavanja 4.250 kom, sbrojem propuštenih proizvoda 4 kom, s troškovima popravljivih neispravnosti od 6 $/kom (uz verovatnoću 0,8) i sa troškovima nepopravljivih neispravnosti od 50 $/kom (uz verovatnoću 0,2).

Koristeći date vrednosti: N= 8.500 kom/mes, c_C= 1,5 $/kom, n_A= 8.500/2= 4.250 kom, n_L= 4 kom, c_D= 0,2·6 $/kom+0,8·50 $/kom= 41,2 $/kom, sa troškovima podešavanja c_A= 980+(1.200250)= 1930 $, uz optimalni interval kontrolisanja kod(41,2)>>(1.930/4.250); (1≤ 4.250) dobijaju se: troškovi kontrolisanja prema formulama (1) i (2):

$$n_{OPT}=\sqrt{\frac{2\cdot 1{,}5\cdot 4.250\cdot 41}{41{,}2-\frac{1.930}{4.250}}}=17{,}6\approx 18\ \text{kom},$$

$$c(x)=\frac{1{,}5}{18}+\frac{18+1}{2}\cdot\frac{41{,}2}{4.250}+\frac{980}{4.250}+\frac{4\cdot 41{,}2}{4.250}=0{,}444\$/\text{kom},$$

odnosno ukupni mesečni troškovi kontrolisanja: 0,444 $/kom 8.500 kom/mes= 3.774 $/mes.Ako se postojeći alat zameni sa boljim alatom tada će troškovi podešavanja procesa (c_A) biti veći zbog nabavne ceneboljeg alata pa zbog $c_D<c_A/n_A$; $n_L \le n_A$treba koristiti sledeću formulu za optimalni interval kontrolisanja:

$$n_{OPT}=\sqrt{\frac{2c_Cn_A}{c_D}}. \qquad (5)$$

pa se sada dobijaju prosečni troškovi kontrolisanja, prema datim formulama (3), (5) i (2):

$$c(x)=\frac{c_C}{\sqrt{\frac{2c_Cn_A}{c_D}}}+\frac{\sqrt{\frac{2c_Cn_A}{c_D}}+1}{2}\cdot\frac{c_D}{n_A}+\frac{c_A}{n_A}+\frac{n_Lc_D}{n_A}=\sqrt{\frac{2c_Dc_C}{n_A}}+\frac{\frac{c_D}{2}+c_A+n_Lc_D}{n_A}.$$

Ako postojeći alat zamenimo sa boljimalatom tada se dobijaju veći troškovi podešavanja c_A= 980+(1.200250)= 1930 $ pa se troškovi kontrolisanja mogu izraziti sa brojem proizvoda između podešavanja (n_A),pomoću formula (4) i (5):

$$c(x)=\sqrt{\frac{2\cdot 41{,}2\cdot 1{,}5}{n_A}}+\frac{\frac{41{,}2}{2}+1.930+4\cdot 41{,}2}{n_A}=\sqrt{\frac{123{,}6}{n_A}}+\frac{2115{,}4}{n_A}.$$

Zamena boljim alatom uvek treba da ima niže troškove kontrolisanja od postojećeg alata,čiji su prosečni troškovi kontrolisanja $c(x)$= 0,444 $/kom. Zato se novi interval kontrolisanja može izračunati iz sledeće nejednačine:

$$\sqrt{\frac{123{,}6}{n_A}}+\frac{2115{,}4}{n_A}\le 0{,}444\ ,0{,}444\sqrt{\frac{123{,}6}{n_A}}+\frac{2115{,}4}{n_A}\ge 0\ ,$$

$$0{,}444n_An_A\sqrt{\frac{123{,}6}{n_A}}+n_A\frac{2115{,}4}{n_A}\ge 0\ ,\ 0{,}444n_An_A\sqrt{\frac{123{,}6}{n_A}}\ 2115{,}4\ge 0\ ,$$

odakle se posle zamene$x=\sqrt{n_A}$ odnosno $x^2=n_A$ dobija jednačina:

$$0{,}444\ x^2x^2\sqrt{\frac{123{,}6}{x^2}}\ 2115{,}4=0\ ,0{,}444x^2x\sqrt{123{,}6}\ 2115{,}4=0\ .$$

sa rešenjima ove kvadratne jednačine:

$x_{1,2}=\frac{-(-\sqrt{123,6})\pm\sqrt{123,6+4\cdot0,444\cdot61,8,4}}{2\cdot0,444}$, x_1= 82,65 i x_2=57,63 .

Kako broj proizvoda mora biti pozitivan dobija se vrednost *x*= 82,65kom pa je postojanost boljeg alata, odnosno broj proizvoda između uzastopnih podešavanja,sada mnogo veći $n_A= x^2$= 82,65^2= 6.831 kom a odnos nove i postojeće postojanosti alata je 6.831 kom/4.250 kom= 1,607, s gotovo dvostruko većom postojanošću alata.Ako je prosečna postojanost boljeg alata dvostruko veća onda je broj proizvoda između sukcesivnih podešavanja je 4250 kom·2= 8500 kom pa se dobijaju: novi optimalni interval kontrolisanja. zbog (41,2) >> (1.930/6.960); (1≤ 6.960). i novi troškovi kontrolisanja, prema formulama (1) i (2):

$$n_{OPT}=\sqrt{\frac{2\cdot1,8\cdot8.500+40}{41,2-\frac{1.930}{8.500}}}=24,95\approx25\ \text{kom.}$$

$$c(x)=\frac{1,8}{18}+\frac{25+1}{2}\cdot\frac{41,2}{8.500}+\frac{1.930}{8.500}+\frac{441,2}{8.500}=0,369\ .$$

Dakle, primena novog boljeg alata, sa dužom postojanošću, omogućava da se sada sa dužim intervalom kontrolisanja od n_A= 6906 kom postignu niži troškovi kontrolisanja od *c(x)*= 0,37 $/kom, čime se postižu daleko manji ukupni mesečni troškovi kontrolisanja: 0,369$/kom8.500 kom/mes= 3.136$/mes ,sa uštedom od 3.774 3.136= 629 $, pa radi povišenja kvaliteta proizvoda svakako treba zameniti postojeći alat sa novim boljim alatom.

7. TROŠKOVI KVALITETA OBRADE PRIMENOM BOLJEG ALATA SA DUŽIM INTERVALOM

Dalje povišenje kvaliteta proizvoda, pored primene novog boljeg alata sa dužom postojanošću, može se postići produženjem vremenskih intervala između uzastopnih podešavanja (n_A), jer će se tada verovatno povećati verovatnoća popravljivih neispravnosti sa 0,8 na 0,9i smanjiti verovatnoća nepopravljive neispravnosti sa 0,2 na 0,1.

Npr. posmatrajmo obradu proizvoda, s dobijenim vrednostima: *N*= 8.500 kom/mes, c_C= 1,5 $/kom, n_A= 8.500/0,1= 85.000kom, n_L= 4 kom, c_D= 0,16 $/kom+0,9·50 $/kom= 45,6 $/kom i s troškovima podešavanja c_A= 980+(1.200250)= 1930 $kako bi se sada dobio optimalni interval kontrolisanja zbog (45,6)>>(1.930/85.000); (1≤ 85.000) i optimalni troškovi kontrolisanja prema formulama (1) i (2):

$$n_{OPT}=\sqrt{\frac{2\cdot1,8\cdot85.000+40}{41,2-\frac{1.930}{85.000}}}=78,69\approx79\ \text{kom.}$$

$$c(x)=\frac{1.930}{8.500}+\frac{1,8}{79}+\frac{79+1}{2}\cdot\frac{41,2}{85.000}+\frac{1.930}{85.000}+\frac{441,2}{85.000}=0,289\$/\text{kom.}$$

pa se primenom novog boljeg alata sa dužim intervalom kontrolisanja od n_A= 85.000 kom dobijaju niže troškove kontrolisanja, čime se postižu još manji ukupni mesečni troškovi kontrolisanja: 0,289$/kom 8.500 kom/mes= 2.465 $/mes ,sa većom uštedom od 3.774 2.465= 1.309 $, pa radi daljeg povišenja kvaliteta proizvoda svakako treba zameniti postojeći alat sa novim boljim alatom i dužim intervalom kontrolisanja.

Dakle, troškovi sa periodičnom promenom alata su mnogo veći nego što sa kombinacijom boljeg alata i dužeg intervala podešavanja procesa pa treba analizirati i druge načine za smanjenje prekomerne periodične promene alata.

8. ZAKLJUČAK

Povišenje kvaliteta rezultata procesa (poluproizvoda, proizvoda, dokumentacije, usluge) uvek zahteva promenu postojeće karakteristike kvaliteta. Najvažniji su troškovi neispravnosti, koji obuhvataju izračunavanje prosečnih troškova neispravnosti, koji se u Americi uglavnom prate, jer oni smatraju da je procenat neispravnosti loš pokazatelj kvaliteta jer nije nikakav pokazatelj kvaliteta za korisnika već samo trošak isporučioca. Deterministički postupci pretpostavljaju da je sa sigurnošću poznato vreme za promenu alata (zbog pohabanosti) ili za zamenu alata (zbog loma ili zamene s dugovečnijim alatom).

Utvrđeno je da su najviši troškova neispravnosti u procesima bez promene alata. Radi povišenja kvaliteta proizvoda treba primeniti periodičnu promenu alata koja omogućava duži interval kontrolisanja. Dalje povišenja kvaliteta proizvoda se postiže uz primenu novog boljeg alata, dok se najniži troškovi kontrolisanja postižu uz primena novog boljeg alata, sa kao i dužim intervalom kontrolisanja.

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RAZLIKE U STAVOVIMA O KORPORATIVNOJ ODGOVORNOSTI PREDUZEĆA PREMA ŠIROJ DRUŠTVENOJ ZAJEDNICI U ODNOSU NA VRSTU OBRAZOVANJA ZAPOSLENIH

Tatjana Savić-Šikoparija[1], Ljubica Duđak[2], Tamara Kliček[3]

Rezime: Prihvatanjem i implementacijom koncepta korporativne odgovornosti, preduzeća mogu generisati odgovornije ponašanje i odgovorniji način života ljudi, kao i unaprediti društvenu i životnu zajednicu u kojoj posluju. Da bi se koncept korporativne odgovornosti prema široj društvenoj zajednici implementirao u strategiju preduzeća, neophodno je dići svest zaposlenih o značaju korporativne odgovornosti i obezbediti razumevanje motiva i ciljeva koje preduzeće korporativno odgovornim aktivnostima prema široj društvenoj zajednici želi postići. U ovom radu su istražene razlike u stavovima zaposlenih o korporativnoj odgovornosti preduzeća prema široj društvenoj zajednici u odnosu na vrstu obrazovanja zaposlenih. Analiza rezultata istraživanja je pokazala da postoje značajne razlike u stavovima zaposlenih o korporativnoj odgovornosti preduzeća prema široj društvenoj zajednici u odnosu na vrstu obrazovanja zaposlenih.

Ključne reči: korporativna odgovornost, preduzeće, šira društvena zajednica, vrsta obrazovanja.

THE DIFFERENCES IN ATTITUDES REGARDING CORPORATE RESPONSIBILITY OF THE COMPANY TOWARDS THE WIDER SOCIAL COMMUNITY IN RELATION TO THE TYPE OF THE EMPLOYEES EDUCATION

Abstract: By implementing and accepting the concept of the corporate responsibility, the companies are able to generate more responsible behavior and more responsible lifestyle of people, as well as to improve social structure and life of community where company is residing. In order to implement the concept of corporate responsibility towards the wider social community into the strategy of the company, it is necessary to raise employee's awareness about the importance of corporate responsibility and to provide an understanding of the motives and goals that the company wants to achieve as a result of implementation of the corporate responsible activities for the wider social community.

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This Study explored the differences in attitudes of the employees regarding corporate responsibility of the company towards the wider social community in relation to the type of the employees education. Analysis of the research results showed that, in regard to the type of the employees education, there are significant differences in attitudes of the employees to the corporate responsibility of the company towards the wider social community.

Key words: corporate responsibility, company, type of education, wider social community.

1 UVOD

Korporativna društvena odgovornost je u savremenoj poslovnoj praksi često korišćen koncept, s obzirom na to da kompanije u značajnoj meri snose odgovornost za dešavanja i aktivnosti od šireg društvenog značaja [1]. U nastojanju da doprinesu rešavanju problema društvene zajednice u kojoj obavljaju svoju poslovnu aktivnost, kompanije sprovode različite korporativne društvene inicijative [2]. Stvaranje dobrog imidža, koji u savremenom poslovanju predstavlja jedan od najvažnijih resursa organizacije u direktnoj je vezi sa načinom na koji ona posluje, pri čemu istraživanje i praksa potvrđuju da su one organizacije koje su inkorporirale načela korporativne odgovornosti u svoju poslovnu filozofiju sposobne da ostvare bolje rezultate i obezbede stabilniji i dugoročniji rast [1]. Aktiviranjem korporativne društvene odgovornosti (CSR), kompanije ne samo da mogu generisati povoljne stavove zainteresovanih strana i bolje i odgovornije ponašanje nego i izgraditi bolji korporativni imidž i ojačati odnose sa zainteresovanim stranama. Međutim, niska svest zainteresovanih strana i nepovoljni stavovi zainteresovanih strana prema društvenim aktivnostima korporativno odgovornog poslovanja ostaju kritične prepreke u poslovnim društvima, kao i pokušaji da preduzeća maksimiziraju poslovne koristi od svojih CSR aktivnosti. Sve to ukazuje na potrebu da kompanije efikasnije predstave ciljeve i motive svojih CSR aktivnosti svojim zaposlenim i tako kvalitetnije implementiraju CSR koncept u svoje strategije.

Mnoge kompanije koje su zaista posvećene naporima u sprovođenju korporativne odgovornosti često ne uspevaju da svoje aktivnosti sprovode efikasno. Korporacije treba pažljivo da razvijaju svoje planove CSR komunikacije koja treba da pruži konzistentne informacije i zadovolji očekivanja svake od zainteresovanih strana i na kraju izgradi poverenje javnosti kako bi izbegle javni skepticizam o korporativnoj odgovornosti i izgradile poverenje. Menadžeri moraju da dublje razumeju ključna pitanja u vezi sa CSR komunikacijom i prenesu ih svojim zaposlenima kako bi kod zaposlenih razvili povoljne stavove o korporativnoj odgovornosti i na taj način obezbedili uspešnost svojih CSR aktivnosti.

Dimenzije kroz koje se najčešće posmatra korporativna odgovornost preduzeća su: korporativna odgovornost prema zaposlenima, korporativna odgovornost prema tržištu, korporativna odgovornost prema široj društvenoj zajednici i korporativna odgovornost prema životnoj sredini.

Korporativna odgovornost je tema mnogih istraživanja i naučnih radova, ali su malo istraživane razlike u stavovima o korporativnoj odgovornosti preduzeća prema široj društvenoj zajednici u odnosu na vrstu obrazovanja zaposlenih. Polazeći od te pretpostavke, ovaj rad ima za cilj da analizira razlike u stavovima o korporativnoj odgovornosti preduzeća prema široj društvenoj zajednici u odnosu na vrstu obrazovanja zaposlenih od kojih će i zavisiti prihvatanje i implementacija koncepta korporativne odgovornosti prema široj društvenoj zajednici u preduzeću.

2 METODOLOGIJA ISTRAŽIVANJA

2.1 Hipoteza istraživanja

Hipoteza istraživanja glasi: Postoji razlika u stavovima o korporativnoj odgovornosti (KO) preduzeća prema široj društvenoj zajednici u odnosu na vrstu obrazovanja ispitanika.

2.2 Cilj istraživanja

Teorijski cilj istraživanja je usmeren na unapređenje teorijskih znanja i pristupa koji proučavaju korporativne odgovornosti preduzeća prema široj društvenoj zajednici. Praktični ciljevi istraživanja su usmereni na određivanje razlika u stavovima o korporativnoj odgovornosti prema široj društvenoj zajednici u odnosu na vrstu obrazovanja, na osnovu čega će se obezbediti razumevanje i prihvatanje korporativne odgovornosti prema široj društvenoj zajednici za zaposlene različitih vrsta obrazovanja i veća posvećenost aktivnostima korporativne odgovornosti prema široj društvenoj zajednici od strane zaposlenih i uspešnost primene koncepta korporativne odgovornosti preduzeća prema široj društvenoj zajednici, što kao rezultat za preduzeće ima uspešnije poslovanje, a za zaposlene i širu društvenu zajednicu, kvalitetniji život.

2.3 Istrument istraživanja

Prilikom istraživanja korišćena je metoda ispitivanja reprezentativnog uzorka anketiranjem. Upitnik se sastojao od zatvorenog tipa pitanja kod kojih je ispitanik birao jednu ili više ponuđenih alternativa odgovora, onu koja najviše odgovara njegovom konkretnom stavu i mišljenju. Korišćeni upitnik, kao osnovni instrument ankete, koncipiran je namenski za potrebe istraživanja, a u skladu sa ciljevima i hipotezom rada. Ispitivanje je obavljeno direktno, što znači da su ispitanici bili unapred obavešteni o činjenici da se podvrgavaju ispitivanju, ali nisu detaljno obavešteni o temi i ciljevima ispitivanja, kako bi se izbegli socijalno poželjni odgovori.

2.4 Uzorak istraživanja

S'obzirom na definisane hipoteze i ciljeve empirijskog istraživanja, uzorak je izabran tako da u njemu budu zastupljeni menadžeri višeg i srednjeg nivoa iz organizacija javnog sistema Vojvodine, koje pripadaju različitim granama.
Uzorak je prigodno sačinjen od ukupno 153 ispitanika, od toga 80 žena i 73 muškaraca.
U tabelama 1, 2, 3 i 4 je prikazana brojčano (n) i procentualno (%) polna, obrazovna struktura po nivou i vrsti obrazovanja ispitanika.

Tabela 1. *Polna struktura ispitanika*

	muški	ženski
n	73	80
%	47.71	52.29

Tabela 2. *Starosna struktura ispitanika*

	do 25 godina	26-35 godina	36-45 godina	46-55 godina	iznad 56 godina
n	6	33	55	54	5
%	3.92	21.57	35.95	35.29	3.27

Tabela 3. *Obrazovna struktura ispitanika - nivo obrazovanja*

	VŠS	VSS	magistar	dr
n	18	92	28	15
%	11.76	60.13	18.30	9.80

Tabela 4. *Obrazovna struktura ispitanika - vrsta obrazovanja*

	tehničko-tehnološke struke	društveno-humanističke struke	prirodno-matematičke struke	ostale struke
n	67	46	20	20
%	43.79	30.07	13.07	13.07

3 REZULTATI ISTRAŽIVANJA

Analiza je urađena na stavovima ispitanika o korporativnoj odgovornosti (KO) prema široj društvenoj zajednici u odnosu na vrstu obrazovanja na uzorku od 153 ispitanika, koji čine 4 subuzorka i to: tehničko-tehnološke struke (67), društveno-humanističke struke (46), prirodno-matematičke struke (20) i ostalo (20). Analiza je sprovedena na stavovima o korporativnoj odgovornosti (KO) prema široj društvenoj zajednici i to: organizacija je definisala društvene ciljeve, društveni cilj treba da odgovara misiji i vrednostima preduzeća, organizacija ima zajedničke korporativno odgovorne inicijative sa drugim organizacijama, organizacija ulaže u obrazovanje i stipendiranje đaka i studenata, organizacija pruža mladima mogućnosti za stažiranje i volontiranje, zastupljen je volonterski rad zaposlenih u zajednici, moguće je meriti uticaj organizacije na društvenu zajednicu i životnu sredinu, donacije organizacije su vidljive u društvenoj zajednici, postoji saradnja organizacije sa nevladinim organizacijama na zajedničkim projektima, organizacija promoviše ličnu odgovornost i društveni angažman, prisutni su inventivni i održivi oblici ulaganja u zajednicu i preduzeće investira u razvoj lokalne zajednice u skladu sa korporativom odgovornošću.

Svaki stav ima 5 modaliteta: *Ne slažem se, Delimično se ne slažem, Nisam siguran/na, ne znam, Delimično se slažem i Slažem se.*

Na osnovu vrednosti p=.000 (analize MANOVA) i p=.000 (diskriminativne analize), zaključuje *se da postoji razlika i jasno definisana granica između vrsta obrazovanja ispitanika u odnosu na stavove o korporativnoj odgovornosti (KO) prema široj društvenoj zajednici (tabela 5.).*

Tabela 5. *Značajnost razlike između tipova obrazovanja ispitanika u odnosu na stavove o korporativnoj odgovornosti (KO) prema široj društvenoj zajednici*

analiza	n	F	p
MANOVA	12	7.984	.000
diskriminativna	12	15477.620	.000

U tabeli 6. će biti prikazano postojanje značajnosti razlike između nekih vrsta obrazovanja ispitanika po određenim stavovima ispitanika, kao i informacije o doprinosu diskriminaciji između tipova obrazovanja ispitanika u odnosu na stavove o

korporativnoj odgovornosti (KO) prema široj društvenoj zajednici, odnosno biće prikazane značajnost razlike za pojedine stavove.

Tabela 6. *Značajnost razlike između tipova obrazovanja ispitanika u odnosu na stavove o korporativnoj odgovornosti (KO) prema široj društvenoj zajednici*

	χ	R	F	p	k.dsk
organizacija definisala društvene ciljeve	.450	.408	9.935	.000	.207
društveni cilj treba da odgovara misiji i vrednostima preduzeća	.496	.478	14.725	.000	.514
zajedničke korporativno odgovorne inicijative sa drugim organizacijama	.510	.435	11.595	.000	.538
obrazovanje i stipendiranje đaka i studenata	.489	.416	10.372	.000	.080
pružanje mladima mogućnosti za stažiranje i volontiranje	.445	.429	11.211	.000	.067
volonterski rad zaposlenih u zajednici	.465	.518	18.243	.000	.325
mogućnost merenja uticaja na društvenu zajednicu i životnu sredinu	.446	.449	12.519	.000	.054
donacije vidljive u društvenoj zajednici	.409	.379	8.311	.000	.170
saradnja sa nevladinim organizacijama na zajedničkim projektima	.441	.329	6.022	.001	.068
preduzeće promoviše ličnu odgovornost i društveni angažman	.504	.504	16.895	.000	.553
prisutni su inventivni i održivi oblici ulaganja u zajednicu	.513	.549	21.404	.000	.068
preduzeće investira u razvoj lokalne zajednice u skladu sa KO	.469	.439	11.855	.000	.064

Legenda: k.dsk je koeficijent diskriminacije

Pošto je *p <.1 prihvata se postavljena hipoteza*, što ukazuje na *postojanje značajne razlike između vrsta obrazovanja ispitanika.* Koeficijenat diskriminacije daje informaciju kod kojih stavova je najveći doprinos diskriminaciji između tipova obrazovanja ispitanika u odnosu na stavove o korporativnoj odgovornosti (KO) prema široj društvenoj zajednici.

U tabeli 7. će biti prikazane karakteristike i homogenost za vrste obrazovanja ispitanika u odnosu na stavove o korporativnoj odgovornosti (KO) prema široj društvenoj zajednici.

Tabela 7. *Karakteristike i homogenost za vrste obrazovanja ispitanika u odnosu na stavove o korporativnoj odgovornosti (KO) prema široj društvenoj zajednici*

	tehničko-tehnološke struke	društveno-humanističke struke	prirodno-matematičke struke	ostalo	dpr %
preduzeće promoviše ličnu odgovornost i društveni angažman	Nisam siguran/na, ne znam"	Slažem se	Ne slažem se, Delimično se neslažem	Nisam siguran/na, ne znam, Slažem se, Delimično se ne slažem	20.421
zajedničke korporativno odgovorne inicijative sa drugim organizacijama	Ne slažem se, Delimično se slažem	Slažem se, Nisam siguran/na, ne znam"	Nisam siguran/na, ne znam*	Delimično se slažem, Slažem se	19.867
društveni cilj treba da odgovara misiji i vrednostima preduzeća	Nisam siguran/na, ne znam, Delimično se slažem	Delimično se slažem, Slažem se	Delimično se ne slažem, Slažem se	-	18.981
volonterski rad zaposlenih u zajednici	Nisam siguran/na, ne znam, Ne slažem se	Slažem se	Ne slažem se, Nisam siguran/na, ne znam"	Slažem se	12.001
organizacija definisala društvene ciljeve	Nisam siguran/na, ne znam*	Slažem se	Delimično se slažem	Delimično se ne slažem, Slažem se	7.644
donacije vidljive u društvenoj zajednici	Ne slažem se, Delimično se neslažem	Slažem se	Ne slažem se, Delimično se ne slažem	Delimično se slažem, Slažem se	6.278
obrazovanje i stipendiranje đaka i studenata	Delimično se ne slažem, Delimično se slažem	Slažem se	Ne slažem se	Nisam siguran/na, ne znam, Delimično se slažem, Slažem se	2.954
prisutni su inventivni i održivi oblici ulaganja u zajednicu	Ne slažem se, Nisam siguran/na, ne znam, Delimično se slažem	Delimično se slažem, Delimično se neslažem,Slažem se	Ne slažem se	Delimično se ne slažem, Nisam siguran/na, ne znam, Slažem se	2.511
saradnja sa nevladinim organizacijama na zajedničkim projektima	Ne slažem se	Slažem se	Delimično se slažem, Ne slažem se	Slažem se	2.511
pružanje mladima mogućnosti za stažiranje i volontiranje	Ne slažem se	Slažem se	Delimično se slažem, Slažem se	-	2.474
preduzeće investira u razvoj lokalne zajednice u skladu sa KO	Delimično se ne slažem, Nisam siguran/na, ne znam, Ne slažem se	Delimično se neslažem,Slažem se	Ne slažem se, Delimično se slažem	Slažem se, Delimično se slažem	2.363
mogućnost merenja uticaja na društvenu zajednicu i životnu sredinu	Delimično se slažem, Ne slažem se	Nisam siguran/na, ne znam, Slažem se	Ne slažem se, Delimično se ne slažem, Delimično se slažem	Slažem se	1.994

n/m	46/67	33/46	20/20	20/20	
%	68.66	71.74	100.00	100.00	

hmg - homogenost; dpr % - doprinos obeležja karakteristikama

Na osnovu stavova ispitanika o korporativnoj odgovornosti (KO) prema široj društvenoj zajednici može se reći da:

- zaposleni *tehničko-tehnološke struke* ne prepoznaju postojanje zajedničkih korporativno odgovornih inicijativa sa drugim organizacijama, nemaju stav o tome da li društveni cilj treba da odgovara misiji i vrednostima preduzeća, kao i o tome da li preduzeće definisalo društvene ciljeve, smatraju da donacije nisu vidljive u društvenoj zajednici, za razliku od obrazovanja i stipendiranje đaka i studenata za koje smatraju da je prisutno. Oni smatraju da nisu prisutni inventivni i održivi oblici ulaganja u zajednicu, kao ni saradnja sa nevladinim organizacijama na zajedničkim projektima.
- zaposleni *društveno-humanističke struke* imaju stav da preduzeće promoviše ličnu odgovornost i društveni angažman, da postoje zajedničke korporativno odgovorne inicijative sa drugim organizacijama, da društveni cilj treba da odgovara misiji i vrednostima preduzeća, da postoji volonterski rad zaposlenih u zajednici, kao i da su definisani društveni ciljevi i donacije vidljive u društvenoj zajednici, kao i obrazovanje i stipendiranje đaka i studenata.
-zaposleni *prirodno-matematičke struke* ne prepoznaju da se promoviše lična odgovornost i društveni angažman, ni volonterski rad zaposlenih u zajednici, kao ni da su donacije vidljive u društvenoj zajednici, niti da postoji obrazovanje i stipendiranje đaka i studenata i da nisu prisutni inventivni i održivi oblici ulaganja u zajednicu, ni saradnja sa nevladinim organizacijama na zajedničkim projektima, niti da preduzeće investira u razvoj lokalne zajednice u skladu sa korporativnom odgovornošću, ali smatraju da društveni cilj treba da odgovara misiji i vrednostima preduzeća.
- zaposleni *ostalih struka* smatraju da postoje zajedničke korporativno odgovorne inicijative sa drugim organizacijama, da postoji volonterski rad zaposlenih u zajednici i da je organizacija definisala društvene ciljeve, kao i da su donacije vidljive u društvenoj zajednici i da postoji obrazovanje i stipendiranje đaka i studenata i saradnja sa nevladinim organizacijama na zajedničkim projektima i preduzeće investira u razvoj lokalne zajednice u skladu sa korporativnom odgovornošću i da je moguće meriti uticaj na društvenu zajednicu i životnu sredinu.

4. ZAKLJUČAK

Za organizaciju se može reći da se ponaša društveno odgovorno ukoliko se odnosi s poštovanjem i na način koji je održiv prema zaposlenima, kapitalu i imovini koji su joj povereni, tržištu, široj društvenoj zajednici i životnoj sredini. Preduzeća su, danas, ravnopravni partneri sa društvenom zajednicom. Misija svake korporativno odgovorne organizacije je da sagledava potrebe društva i prilikom donošenja odluka uzme u obzir celokupni uticaj na širu društvenu zajednicu u kojoj posluje, kao i na životnu okolinu.
U svim segmentima korporativne odgovornosti, komunikacija zauzima izuzetan značaj, bilo da se radi o razvoju svesti, povećanju stepena razumevanja, prihvatanja ili primeni koncepta korporativne odgovornosti u organizaciji ili u celokupnoj društvenoj zajednici. Sva istraživanja koja su do sada rađena u Srbiji su ukazala da zaposleni, potrošači i celokupna zajednica nemaju razvijenu svest o korporativnoj odgovornosti, niti su

dovoljno informisani o društveno odgovornim aktivnostima organizacija. Radi toga, potrebno je obezbediti razumevanje korporativne odgovornosti u svim njenim dimenzijama, a posebno prema široj društvenoj zajednici u kojoj posluje i egzistira organizacija, kao i podići nivo svesti zaposlenih o važnosti njihovog odgovornog stava i uticaja organizacije na širu društvenu zajednicu i na delovanjem zaposlenih i organizacije stabilno graditi imidž "dobrog korporativnog građanina" i reputaciju organizacije koja prihvata i razvija društvenu odgovornost i brigu prema široj društvenoj zajednici [3]. Analizom rezultata istraživanja predstavljenog u ovom radu je zaključeno da zaposleni različitih vrsta obrazovanja imaju različite stavove o korporativnoj odgovornosti preduzeća prema široj društvenoj zajednici, te je iz tog razloga neophodno razviti i različite pristupe kojima će se obezbediti razumevanje, prihvatanje i efikasno sprovođenje aktivnosti korporativne odgovornosti prema široj društvenoj zajednici za zaposlene različitih vrsta obrazovanja.

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NOVO IZDANJE STANDARDA ZA KOMPETENTNOST LABORATORIJA ZA ISPITIVANJE I KALIBRACIJU

Misada Oruč[1], Raza Sunulahpašić[2], Branka Muminović[3], Aida Imamović[4]

Sažetak:Laboratorija predstavlja jednu cjelinu u okviru koje se obavljaju ispitivanja mjerenjem. Ona predstavljava značajan element za obezbjeđenje kvaliteta u sistemu trgovine, posebno međunarodne. Naime, laboratorija svojim kompetentnim rezultatima ispitivanja obezbjeđuje uklanjanje barijera u međunarodnoj trgovini i ubrzava protok roba, koji se zasniva na međunarodnom kredibilnom sistemu priznavanja rezultata ispitivanja. Laboratorija je tijelo koje obavlja jednu ili više slijedećih aktivnosti: kalibraciju,ispitivanje, uzorkovanje, povezano s naknadnim kalibracijama i ispitivanjem. Laboratorija će uspostaviti, dokumentirati,implementirati i održavati sistem upravljanja koji je sposoban da podržava i demonstrira dosljedno postizanje zahtjeva ovog dokumenta, osiguravajući kvalitet laboratorijskih rezultata.
Primjenom standarda ISO/IEC 17025 odnosno BAS EN ISO/IEC 17025 olakšava se saradnja laboratorija i drugih tijela, na nacionalnom i međunarodnom nivou. Od laboratorija se danas zahtijeva da funkcionišu na način koji osigurava da su njihovi postupci i podaci budu pouzdani. Pored toga, rezultati su prihvatljiviji na međunarodnom nivou kada laboratorije posluju u skladu sa ovim standardom.
U ovom radu dat je pregled nove verzije standarda ISO/IEC 17025:2017 i promjene koje donosi u odnosu na raniju verziju standarda.

Ključne riječi: Ispitivanje i kalibracija, Laboratorija, Standard ISO/IEC 17025

NEW EDITION STANDARD FOR COMPETENCE LABORATORY FOR EXAMINATION AND CALIBRATION

Abstract. The Laboratory is one of the units within which measurements are performed. It represents an important element for quality assurance in the trade system, especially international. Namely, with its competent test results, the laboratory provides removal of barriers in international trade and speeding up the flow of goods, which is based on an international credible system for the recognition of test results. The laboratory is in the body which performs one or more of the following activities: calibration, testing, sampling, associated with subsequent calibration and testing. The laboratory will

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establish, document, implement and maintain a management system that is capable of supporting and demonstrating consistent achievement of the requirements of this document and ensuring the quality of laboratory results.
The implementation of ISO/IEC 17025 or BAS EN ISO/IEC 17025 facilitates the cooperation of laboratories and other bodies, both nationally and internationally. Laboratories are now required to function in a way that ensures that their procedures and data are reliable. In addition, the results are also more acceptable at the international level when laboratories operate in accordance with this standard. In this paper,we review the new version of ISO / IEC 17025: 2017 and the changes it brings in relation to the earlier version of the standard.

Keywords: Testing and calibration, Laboratory, ISO/IEC 17025 standard

1 UVOD

Laboratorija je tijelo koje vrši jednu ili više slijedećih aktivnosti: kalibracija, ispitivanje, uzorkovanje, povezano sa naknadnim kalibracijama i ispitivanjem. Kalibracija, ispitivanje i analiza uzoraka, predstavlja svakodnevnu praksu laboratorija širom svijeta uz obavezno obezbjeđenje pouzdanosti rezultata ispitivanja ili kalibracije.

Tokom proteklih godina, standard ISO/IEC 17025, *Opšti zahtjevi za kompetentnost ispitnih i kalibracionih laboratorija,* postao je međunarodna referenca za laboratorije koje žele da pokažu svoje sposobnosti kada je riječ o pouzdanim rezultatima. Ovaj međunarodni standard, koji su zajednički pripremali i revidirali ISO i IEC (Međunarodna komisija za elektrotehniku- International Electrotechnical commission), sadrži niz zahtjeva koji omogućavaju laboratorijama da poboljšaju svoju mogućnost konstantnog pružanja validnih rezultata.Kako je od objavljivanja ovog standarda 2005. godine došlo do velikih promjena u okruženju u kojem laboratorije posluju, neophodna revizija ovog standarda počela je još 2015. godine. Objavljivanje ovog standarda na međunarodnom nivou bilo je 30.11. 2017. godine [1], a kao BAS EN ISO/IEC 17025 zvanično je objavljen 22.05.2018.godine.

Radi promjena tržišnih uslova i tehnologije, novo izdanje standarda obuhvata aktivnosti i nove metode rada današnjih laboratorija. On uključuje tehnička dostignuća, rječnik i napredak IT tehnologija te uzima u obzir i najnoviju verziju standarda ISO 9001: 2015 (Sistemi upravljanja kvalitetom-Zahtjevi).

Također, sve laboratorije akreditovane prema ISO/IEC 17025 ili ISO 15189 (kompetentnost za medicinske laboratorije) moraju primjenjivati procedure za određivanje mjerne nesigurnosti za sve metode koje primjenjuju u svom radu [2,3]. Neke laboratorije ne rade kao laboratorije sa jasno definisanim laboratorijskim prostorom i uslovima. S druge strane, postoje i laboratorije koje su dio velikih poslovnih sistema i rade u njihovom sklopu. Za ovakve slučajeve, preporučuje se certifikacija prema modelu ISO 9001.

Kalibracioni ili ispitni laboratorij koji obavlja kalibracije za vlastite potrebe, mora posjedovati proceduru za procjenu mjerne nesigurnosti za sve kalibracije i sve vrste kalibracija. Ispitni laboratoriji moraju imati i primjenjivati procedure za procjenu mjerne nesigurnosti. U određenim slučajevima priroda metode za ispitivanje može spriječiti strogi, mjeriteljski i statistički opravdan, proračun mjerne nesigurnosti. U ovim slučajevima, laboratorij mora barem poduzeti mjere na identificiranju svih komponenti nesigurnosti i učiniti procjenu prihvatljivom, te osigurati da način izvještavanja o rezultatu ne pruža pogrešan utisak o nesigurnosti. Prihvatljiva procjena se mora temeljiti na poznavanju performansi metode i područja u kojem se vrši mjerenje te mora uključiti, na primjer, prethodno iskustvo i podatke o validaciji.

U slučaju kada metoda mjerenja omogućava, mora se izvršiti njena metrološka i statistička validacija, kao i izračunati uticaj mjerne nesigurnosti na rezultate mjerenja. Međutim, kada to nije moguće, potrebno je ocijeniti uticaj mjerne nesigurnosti na rezultate mjerenja i taj uticaj uključiti u izvještaj o mjerenjima. Ocjena tog uticaja treba da bude zasnovana na znanju o metodi i proceduri mjerenja, prethodnim istim i/ili sličnim mjerenjima i validnim podacima, [3].

2 STANDARD ISO/IEC 17025

Najpopularniji standard za kompetentnost laboratorija za ispitivanje i kalibraciju, ISO/IEC 17025 je, kako je već navedeno, ažuriran kako bi se uzela u obzir najnovija dostignuća u laboratorijskom okruženju i radnim praksama. On omogućava da se olakša saradnja između laboratorija i drugih tijela obezbjeđivanjem boljeg prihvatanja rezultata između različitih zemalja, [4].

Ovim međunarodnim standardom utvrđuju se opšti zahtjevi za kompetentnost, nepristrasnost i konzistentan rad laboratorija. On je primjenljiv na sve organizacije, bez obzira na broj članova osoblja koji obavljaju laboratorijske aktivnosti. U svrhu potvrđivanja ili priznavanja kompetentnosti laboratorija, ovaj međunarodni standard također mogu da primenjuju korisnici usluga laboratorija, regulatorna tijela, organizacije u kojima se provodi kolegijalno ocjenjivanje, uključujući i šeme u kojima se koristi kolegijalno ocjenjivanje, akreditaciona tijela i mnogi drugi, [1].

2.1 Izmjene u novom standardu

U novom izdanju standarda EN ISO/IEC 17025 prisutan je drugačiji raspored zahtjeva za sistem upravljanja i tehničku kompetentnost u odnosu na izdanje standarda iz 2005. godine. Zbog preglednosti prikaza zahtjeva standarda u tabeli 1. su dati uporedo, zahtjevi standarda EN ISO/IEC 17025 iz 2005. i 2017. godine, odnosno kao BAS EN ISO/IEC 17025 standarda iz 2006.i 2018.godine.

Tabela 1. *Glavne razike u standardima iz 2005. i 2017.godine odnosno kao BAS standarda iz 2006. i 2018.godine*

Zahtjev BAS EN ISO/IEC 17025:2018		Zahtjev BAS EN ISO/IEC 17025:2006	
4. Opšti zahtjevi	4.1 Nepristrasnost	4.1 Organizacija	4.1.4, 4.1.5 b) i d)
	4.2 Povjerljivost		4.1.5 c), 4.7 Odnosi sa kupcem
5. Zahtjevi za strukturu	5.1 5.4 5.5 a) i b) 5.6 a) 5.7a)	4.1 Organizacija	4.1.1 4.1.2 4.1.5 e) i f) 4.1.5 a) 4.1.6
6. Zahtjevi za resurse	6.1 Opšte		
	6.2 Osoblje	5.2 Osoblje	
	6.3 Objekti i uslovi sredine	5.3 Uvjeti za smještaj i okolinu	
	6.4 Oprema	5.5 Oprema	
	6.5 Metrološka sljedivost	5.6 Sljedivost mjerenja	
	6.6 Eksterno nabavljeni proizvodi i usluge	4.6 Nabavka usluga i proizvoda	4.6.2
7. Zahtjevi za proces	7.1 Preispitivanje zahtjeva, ponuda i ugovora	4.4 Preispitivanje zahtijeva ponuda i ugovora	
	7.2 Izbor, verifikacija i validacija metoda	5.4 Metode za ispitivanje i kalibracije i metoda validacije 5.4.2 Izbor metode	

		5.4.3. Metode koje je razvio laboratorij 5.4.4. Nestandardne metode 5.4.5 Validacija metoda
	7.3 Uzorkovanje	5.7 Uzorkovanje
	7.4 Rukovanje predmetima ispitivanja ili kalibracije	5.8 Postupanje sa predmetima ispitivanja i kalibracije
	7.5 Tehnički zapisi	4.13.2 Tehnički zapisi
	7.6 Vrednovanje mjerne nesigurnosati	5.4.6 Procjena mjerne nesigurnosti
	7.7 Obezbjeđenje validnosti rezultata	5.9 Osiguranje kvaliteta rezultata ispitivanja i kalibracija
	7.8 Izvještavanje o rezultatima	5.10 Izvještavanje o razultatima
	7.9 Prigovori	4.8 Prigovori
	7.10 Neusaglašeni posao	4.9 Kontrola neusklađenosti posla ispitivanja i/ili kalibracija
	7.11 Kontrola podataka i upravljanje informacijama	5.4.7 Kontrola podataka
8. Zahtjevi za sistem upravljanja	8.1 Opcije	
	8.2 Sistem upravljanja dokumentima	4.3 Kontrola dokumenata
	8.3 Kontrola dokumenata	
	8.4 Kontrola zapisa	4.13 Kontrola zapisa
	8.5 Postupanje sa rizicima i prilikama	4.12 Preventivne akcije
	8.6 Poboljšanja	4.10 Poboljšavanje
	8.7 Korektivne akcije	4.11 Korektivna akcija
	8.8 Interni auditi	4.14 Interni auditi
	8.9 Preispitivanje od rukovodstva	4.15 Preispitivanje od rukovodstva

Glavne izmjene standarda ISO/IEC 17025, kako se navodi u saopštenju Međunarodne organizacije za standardizaciju (ISO), ali iprema drugim literaturnim navodima i prikazima u tabeli 1. obuhvataju slijedeće, [5,6]:

-*Procesni pristup:* sada odgovara pristupu u novijim standardima kao što su ISO 9001 (upravljanje kvalitetom), ISO 15189 (kvalitet medicinskih laboratorija) i ISO/IEC 17021-1 (zahtjevi za tijela koja provode audit i certifikaciona tijela). U izmijenjenom standardu više pažnje poklanja se rezultatima procesa nego detaljnom opisu zadataka i koraka u okviru procesa.

-*Prigovori:* zahtjevi koji se tiču prigovora, u novom standardu svrstani su među procesne zahtjeve. Ti zahtjevi su prošireni i traži se više detalja nego što je to slučaj u trenutno važećem standardu.

- Zahvaljujući većem *naglasku na informacionim* tehnologijama standard sada prepoznaje i uključuje korištenje računarskih sistema, elektronskih evidencija i elektronskih rezultata i izvještaja. Moderne laboratorije sve više u radu koriste informacione i komunikacione tehnologije te se smatra da je bilo potrebno obratiti pažnju na navedeno.

-*Upravljanje informacijama* je novi zahtjev. Od laboratorija se traži validacija laboratorijskog sistema upravljanja informacijama i cjelokupan nadzor nad svim podacima i informacijama, kako u računarskim tako i u neračunarskim sistemima.

- Nova verzija standarda uključuje i poglavlje zasnovano na razmišljanju o *riziku* i objašnjenje dodirnih tačaka sa novom verzijom ISO 9001:2015, Sistemi upravljanja kvalitetom –Zahtjevi. Laboratorija mora posvetiti posebnu pažnju tome, kako upravljati *rizikom nepristrasnosti*, a za što će vjerojatno morati osmisliti poseban

postupak, tj. kako analizirati rizik nepristrasnosti, kako ga otkloniti ili umanjiti, kako ga trajno pratiti i slično, [6]. Ovo je novi zahtjev gdje laboratorija mora planirati radnje koje se odnose na rizike i prilike te vrednovati učinkovitost tih radnji.

-*Terminologija* je aktuelizirana kako bi bila u skladu sa današnjim vremenom i činjenicom da štampane priručnike, zapise i izvještaje postupno zamjenjuju elektronske verzije. Primjeri uključuju izmjene Međunarodnog rječnika metrologije (VIM) i usklađivanje sa terminologijom ISO/IEC-a koja sadrži skup zajedničkih izraza i definicija za sve standarde koji se odnose na ocjenjivanje usklađenosti. Novo izdanje standarda donosi oko devet definicija različitih izraza (tako i izraz„laboratorija“).

-Također usvojena je nova *struktura* kako bi se standard uskladio sa ostalim postojećim ISO/IEC standardima u području ocjenjivanja usklađenosti kao što je serija standarda ISO/IEC 17000 o ocjenjivanju usklađenosti.Promjena strukture provedena je iz razloga što je standard usvojio „procesni pristup“ pa se sam proces sagledava neovisno o drugim zahtjevima za osposobljenost laboratorija.

-*Povjerljivost*. Pojačani su zahtjevi i u pogledu povjerljivosti. Uvode se i nove situacije kao npr. ako se informacija o kupcu dobije iz drugog izvora, ona se smatra povjerljivom i čak se ne smije odati kupcu bez dopuštenja tog izvora, [6].

-*Osoblje i oprema.* Način na koji će laboratorij pratiti osposobljenost svog osoblja stavljen je u potpunosti na izbor laboratoriji. Novi zahtjev putem kojeg će se tražiti od laboratorija je zapis ("dokaz ovjere") o tome da je oprema s kojom se provode aktivnosti u skladu sa ISO/IEC 17025. Mjeriteljska sljedivost detaljnije je opisana u novom izdanju standarda te su jasnije istaknute neke pojedinosti o tome kako laboratorij može ostvariti traženu sljedivost svojih rezultata, [6].

-*Vanjski proizvodi i usluge.* Nabava i podugovaranje te svi oblici vanjskih usluga i proizvoda se u novom se izdanju standarda posmatraju jedinstveno.

-*Metode i procjena mjerne nesigurnosti.* Laboratorij će morati preispitati kriterije metode (ispitivanja, umjeravanja i uzorkovanja) te potvrditi (zapisom) da ih ispunjava. Sada je to postao čvrst zahtjev za procjenu mjerne nesigurnosti. Osim toga, kad se procjenjuje mjerna nesigurnost u obzir se mora uzeti i doprinos mjernoj nesigurnosti koji proizilazi iz uzorkovanja, [6].

-*Pravilo za donošenje odluke* je novi izraz, a pojavljuje se kod potreba laboratorija da iskažu saglasnost rezultata s postavljenim kriterijima (standardizovanim, zakonskim ili slično).

-*Uzorkovanje i kvalitet rezultata.* Nova definicija "laboratorija" ističe da je to tijelo koje obavlja jednu ili više aktivnosti, a te aktivnosti su ispitivanje, umjeravanje i uzorkovanje povezano s naknadnim ispitivanjima i umjeravanjima. Osiguravanje kvaliteta rezultata preimenovano je u „osiguravanje tačnosti/validnosti rezultata“. Preciznije su postavljeni zahtjevi u slučaju prikazivanja izjava o saglasnosti, mišljenja i tumačenja rezultata.

-*Poboljšavanje.* Zahtjevi koji se tiču usluge kupcu u novom su izdanju standarda obuhvaćeni u zahtjevima za poboljšavanje ili poboljšanje. Standard traži da laboratorij prepozna i odabere *prilike za poboljšanje*. Općenito, standard daje zahtjeve za upravljanje rizicima, ali *rizik nepristrasnosti* razmatra se posebno u odnosu na druge rizike.

-*Preispitivanja upravljanja (ocjene uprave).* U novom izdanju standarda razlikuju se ulazni podaci izvještaja uprave i izlazni podaci.

-Izmijenjeno je i *područje primjene* kako bi se obuhvatile sve aktivnosti laboratorija,uključujući ispitivanje, kalibraciju i uzorkovanje u sklopu naknadne kalibracije i ispitivanja.

Iz prethodnog pregleda da se zaključiti da će laboratoriji morati promijeniti cjelokupni pristup i svoje procese promatrati na sasvim *drugačiji način* nego što je to

bilo do sada. Usklađivanje s novim izdanjem standarda tražiti će *punu pažnju* laboratorija koji su navikli djelovati u skladu s trenutno važećim izdanjem, [6].

2.2 Osnovne izmjene u odnosu na EN ISO/IEC 17025:2005

Osnovne izmjene koje se ukratko mogu dati, iako su detaljnije obrazložene u prethodnoj tački, kod novog izdanja standarda u odnosu na verziju EN ISO/IEC 17025:2005 se fokusiraju na slijedeće, [1]:

- laboratorijske aktivnosti mogu da obuhvataju etaloniranje, ispitivanje i uzorkovanje, povezano sa naknadnim etaloniranjem ili ispitivanjem;
- stavljanje akcenta na nepristrasnost umjesto na nezavisnost;
- orijentisanost na procesni pristup;
- stavljanje akcenta na rezultate procesa, umjesto na detaljan opis zadataka i koraka;
- smanjivanje obima potrebne dokumentacije;
- uvođenje rizika i prilika, kao novih zahtjeva;
- isticanje mogućnosti podugovaranja;
- uvođenje aspekta informacionih tehnologija u domenu rizika, integriteta podataka, povjerljivosti, validacije softvera, elektronske dokumentacije;
- uvođenje novog termina „metrološka sljedljivost";
- omogućavanje laboratoriji da izdaje izjavu o usaglašenosti sa aspekta zadovoljava/ne zadovoljava.

Svaka laboratorija prema novom standardu mora imati i vodit i *zapise* za slijedeće, [2]:

a) utvrđivanje uslova nadležnosti;
b) izbor osoblja;
c) obuka osoblja;
d) nadzor osoblja;
e) odobrenje osoblja;
f) praćenje nadležnosti osoblja kao i neke obavezne eksplicitne autorizacije .

Laboratorija *ovlašćuje* svoje osoblje za izvođenje specifičnih laboratorijskih aktivnosti, uključujući ali ne ograničavajući se na:

a) razvoj, modifikaciju, verifikaciju i validaciju metoda;
b) analizu rezultata, uključujući izjave o usaglašenost ili mišljenja i tumačenja;
c) izvještavanje, pregled i odobravanje rezultata.

3. ZAKLJUČCI

Ovo je treće izdanje standarda ISO/IEC 17025 za osposobljenost laboratorija koje donosi značajne novosti laboratorijima koje ga primjenjuju. Od objavljivanja prvog izdanja 1999.godine, ovaj se standard nametnuo kao jedan standard za sve laboratorije, a tome je doprinijela i akreditacija laboratorija jer su taj standard akreditaciona tijela su prepoznala kao osnovni dokument koji daje zahtjeve za osposobljenost laboratorija, [6].

On je primjenljiv na sve organizacije, bez obzira na broj članova osoblja koji obavljaju laboratorijske aktivnosti. U svrhu potvrđivanja ili priznavanja kompetentnosti laboratorija, ovaj međunarodni standard takođe mogu da primjenjuju korisnici usluga laboratorija, regulatorna tela, organizacije u kojima se sprovodi kolegijalno ocenjivanje, uključujući i šeme u kojima se koristi kolegijalno ocenjivanje, akreditaciona tijela i mnogi drugi, [1].

Upravljanje kvalitetom u laboratoriji je jedan od krucijalnih zahtjeva moderne prakse mjerenja,a poseban značaj je postignut donošenjem standarda ISO/IEC 17025, posebno zadnje verzije, [3].

Laboratorije koje su već akreditovane prema ISO/IEC 17025:2005 odnosno BAS EN ISO/IEC 17025: 2006 imati će tranzicioni period od tri godine od datuma objavljivanja novog standarda da usklade svoje procese s novom verzijom standarda.

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STRATEŠKO UPRAVLJANJE I IMPLEMENTACIJA MOBILNE TEHNOLOGIJE U VISOKOM OBRAZOVANJU

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Rezime: Povećana primena mobilne tehnologije među studentima, kao i unapređenje funkcionalnosti uređaja, dovodi do implementacije sistema m-učenja na univerzitetskom nivou. Mobilno učenje, kao oblik učenja na daljinu koji se zasniva na korišćenju mobilne tehnologije, omogućava novi proces interakcije i komunikacije profesora i studenata. Uticaj mobilne tehnologije na akademska ostvarenja studenata u poređenju sa tradicionalnim učenjem još uvek nije dovoljno istražena oblast. Treba da se istraže faktori koji doprinose povećanom interesu za primenom mobilnih uređaja za učenje, kao i faktore koji ograničavaju primenu mobilne tehnologije u obrazovanju. Razvoj savremeno informaciono-komunikacionih tehnologija i poboljšanih alata uticao je na kreiranje značajnih aplikacija gejmifikacije u visokom obrazovanju. Pored toga, univerziteti razvijaju aplikacije koje pružaju osnovne informacije o univerzitetu, važnim lokacijama za svakodnevni život studenata.

Ključne riječi: aplikacije gejmifikacije, mobilne tehnologije, strategija, studenti, visoko obrazovanje

STRATEGIC MANAGEMENT AND MOBILE TECHNOLOGY IMPLEMENTATION IN HIGHER EDUCATION

Abstract: Increased mobile application utilisation among students followed by functional device improvement leads educational technology to higher university level. M – learning, as a form of distance education which uses mobile device educational technology is a new wave of interaction and communication between professors and students. Unfortunately, this scientific field is dealing with lack of research evidence: casual relationship between mobile technology and student academic achievement is still unknown likewise its advantage in regard to traditional learning. That is why a special attention should be paid to both factors: to the ones that contribute to increased

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interest in mobile application usage for m-learning and to the opposite ones too, which actually limit this interest. Massive social adoption of modern information and communication technology with improvement in quality management system have an effect on gamification utilisation in higher education. University mobile applications are therefore the main source for basic information in student everyday life.

Key words: gamification for mobile applications, high education, mobile technologies, strategy, students

1 UVOD

Savremene informaciono-komunikacione tehnologije su znatno olakšale proces transfera znanja i razvoja novih oblika učenja. Univerziteti su prihvatili nove trendove, te uvode tehnološke inovacije u sam proces pružanja usluge. Studenti mogu da slušaju i gledaju predavanja renomiranih profesora sa inostranih univerziteta uz pomoć savremene tehnologije, bez obzira na vremenske razlike i njihovu prostornu udaljenost. Univerziteti primenjuju savremene oblike učenja i nastave u cilju stvaranja globalne konkurentnosti na tržištu visokog obrazovanja.

Danas studenti mnogo češće gledaju internet stranicu fakulteta putem mobilnog telefona, nego putem laptopa ili kompjutera. Univerziteti treba da formatiraju svoje *web* stranice da funkcionišu kako na računaru, tako i na pametnim telefonima i tabletima. Prilikom upisa, 20 % studenata ukoliko imaju loše iskustvo sa *web* stranicom na njihovom mobilnom uređaju, više ne razmatraju taj fakultet kao opciju upisa.

Mnogi istraživači smatraju da uticaj mobilne tehnologije na akademska ostvarenja studenata u poređenju sa tradicionalnim učenjem još uvek nije dovoljno istražena oblast, a i da treba istražiti faktore koji ograničavaju primenu mobilne tehnologije u obrazovanju. Mobilno učenje (m-učenje) je oblik učenja na daljinu koji se zasniva na korišćenju mobilne tehnologije. Little (2013) smatra da je razvoj poboljšanih alata i tehnologije povećao tražnju za mobilnim uređajima u obrazovne svrhe [1]. Mnogi univerziteti su uvideli značaj kreiranja i primene aplikacije koje pružaju osnovne informacije o univerzitetu, važnim lokacijama za svakodnevni život studenata. To je posebno od koristi za buduće studente i studente koji su na razmeni da se upoznaju sa univerzitetom.

2 PRIMENA MOBILNIH APLIKACIJA U VISOKOOBRAZOVNIM INSTITUCIJAMA

Postoje dve alternative mobilne aplikacije, koje se koriste u obrazovanju: 1.veb-aplikacije, koje profesori i studenti mogu da koriste kroz pretraživač i 2. nativne aplikacije. Nativne aplikacije predstavljaju softverske aplikacije, koje se posebno razvijaju i instaliraju za svaki mobilni operativni sistem i mogu se koristiti uz pomoć korisničkog interfejsa. Nativne aplikacije se posebno razvijaju za jednu platformu i mogu da u potpunosti koriste hardverske komponente uređaja – mogu da koriste kameru, GPS, akcelerometar, kompas, listu kontakata, itd. [2].

Značajne aplikacije gejmifikacije koje se koriste u visokom obrazovanju su [3]:

1. ***Kahoot*:** Aplikacija *Kahoot* se koristi na univerzitetima radi poboljšanja rezultata učenja. Studenti pokušavaju da pronalaze tačne odgovore na pitanja, koja im se prikazuju na ekranu projektora i daju odgovor koristeći neki od svojih uređaja (desktop, laptop, tablet, telefon). Aplikacija *Kahoot* je korisna za razvoj takmičarskog duha i pozicije liderstva u grupnom takmičenju. Studenti su motivisani da u kraćem vremenskom periodu pronađu tačan odgovor jer

dobijaju veći broj osvojenih poena i bolju poziciju među takmičarima. Najveća prednost ove aplikacije je ta da se zasniva na korišćenju interneta i da je besplatna za mobilne uređaje. Izuzetno je lako koristiti aplikaciju, koja omogućava studentima sticanje saradničke pobedničke filozofije.

2. ***ClassDojo*:** Aplikacija *ClassDojo* je veoma popularna u interakciji između profesora, roditelja i studenata, koja trenutno ima 35 miliona korisnika. Prevedena je i koristi se na više od 35 jezika. Prednost ove aplikacije je što omogućava roditeljima uključenost u radu studenata i obrazovnom procesu. Roditelji imaju pristup aplikaciji, mogu da komuniciraju sa profesorima, informišu se o rezultatima rada i ponašanju i dobijaju izveštaj o napredovanju svog deteta. Kroz *ClassDojo*, nastavnici kontrolišu rad u učionici na delotvoran i zanimljiv način.
3. ***Classcraft*:** Aplikaciju *Classcraft* studenti posmatraju korišćenjem projektora, a u njoj učestvuju uz pomoć tableta i laptopa. Nastava je uz pomoć aplikacije dosta zanimljivija i studenti stiču znanje pomoću igre i avanturističkih metoda rada. Prednost korišćenja aplikacije je u kooperaciji među studentima, učenje kroz zabavu, povećanje motivacije studenata.
4. ***Socrative*:** Prednost aplikacije je jednostavnost njene upotrebe i dostupna je svima jer je besplatna. Studenti stiču znanje odgovarajući na pitanja na svojim mobilnim uređajima i odmah dobijaju povratnu informaciju o tačnosti rezultata pitanja. Samim tim skupljaju poene za tačne odgovore, koji im mogu obezbediti lidersku poziciju u grupnim aktivnostima studenata. Može da se primenjuje među studentima koji bolje znaju tematiku predavanja radi pokretanja kooperativne diskusije.

3 PREDNOSTI I NEDOSTACI UČENJA UZ POMOĆ MOBILNIH APLIKACIJA

Prema Hussin, Manap, Amir i Krish (2012) mobilno učenje ima veliki potencijal da bude efektivan alat za učenje usled brzog rasta nove generacije mobilnih uređaja, kao što su tableti, mobilni telefoni, ali i napredovanja u bežičnoj tehnologiji [4]. Low i O'Connel (2006) su izjavili da je prednost mobilnog učenja fleksibilnost i da daje osećaj slobode studentima [5]. Osnovna prednost korišćenja mobilne tehnologije u nastavnom procesu je pristup nastavnim sadržajima, izvorima informacija i znanja sa bilo kog mesta i u bilo koje vreme.

Profesori koriste informaciono-komunikacionu tehnologiju da podstiču i motivišu studente da uče. Brojne studije pokazuju da postoji povećano interesovanje za učenjem studenata, kada se koriste mobilni uređaji u procesu nastave. Huang, Liao, Huang i Chen (2014) smatraju da korišćenje mobilnih uređaja može značajno da utiče na stvaranje pozitivnije percepcije nastavnih aktivnosti i na interesovanje studenata prema temi i učenju [6]. Rezultati njihove studije pokazuje da se samo 6% studenata u grupi ne dopadaju nastavne aktivnosti, dok je znatno veći procenat studenata (25%) u tradicionalnom okruženju reklo da im se ne dopada.

Prema studiji Conole i saradnika (2006), percepcija i stavovi studenata prema korišćenju mobilnih telefona u obrazovne svrhe u Velikoj Britaniji se svodi na odabir tehnologije na osnovu stepena do kojeg će poboljšati učenje [7]. Hwang, Huang, Shadiev, Wu i Chen (2014) ističu da studenti mogu biti motivisaniji kada koriste mobilne tehnologije, ali je njihovo obrazovno postignuće i dalje nezadovoljavajuće [8].

Percepcija i stavovi profesora prema mobilnoj tehnologiji je ključan faktor u korišćenju mobilnih uređaja u obrazovanju. Prema nekim istraživanjima nastavnici smatraju da su mobilni uređaji alati koji ometaju i skreću pažnju sa procesa učenja. Froese i saradnici (2012) su sproveli istraživanje na koledžu u Kentakiju, koje pokazuje

da su rezultati studenata koji šalju tekstualne poruke tokom davanja instrukcija 27% niži od studenata koji utišaju telefon tokom časa [9]. Ova studija pokazuje da korišćenje mobilnih telefona u toku predavanja može negativno da utiče na proces učenja i rezultate pamćenja materijala. Pored brojnih prednosti, m-učenje još uvek nije dovoljno razvijeno, ne samo u našoj zemlji već i u mnogim razvijenijim državama, jer postoje brojne predrasude i otpor od strane društvene zajednice.

4 ZAKLJUČAK

Poslednjih godina visokooobrazovne institucije su se suočile sa turbulentnim i dramatičnim promenama iz spoljnog okruženja, koje su inicirale uvođenje promena u unutrašnjem okruženju. Najvažnije promene iz spoljnjeg okruženja su: promene u demografskoj strukturi, tehnološke inovacije, smanjenje finansijske podrške od strane države i dr. Mnoge visokoobrazovne institucije su shvatile značaj uvođenja strateškog planiranja i primene njegovih načela kao sredstava za definisanje i sprovođenje strateško važnih promena radi bržeg prilagođavanja okruženju.

Savremeni oblici učenja i nastave, koji su razvijeni zahvaljujući korišćenju informaciono-komunikacionih tehnologija, predstavljaju značajnu osnovu za stvaranje konkurentnosti visokoobrazovnih institucija na tržištu usluga visokog obrazovanja. Takođe, fakulteti usklađuju svoje studijske programe sa potrebama i zahtevima korisnika usluga, promenama u okruženju, promenama u ponudi konkurentnih obrazovnih institucija.

Visokoobrazovne institucije su uvidele da implementacija novih tehnologija i praćenje trendova, značajno utiče na postizanje konkurentske prednosti i prilagođavanje promenljivim uslovima tržišta. U današnje vreme visokoobrazovne institucije su fokusirane da budu prisutne na svakoj platformi i da ažuriraju informacije u svakom trenutku.

Mobilno učenje je novi način komunikacije i uspostavljanja saradnje između nastavnika i studenata u odnosu na tradicionalan način učenja. U odnosu na tradicionalan način učenja, ima mnoge prednosti, ali i nedostatke. Nastavnicima omogućava veću slobodu i fleksibilnost da sa studentima rade koristeći online aplikacije kad god treba. Studenti koriste aplikacije na pametnim telefonima, koje im pomažu da pristupe audio i video materijalima, odgovaraju na kvizove, razmenjuju informacije, postavljaju pitanja, učestvuju na javnim četovima, omogućavaju im kvalitetnu podršku učenju u smislu planiranja, zapisivanja bilješki.

Korišćenje mobilnih telefona kao nastavnog alata u Srbiji, ali u mnogim zemljama sveta, nailazi na otpor i predrasude društvene zajednice. Mnoge studije su ukazale na brojne prednosti mobilnog učenja, međutim na brojim fakultetima i školama upotreba mobilnih telefona je zabranjena. Univerziteti kao obrazovne institucije su zabrinuti zbog sve veće nezainteresovanosti univerzitetskih studenata za tradicionalni način učenja [10]. Da bi se stav društvene zajednice promenio, potrebno je jasno definisati politiku i standarde korišćenja mobilnih uređaja u nastavnom procesu.

Razvoj savremene informaciono-komunikacione tehnologije je uticao na stvaranje novih oblika promocije i distibucije obrazovnih usluga. Primenom ove tehnologije visokoobrazovne institucije razvile su nove, dvosmerne oblike komunikacije sa ciljnom publikom putem blogova, mikroblogova i društvenih mreža i tako razmenjuju mišljenja, komentare i informacije. Savremeni kanali distribucije omogućavaju studentima dostupnost obrazovne usluge bez fizičkog prisustva u visokoobrazovnoj instituciji zahvaljujući korišćenju informaciono-komunikacionih tehnologija.

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A HEURISTIC "MINIMAL DEVIATION" ALGORITHM FOR SOLVING FLEXIBLE JOB SHOP SCHEDULING PROBLEMS

Vassil Guliashki[1], Gašper Mušič[2], Galia Marinova[3]

Abstract: A constructive heuristic algorithm for solving flexible job shop scheduling problems optimizing the makespan is proposed. It is based on the idea to create a feasible schedule, assigning the operations on machines according their shortest processing times (SPT), which is the ideal case, and if this is impossible – to re-assign the corresponding operation, permitting the minimal possible deviation from SPT. A strategy for re-assignment of operations from the bottleneck machine to other possible machines is proposed. The obtained results show that the algorithm could be used to solve large-sized flexible job shop scheduling optimization problems.

Key words: Flexible Job Shop Scheduling Problem, Heuristic algorithm, Optimization.

1 INTRODUCTION

The job shop scheduling problem is met in many real-life situations (see [1, 2]). For example the management of electric power grids, in particular smart grids, requires solutions of scheduling optimization problems (see [3]). The job shop scheduling problem is an important optimization problem, connected with the manufacturing systems in the industry. This problem arises in the planning and controlling the manufacturing process. In short it can be described as follows: There are a number of *n* jobs to be executed. Each job consists of a given sequence of operations which need to be performed in this sequence only, using a number of *m* machines. All operations for each job must be performed in the order given by the sequence. Each operation demands the use of a particular machine for a given time. Each machine can process only one operation at a time. The goal is to find a schedule optimizing the above problem according to the given objective function (cost function, makespan, tardiness, maximal workload etc.). Scheduling consists of assigning each operation of each job a start time and a completion time on a time scale of the machine with the preference relations. In this paper the minimization of the total makespan *Cmax* (the time for completion all operations of all jobs) is considered [4].

The job shop scheduling problem (JSSP) is a difficult computational problem. Optimal solutions for job shop scheduling can be found in polynomial time if the number of jobs

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is 2, or if the number of machines is 2 and all jobs have 1 or 2 operations, or if the number of machines is 2 and all operations have duration 1. In all cases the problem obtained by incrementing the number of machines, jobs, operations or durations by 1, is NP-hard [5, 6].

Formulation of Flexible Job Shop Schedulig Problem (FJSSP)

The FJSSP is formulated as follows: There is given a set of k jobs: J_1, ... , J_k, which have to be performed on m machines M_1, ... , M_m. For each job there is given the sequence of the operations composing this job. Namely: $J_i = (O_{i,1},..., O_{i,nj(i)})$, nj is the number of operations for the corresponding job, i=1,...,k. The total number of operations is:

$$\sum_{i=1}^{k} nj(i) = n$$

Unlike the classical JSP where each operation is processed on a predefined machine, each operation $O_{i,j}$ in the FJSSP can be processed on one machine M_l out of several machines $M_l \in M_{ij}$, $M_{ij} \subseteq M$. If $M_{ij} \subset M$ for at least one operation, then it is a partial flexibility of JSP (P-FJSP); while if $M_{ij} \equiv M$ for each operation, then it is a total flexibility of JSSP (T-FJSSP).

The processing times for each operation $O_{i, j(i)}$ on each possible machine are known: $p_{i,j,l}$, i=1,...,k; j = 1,..., $j(i)$; l = 1,...,m;. In case some operation cannot be processed on a given machine, the corresponding processing time is $p_{i,j,l} = \infty$.

The proposed heuristic algorithm "Minimal Deviation" has the goal to minimize C_{max}, assigning the operations on machines in such a way, that their processing times have a minimal possible deviation from the shortest processing times.

Several priority rules are included in the novel algorithm. All dispatching rules used in the heuristic algorithm are described in section 2.

2 BASIC CONCEPTS

The constructive heuristic is based on two simple ideas:

1) re-assignment of operations on machines, where the machine workload, i.e. the total machine processing time is "non-optimal" (greater than the sum of shortest processing times (SPT)), so that the time-loss compared to SPT is minimal.
2) arrangement of operations in a feasible schedule, so that the sum of idle times on each machine is minimized.

The minimization of makespan *Cmax* (the time for completion all operations of all jobs) is considered.

Having n operations, which can be processed on m machines, in case that the operations are uniformly distributed on all machines, the mean machine workload, i.e. the mean time necessary for one machine to process the corresponding operations is:

$$t_{mean} = \frac{\sum_{i=1}^{n} SptOi}{m},$$

where *SptOi* are the shortest processing times for all operations *Oi*, i=1,...,n; If there is uniform distribution of all shortest processing times on all machines without idle times in a feasible schedule, then this is the optimal solution, and $Cmax = \lceil t_{mean} \rceil$. The value $\lceil t_{mean} \rceil$ can be accepted as a lower bound for the makespan *Cmax*, because this is the ideal case. Usually there are idle times on the machines and there is no uniform distribution of all SPT on the machines. For these reasons some deviation Δ_j from $\lceil t_{mean} \rceil$

- value will be present on each machine, $j = 1,...,m;$. Some Δ_j could be positive, and some Δ_j could have negative values. A natural idea is to minimize $\max(\Delta_j)$, $j = 1,...,m;$ creating a feasible schedule and to obtain *Cmax* in this way.

2.1 Initialization

a) According to the problem task let there exist n_j operations with shortest processing times, assigned to each machine $j = 1,...,m;$. In case for one operation there are several machines with SPT, then this operation is assigned to the machine M_j with lowest index j. It holds: $\sum_{j=1}^{m} n_j = n$.

b) For each machine the total minimal processing time for operations assigned on it (without idle times) is:

$tmin_j = \sum_{j=1}^{n_j} SptO_j$, $j = 1,...,m;$.

Correspondingly: $\Delta_j = tmin_j - \lceil t_{mean} \rceil$, $j = 1,...,m;$. Assume $\max(\Delta_j)$ is obtained on machine M_{jmax}. This machine is the bottleneck machine.

c) The initial feasible schedule is generated as follows: All operations are arranged according their shortest processing times in a decreasing order. In case the operation $O_{i,k}$ should take the current position in this sequence and the operations of job i having second index lower than k are still not included in the sequence, these operations are included in the sequence before $O_{i,k}$ keeping the order of increasing second index. After the arrangement of all operations they are assigned to machines according their shortest processing times in the obtained sequence. In case for one operation there are several machines with SPT, then this operation is assigned to the machine M_j with lowest index j.

2.2 Re-assignment of operations on different machines

The re-assignment of operations is usually connected with time losses (except the case, when there are several machines performing one and the same operation in SPT). One strategic consideration is to re-assign those operations, which lead to minimal time loss. Let O_{ij} denote an operation, where the first index denotes the job-number, and the second index denotes the operation number in the operations sequence for the concrete job. In some problem tasks it could happen, that some machines are missing operations having a concrete second index. This circumstance may cause occurrence of idle times on the corresponding machine. Second strategic consideration is to direct operations having concrete second index from the bottleneck machine to those machines, which are missing operations having this concrete second index. Such operations on a bottleneck machine have higher priority for re-direction. One operation is rejected from re-assigning in case the minimum time loss at its re-assignment exceeds the time threshold, determined in advance for the time loss.

The re-assignment includes operations transfer from the bottleneck machine to the other possible machines minimizing $\max(\Delta_j) = \Delta_{jmax}$. The re-assignment procedure starts every time with different operation, chosen for strategic reasons. After some current re-assignment it could happen, that the bottleneck machine is a new one, i. e. the index *jmax* should be updated. The re-assignment procedure terminates if the minimization of Δ_{jmax} is further impossible.

2.3 Creating feasible schedule minimizing the idle times on each machine

Once the operations are assigned to the machines, a feasible schedule should be created. The main idea here formally is to minimize the idle times on each machine.

The following dispatching rules are suggested to create the feasible schedule:

a) Select the operation having minimal second index.

b) Among the operations having one and the same second index select first this one, having earliest possible starting time. If there are several operations with the same second index and the same earliest possible starting time on one and the same machine, select first the operation having longest processing time. In case of idle times, there may be possible the selected operation to start in a time window, but the window may be narrower than operation processing time. In this case the time window is enlarged by the several time units, so that the operation can be performed in it.

c) Let an arbitrary index be denoted by "*". In case some machine *k* is missing operations having concrete second index *j*, the priorities of operations O_{*j-1} preceding the corresponding O_{*j} operations on the *k*-th machine are organized in such way, that the operation with minimal processing time is selected to be performed first. In this way the possible idle time which will arise on the *k*-th machine could be decreased.

d) The last operations of all jobs are put in a subset O_{last} and are considered after including all other operations in the schedule. The selection rule for them is: select first this one $O_{**} \in O_{last}$, having earliest possible starting time.

e) In case the bottleneck machine has the operation O_{ij} as a last processed operation in its sequence, the operations O_{i1}, O_{i2}, ... are considered for possible re-direction on other machines, with the aim to minimize the idle times on the bottleneck machine and the starting time of operation O_{ij}.

3 DESCRIPTION OF THE CONSTRUCTIVE HEURISTIC "MINIMAL DEVIATION"

3.1. The re-assignment procedure

Determine a time threshold $t_{losslim}$, restricting the time loss in case of re-assigning an operation. The time threshold is measured in correspondent time units according to the problem task.

- Assign all operations on the machines according to their SPT. In case for one operation there are several machines with SPT, then this operation is assigned to the machine M_j with lowest index *j*.
- Determine all possible re-assignments leading to time loss $t_{loss} \leq t_{losslim}$.
- Determine the priority re-assignments according the rule "missing operations having a concrete second index" on each machine.
- Perform the following re-assignment procedure:

Step 1. *Start with new re-assignment operation from bottleneck machine to one of the other machines.*

Step 2. *Update* Δ_{jmax} *and jmax.*

Step 3. *In case there are other possible re-assignment movement from the bottleneck machine select first that one, which leads to minimal time loss and make it. Update* Δ_{jmax} *and jmax. again.*

Step 4. *Repeat Step 3 until there is a decrease of* Δ_{jmax}.

Step 5. Use the re-assignment found out combination to create a new feasible schedule.

- Repeat the re-assignment procedure, starting with new re-assignment operation as far as it is still possible.

Usually the number of re-assignment combinations found by this procedure is drastically smaller than the huge number of random combinations explored for example by genetic algorithms and by other heuristic algorithms applying stochastic operators.

3.2. Generating a feasible schedule with minimal idle times on each machine

Step 1. Among operations, not included in the schedule select the operation having minimal second index *j*. If one such operation is the last one in the corresponding job, put its indices in the set O_{last} and do not consider it. If no other operations are available besides the operations in O_{last}, go to Step 5.

Step 2. On each machine select an operation according the following rules

- Let "*" denote an arbitrary index.

- On each machine select the O_{*j} operation (if there are available some O_{*j} operations), having earliest starting time. If there are several such operations on the same machine, select the operation with longest processing time to be processed first.

- In case there are O_{*j} operations assigned on different machines, among them select the operation having longest processing time to be processed first.

- In case some machine *k* is missing operations having concrete second index *j*, the priorities of operations O_{*j-1} foregoing the corresponding O_{*j} operations on the *k*-th machine are organized in such a way, that the operation with minimum processing time is selected to be processed first.

Step 3. Input the selected operation on each machine into the schedule. In case the selected operation should start in a time window, which is narrower that its length, then the time window is enlarged by the necessary time units, so that the operation can be performed in it. This happens by changing the starting time of the operation assigned after the time window to a correspondent later moment, i.e. operations are shifted to the right.

Step 4. Check if there are available O_{*j} operations, which are still not included in the schedule. If "yes" - go to Step 2, otherwise go to Step 1.

Step 5. Include consecutively all operations from O_{last} into the schedule, using the selection rule: Select first this one $O_{**} \in O_{last}$, having earliest possible starting time. The feasible schedule is ready.

3.3. The "Minimal Deviation" heuristic algorithm

Step 1. /* Initialization */

For shortest processing times of all operations calculate $\lceil t_{mean} \rceil$ (the mean processing time, necessary for one machine). Determine the index of bottleneck machine *jmax.* Calculate Δ_{jmax}.

Arrange all operations in an initial sequence as described in 2.1 c).

Assign the arranged operations in an initial feasible schedule according to their shortest processing times.

Step 2. /*Attempt for minimization of idle times */

In case of idle time window on a given machine, try to start earlier some operation processed after this window on the same machine, for example at the beginning of the idle time window. Perform change of operation position leading to minimization of idle times. Consider the operations after the moved operation in the initial sequence as not included in the schedule. Apply the procedure described in 3.2.

Step 3. /* Determination the possibilities for re-assignment of operations on different machines */

Check if there are missing operations having a concrete second index on a concrete machine. In such a case find the possibilities for re-assignment on this machine of operations having such second index. Arrange the re-assignment possibilities in a sequence according the time loss caused by each one re-assignment in a decreasing order. Ask the decision maker (DM) to determine the time threshold $t_{losslim}$, accepted for the time loss in case of re-assigning an operation.

For the given time threshold $t_{losslim}$ determine re-assignment combinations and calculate the value of Δ_{jmax} for each of them.

Step 4. /* Generating new schedules based on re-assignment combinations */

For each re-assignment combination perform Step 1. and Step 2. of the algorithm trying to minimize Δ_{jmax}. Create a list of three best solutions.

Step 5. /* Final improvement of the best schedules */

For each of obtained three best schedules, perform the procedure described in 2.2.e) making an attempt to minimize the idle times on the bottleneck machine and the starting time of the last operation, processed on this machine.

Step 6. /* Check for new re-assignment combinations */

Show the best obtained schedule to the DM. In case he/she is satisfied with it, then END. Otherwise DM can change the time threshold $t_{losslim}$ by a greater one. Then new re-assignment combinations are determined. Go to **Step 4**.

4 ILLUSTRATIVE EXAMPLE

The illustrative example considered is taken from [7]. It is presented in Table 1 :

Table 1. *Jobs and operations*

JOB	OPERATION (machine/processing time)			
	O_{*1}	O_{*2}	O_{*3}	O_{*4}
J_1	M1/7	∞	M1/3	M1/2
	∞	M2/3	∞	M2/4
	M3/4	∞	M3/6	∞
J_2	M1/8	∞	M1/7	M1/8
	M2/12	∞	M2/14	∞
	∞	M3/4	∞	M3/4
J_3	M1/10	∞	M1/2	M1/6
	M2/15	M2/2	∞	M2/3
	M3/8	M3/6	M3/4	∞
J_4	∞	M1/6	∞	M1/9
	M2/9	∞	M2/7	M2/6
	M3/5	M3/2	M3/12	M/3
J_5	M1/10	∞	M1/5	M1/4
	∞	M2/7	M2/8	M2/6
	M3/15	M3/14	∞	M3/8

For this problem $t_{mean} = \frac{\sum_{i=1}^{20} SptOi}{3} = 31$; $t_{min1} = 41$; $t_{min2} = 22$; $t_{min3} = 30$.

- *Re-assignment procedure*

  On machine M1 are missing operations (with SPT) having second index 2.

On machine M2 are missing operations (with SPT) having second index 1. On machine M3 are missing operations (with SPT) having second index 3.

Let the time threshold, accepted for the time loss in case of re-assigning an operation is accepted to be: $t_{losslim} = 4$.

The time threshold could be tuned depending on the concrete task, so that there are enough possible re-assignments, but the number of re-assignment combinations is not very high. All possible re-assignments are presented in Table2.

Table 2. *All possible re-assignments*

M1			**M2**			**M3**		
Ope-ration	Re-assign.	Time loss	Ope-ration	Re-assign.	Time loss	Ope-ration	Re-assign.	Time loss
O_{21}	M1→ M2	4	O_{32}	M2→ M3	4	O_{11}	M3→ M1	3
O_{51}	M1→ M3	**5**	O_{52}	M2→ M3	**7**	O_{31}	M3→ M1	2
O_{13}	M1→ M3	3	O_{43}	M2→ M3	**5**	**O_{41}**	M3→ M2	4
O_{23}	M1→ M2	**7**	O_{34}	M2→ M1	3	O_{42}	M3→ M1	4
O_{33}	M1→ M3	2				O_{24}	M3→ M1	4
O_{53}	M1→ M2	3				O_{44}	M3→ M2	3
O_{14}	M1→ M2	2						
O_{54}	M1→ M2	2						

The re-assignments leading to time loss $t_{loss} \leq t_{losslim}$ should ignore the operations O_{51}, O_{23}, O_{52}, O_{43}. Two other operations O_{12} and O_{22} are fixed to be processed on M2 and M3 correspondingly. The priority re-assignments are: **O_{21}**, **O_{13}**, **O_{33}**, and **O_{41}**. The re-assignment combinations obtained after applying the re-assignment procedure and after generating a feasible schedule are shown in Table 3:

Table 3. Obtained re-assignment combinations

Re-assignment combination:		*Cmax*	Re-assignment combination:		*Cmax*
1	O_{21}, M1→M2, time loss = 4 t_{min1} = 33; t_{min2} = 34; t_{min3} = 30. t_{real1} = 42, (idle time = 9); t_{real2} = 34; t_{real3} = 38, (idle time = 8).	42	6	O_{33}, M1→M3, time loss = 2, O_{54}, M1→M2, time loss = 2, t_{min1} = 35; t_{min2} = 28; t_{min3} = 34. t_{real1} = **35**; t_{real2} = **35**, t_{real3} = **34**.	35
2	O_{21}, M1→M2, time loss = 4, O_{33}, M1→M3, time loss = 2, t_{min1} = 31; t_{min2} = 34; t_{min3} = 34. t_{real1} = 36, (idle time = 5); t_{real2} = 34; t_{real3} = 34.	36	7	O_{33}, M1→M3, time loss = 2, O_{54}, M1→M2, time loss = 2, O_{14}, M1→M2, time loss = 2, t_{min1} = 33; t_{min2} = 32; t_{min3} = 34. t_{real1} = 33; t_{real2} = 39, t_{real3} = 34.	39
3	O_{21}, M1→M2, time loss = 4, O_{13}, M1→M3, time loss = 3, t_{min1} = 30; t_{min2} = 34; t_{min3} = 36. t_{real1} = 36, (idle time = 6); t_{real2} = 34; t_{real3} = 36.	36	8	O_{13}, M1→M3, time loss = 3, O_{54}, M1→M2, time loss = 2, t_{min1} = 34; t_{min2} = 28; t_{min3} = 36. t_{real1} = 34; t_{real2} = 35, (idle time = 7); t_{real3} = 36.	36
4	O_{21}, M1→M2, time loss = 4, O_{13}, M1→M3, time loss = 3, O_{42}, M3→M1, time loss = 4, t_{min1} = 36; t_{min2} = 34; t_{min3} = 34. t_{real1} = 36; t_{real2} = 36, (idle time = 2); t_{real3} = 39, (idle time = 5).	39	9	O_{13}, M1→M3, time loss = 3, O_{33}, M1→M3, time loss = 2, O_{14}, M1→M2, time loss = 2, O_{41}, M3→M2, time loss = 4, t_{min1} = 34; t_{min2} = 35; t_{min3} = 35. t_{real1} = **34**; t_{real2} = **35**; t_{real3} = **35**.	35

Re-assignment combination:		*Cmax*	Re-assignment combination:		*Cmax*
5	O_{33}, M1→M3, time loss = 2, O_{53}, M1→M2, time loss = 3, t_{min1} = 34; t_{min2} = 30; t_{min3} = 34. t_{real1} = 34; t_{real2} = 37, (idle time = 7); t_{real3} = 37, (idle time = 3).	37			

5 CONCLUSIONS

A constructive heuristic "minimal deviation" algorithm for solving FJSSP optimizing the makespan is presented in this paper. It creates a feasible schedule, assigning the operations on machines according their shortest processing times (SPT). Then a strategy for re-assignment of operations from the bottleneck machine to other possible machines is proposed. The goal is minimization of makespan *Cmax*. An illustrative example with 5 jobs and 20 operations, processed on 3 machines is presented, where the optimal solution is found. Also several near-optimal solutions of good quality are found. The obtained result is encouraging. The presented heuristic performs very efficiently, because only small number of strategic combinations of operations assignments have to be enumerated. An indirect measure of solution quality is the deviation of obtained solutions from the ideal solution based on shortest processing times. Based on this measure the DM can make a decision, is he/she satisfied or not with the quality of the obtained solutions and correspondingly to terminate or to continue the calculations. A field for further research is to investigate the behavior of proposed heuristic algorithm on a large sample of benchmark test instances and to evaluate the quality of the obtained solutions statistically.

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STATISTIČKE KONTROLE KVALITETA – STUDIJA SLUČAJA

Lana Šikuljak[1], Ranka Gojković[2], Slaviša Moljević[3]

Rezime: U konkurentnom okruženju u kojem živimo organizacije se sve više trude da proizvedu kvalitetan proizvod po najnižim mogućim troškovima, kako bi osigurali svoj opstanak na tržištu. Niz aktivnosti koje se preduzimaju u tom cilju predstavljaju statističku kontrolu kvaliteta (Statistical Process Control – SPC). Ovaj rad predstavlja studiju slučaja o primjeni statističke kontrole kvaliteta, a sve u cilju kontrole i stalnog poboljšanja kvalitet proizvoda. U radu su opisana potrebna mjerenja, standardi koji definiraju proces i statistički alati koji relativno jednostavno omogućuju uvid u stanje kvalitete.

Ključne riječi: Statistička kontrola kvaliteta, Kvalitet, Kontrolne karte

STATISTICAL PROCESS CONTROL – CASE STUDY

Abstract: In a competitive environment in which we live organizations are increasingly trying to produce a quality product at the lowest possible cost, in order to ensure their survival on the market. A series of activities undertaken for this purpose are statistical process control (SPC). This paper presents a case study on the application of statistical process control, all for the purpose of controlling and continuously improving the quality of the product. The paper describes the necessary measurements, standards that define the process and statistical tools that relatively easily provide insight into the state of quality.

Key words: Statistical Process Control, Quality, Control charts

1 UVOD

Zadovoljstvo potrošača se može obezbjediti proizvodima većeg kvaliteta, dok se veći kvalitet proizvoda može postići povećanjem kvaliteta procesa. Dakle, otkrivanjem i eliminisanjem defekata u procesima, spriječiće se pojava defektnih proizvoda, koji preko nezadovoljstva potrošača narušavaju reputaciju preduzeća i u

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konačnom smanjuju kvalitet njegovog poslovanja. Za otkrivanje defekata posebno su značajne kontrolne karte.

Kontrolna karta predstavlja veoma efikasan alat za regulisanje i upravljanje kvalitetom proizvoda i procesa rada.

Kontrole karte se koriste za otkrivanje promjena u procesu. Obezbjeđuju ispitivanje uzroka promjene ili regulisanje procesa, čime se održava sposobnost procesa i unaprjeđuje proces u vremenu. Osim preglednog prikazivanja podataka kontrolne karte ukazuju na promjene procesa, obezbjeđuju otkrivanje slučajnih varijacija i varijacija nastalih kao rezultat posebnih uzroka. Ključni aspekt primjene statističke kontrole procesa, pa tako i kontrolnih karti kao osnovnog alata u statističkoj kontroli procesa, je da se dobije predvidljiv proces, a time i predvidljiv rezultat.

2 STATISTČKA KONTROLA KVALITETA

Jedan od fundamentalnih ciljeva upravljanja procesom jeste identifikovanje procesa koji su van kontrole, preuzimanje odgovarajućih postupaka kako bi se isti doveli u stanje statističke kontrole i njihovo održavanje u stanju statističke kontrole. Niz aktivnosti koje se preduzimaju u tom cilju predstavljaju statističku kontrolu kvaliteta (Statistical Process Control – SPC). Kontrolne karte su jedna od najvažnijih i najstarijih tehnika statističke kontrole kvaliteta.

2.1 Kontrolne karte

Kontrolne karte su grafički prikaz promjene vrijednosti kontrolisanih parametara sa redoslijedom kontrolisanja. Omogućavaju neprekidno praćenje tehnoloških procesa i blagovremeno otkrivanje njihovog narušavanja. Kontrolnim kartama je obezbijeđeno statističko praćenje kvaliteta materijala, dijelova i proizvoda i utvrđivanje sposobnosti procesa i stanja proizvodne opreme.

Kontrolne karte su specijalne dijagramske forme čiju osnovu čini mreža horizontalnih i vertikalnih linija. Na apcisu se nanosi vrijeme odvijanja toka procesa ili redni brojevi uzorka, koji po određenom planu slijede vremenski proces, a na ordinatu se unose karakteristike kvaliteta ili statističke karakteristike uzorka. Na mrežu se zatim unose, u vidu tačaka, rezultati mjerenja nivoa i toka kvaliteta procesa (proizvoda/usluge) na osnovu uzorka. Tako se dobija veoma pregledna slika kvaliteta u vremenskom odvijanju procesa. Kada se u ovako formulisan dijagram ucrtaju centralna linija i kontrolne granice tada je kontrolna karta kompletna (slika 1) [1].



Slika 1. *Kontrolna karta*

2.1.1 $\overline{X}$ – R kontrolne karte

Za praćenje numeričkih karakteristika kvaliteta proizvoda najčešće se koriste X-R kontrolne karte.

Klasične kontrolne karte, u kojima se prati kretanje aritmetičkih sredina X i raspona R uzoraka koji se povremeno uzimaju iz procesa sastavljene su tako da koriste potpunu prednost ocjene na osnovu matematičke statistike. Takva karta omogućava brze i pouzdane ocjene prikazivanja i praćenja promjene tehnološkog procesa. Naročito je pogodna u procesima u kojima se proizvodi na posmatranoj operaciji pojedinačno tretiraju, ali se takođe uspešno primenjuje i u procesnoj industriji. Kontrolnom tehnologijom definiše se veličina uzorka i učestalost kontrolisanja, a kontrolor mjeri karakteristiku kvaliteta čije se variranje posmatra. Kontrolor u svakom posmatranju evidentira pojedinačne vrijednosti za posmatranu karakteristiku kvaliteta na uzorku koji ispituje.

Uzorak za ove kontrolne karte je mali, što znači n<25, a u praksi se najčešće uzima n=5, n=10 ili između 5 i 10. Da bi ovu kontrolnu kartu mogli podvrći statističkoj analizi potrebno je da broj posmatranja bude bar 20 (k≥20). Kontrolor u svakom posmatranju evidentira pojedinačne vrijednosti X za posmatranu karakteristiku kvaliteta na uzorku n koji ispituje. Iz ovih vrijednosti se za svako posmatranje izračunava prosječna vrijednost X i raspon R [2].

2.2 Sposobnost procesa

Analiza mogućnosti i sposobnosti procesa je ispitivanje varijacija i raspodjele karakteristika procesa sa ciljem ocjene sposobnosti procesa za izradu proizvoda u granicama rasipanja utvrđenim tehničkim zahtjevima.

Sposobnost procesa se češće ispituje, analizira i ocjenjuje korištenjem indeksa sposobnosti kao što su: indeks potencijala ili preciznosti procesa Cp (mjera rasipanja procesa) i indeks sposobnosti - tačnosti Cpk (mjera podešenosti procesa).

Indeks potencijala procesa je odnos propisane (T) i prirodne tolerancije ili rasipanja procesa (Tp):

$$C_p = \frac{GGT - DGT}{6 \cdot \sigma} = \frac{T}{T_p} \tag{1}$$

Indeks potencijala procesa Cp ukazuje na preciznost i rasipanje procesa, pa se često naziva i indeksom preciznosti. U zavisnosti od vrijednosti Cp proces se ocjenjuje kao:

- neprecizan Cp <1,
- kritično precizan 1 < Cp < 1,33 i
- precizan Cp $\geq$ 1,33. [3] [4]

Indeks sposobnosti procesa Cpk ukazuje na tačnost (podešenost) procesa i opreme i često se naziva indeksom tačnosti.

$$C_{pk} = \min\left\{\frac{GGT - \overline{X}}{3 \cdot \sigma}, \frac{\overline{X} - DGT}{3 \cdot \sigma}\right\} \tag{2}$$

Zavisno od vrijednosti Cpk proces se ocjenjuje kao:

- netačan (nepodešen) Cpk < 1,
- kritiþno tačan (kritično podešen) 1 < Cpk < 1,33 i
- tačan (podešen) Cpk ≥ 1,33. [3] [4]

Procesi (oprema) su sposobni ukoliko su precizni i tačni ili kada su indeksi: »

- preciznosti Cp ≥ 1,33 (atributivna ocjena: precizan) i
- tačnosti Cpk ≥ 1,33 (atributivna ocjena: tačan - podešen) [5]

3 STUDIJA SLUČAJA

Praktična primjena i značaj kontrolnih karata tipa X – R prikazana je na primjeru izrade valjčića za konusne ležajeve. Prilikom kontrole valjčića, vrše se mjerenja na omotaču, širem čelu, kontrolišu se prečnici i radijusi. U ovom radu je posmatran parametar Ks, koji predstavlja visinu neravnina koja se mjeri na širem čelu valjčića, tj. na stazi klizanja. Može se reći da se mjerenje vrši na stazi klizanja, u tački gdje se valjčić oslanja na unutrašnji prsten ležaja. Ovo mjesto je izloženo opterećenju, zbog čega je izuzetno važna tačnost za ispravno funkcionisanje valjčića.

Dozvoljena odstupanja za parametar Ks data su u tablici 1.

Tabela 1. *Izvod iz standarda za dozvoljena odstupanja parametara*

Class	*RTD10*		*RTL01Z*	*RTL01H*	*RTL01L*	*RTS20A*	*RTS51A*
	Dw (µm)		*Ks (µm)*	*L (µm)*		*Ra√D S (µm)*	*Ra√R S (µm)*
	>	*≤*	*max.*	*high*	*low*	*max.*	*max.*
II	-	10	5	0	-300	0,10	0,16
	10	20	6	0	-350	0,10	0,16
	20	30	8	0	-350	0,16	0,25
III	-	10	8	0	-300	0,20	0,25
	10	20	10	0	-350	0,20	0,25
	20	30	12	0	-350	0,20	0,25
IIIB225	-	10	8	0	-300	0,12	0,25
	10	20	10	0	-350	0,12	0,25
	20	30	12	0	-350	0,16	0,25
MP			*645 1*	*300*			

Postupak mjerenja podrazumijeva da se vrh komparatora postavi na tačno definisano mjesto na stazi, valjčić se postavlja u preciznu matricu i sve zajedno se okreće nekoliko puta. Potom se očitava najveće odstupanje komparatera, što predstavlja parametar Ks za jedno mjerenje (Slika 2.).



Slika 2. *Postupak mjerenja*

Mjeri se ukupno 20 uzoraka, periodično, na svakih sat vremena, sa veličinom uzoraka $n = 5$. U sljedećoj tabeli prikazani su podaci o izmjerenim vrijednostima parametra Ks.

Tabela 2. *Izmjerene visina neravnina na širem čelu valjčića Visina neravnina Ks*

R. br. uz.	Redni broj dijela					$\overline{X}$	R
	1	2	3	4	5		
1	0	3	5	7	10	5	10
2	5	0	5	3	7	4	7
3	4	2	10	8	7	6,2	8
4	3	5	7	10	0	5	10
5	4	5	10	3	7	5,8	7
6	5	10	8	3	2	5,6	8
7	2	2	3	0	4	2.2	4
8	10	6	4	2	3	5	8
9	9	4	3	3	2	4,2	7
10	2	3	5	3	5	3,6	3
11	9	3	4	5	7	5,6	6
12	7	2	5	3	3	4	5
13	3	8	4	4	5	4,8	5
14	5	3	4	3	4	3,8	2
15	5	4	8	2	3	4,4	6
16	6	4	2	5	5	4,4	4
17	5	4	2	4	2	3,4	3
18	3	2	6	5	4	4	4
19	4	5	2	3	3	3,4	3
20	5	2	4	7	5	4,6	5

Izračunavanje centralnih linija:

$$\overline{\overline{x}} = \frac{1}{20}\sum_{i=1}^{20}\overline{x} = 4,45\left[\mu m\right]$$

$$\overline{R} = \frac{1}{20}\sum_{i=1}^{20}\overline{R_i} = 5,75\left[\mu m\right]$$

Proračun gornje i donje kontrolne granice za $\overline{\overline{x}}$ kontrolnu kartu:

$$GKG_{\overline{x}} = \overline{\overline{x}} + A_2\overline{R}$$

$$DKG_{\bar{x}} = \bar{\bar{x}} - A_2 \bar{R}$$

Za $n = 5$ iz odgovarajućih tabela dobijamo da je $A_2 = 0,577$.

$$GKG_{\bar{x}} = 4,45 + 0,577 \cdot 5,75 = 7,767 [\mu m]$$

$$DKG_{\bar{x}} = 4,45 - 0,577 \cdot 5,75 = 1,133 [\mu m]$$

Proračun gornje i donje kontrolne granice za R kontrolnu kartu:

$$GKG_R = D_4 \bar{R} \qquad DKG_R = D_3 \bar{R}$$

Za $n = 5$ iz odgovarajućih tabela dobijamo da je $D_3 = 0, \quad D_4 = 2,114$.

$$GKG_R = D_4 \bar{R} = 2,114 \cdot 5,75 = 12,16 [\mu m]$$

$$DKG_R = D_3 \bar{R} = 0 \cdot 0,0058 = 0 [\mu m]$$



Slika 3. $\bar{X}$ – *R kontrolna karta*

Na slici 3. se može vidjeti da se sve izmjerene tačke nalaze unutar kontrolnih granica.

Stabilan proces je onaj koji proizvodi rezultate procesa od kojih su svi, ili zadovoljavajući broj unutar kontrolnih granica. Po pravilima, posljednjih 25 tačaka mora biti u navedenim granicama, a s obzirom da se svih 20 tačaka nalazi u kontrolnim granicama, možemo zaključiti da je proces stabilan.

Pošto se može dogoditi da je proces nestabilan iako su osnovna pravila ispunjena, potrebno je dalje tumačiti dobijenu kontrolnu kartu, odnosno odrediti maksimalni broj tačaka koje uzastopno rastu/opadaju kao i maksimalni broj uzastopnih vrijednosti ispod/iznad centralne linije. Sa kontrolne karte možemo vidjeti da je maksimalni broj tačaka koje rastu odnosno opadaju 2. Proces se u kritičnom stanju

nalazi ukoliko taj broj prelazi 5, a nestabilan je ukoliko prelazi 7 [6], tako da je proces stabilan sa ove tačke gledišta. Konačan zaključak, koji možemo izvesti iz prethodnih tumačenja na osnovu jasno definisanih pravila, je da je proces stabilan i predvidljiv ali da postoji vjerovatnoća da će se pojaviti nestabilno stanje.

U cilju određivanja sposobnosti procesa biće određeni indeks potencijala i indeks sposobnosti procesa.

Propisana tolerancija za drugu klasu (tabela 1.) iznosi:

$$T = 8[\mu m]$$

Prirodna tolerancija:

$$T_p = 6 \cdot \sigma = 5,78619[\mu m]$$

Gdje standardna devijacija izračunata korišćenjem Minitab programa iznosi:

$$\sigma = 0,964365[\mu m]$$

Indeks potencijala procesa:

$$C_p = \frac{T}{T_p} = 1,382602 > 1,33$$

Indeks sposobnosti procesa:

$$C_{pk} = \min\left\{\frac{GGT - \overline{X}}{3 \cdot \sigma}, \frac{\overline{X} - DGT}{3 \cdot \sigma}\right\} = 1,538145 > 1,33$$

Na osnovu rezultata mjerenja evidentno je da proces spada u grupu preciznih i tačnih procesa, prema klasifikaciji datoj u odjeljku 2.

4 ZAKLJUČCI

Statistička kontrola kvaliteta se pokazala kao pouzdan, neizbježan i nezamjenljiv alat u kontroli procesa. Statistički podaci predstavljaju i pokazatelje kojima se definiše prihvatanje određenog proizvoda/usluge, odnosno definiše interval pouzdanosti za datu karakteristiku kvaliteta. Kontrolne karte, kao inženjersko-matematičko sredstvo, predstavljaju veoma pogodan alat za ostvarenje ciljeva statističke kontrole. Optimalnom primjenom kontrolnih karata obezbjeđuje se konstantno praćenje procesa, usmjeravanje ka željenom toku i preduzimanje eventualnih korektivnih mjera. Takođe, njihovom primjenom osigurava se ispunjenje projektovanih ili zahtijevanih karakteristika kvaliteta, odnosno ispunjenje zahtjeva određenog standarda. Svojom jednostavnošću primjene i pouzdanošću obezbjeđuju korisnicima pogodnost u radu i relevantne pokazatelje procesa, a kontrolorima procesa daju validne podatke o toku procesa. Kao takve, predstavljaju alat kojim se čitav proces drži u zadatim granicama.

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MOTIVACIJA U PRIVATNOM I DRŽAVNOM SEKTORU

Mirjana Jokanović[1], Aleksandra Koprivica[2], Petar Ivanković[3]

Rezime: Pitanje motivacije zaposlenih jedno je od pitanja vezanih za upravljanje poslovanjem, koje se u poslednjih nekoliko godina sve češće postavlja i sve više dobija na značaju. Kako bi uspješno poslovalo, svako preduzeće bi trebalo da pronađe optimalnu kombinaciju materijalnih podsticaja za svoje zaposlene, koja će zavisiti od brojnih faktora: sektora u kome posluje, konkurencije na tržištu radne snage, prirode posla, strukture zaposlenih i sl., te nematerijalnih. Rad se bavi istraživanjem i poređenjem motivacije i motivacijskih faktora u privatnom i državnom sektoru.

Ključne riječi: motivacija, organizacija, zaposleni

THE MOTIVATION IN PRIVATE AND PUBLIC SECTOR

Abstract: The issue of employee motivation is one of the issues related to business management, which has become more and more important in the last few years. In order to successfully do business, each company should find the optimal combination of material incentives for its employees, which will depend on a number of factors: the sector in which it operates, the competition in the labor market, the nature of the work, the structure of employees, etc., and the intangible. The paper deals with research and comparison of motivation and motivation factors in the private and public sector.

Key words: motivation, organization, employees

1 UVOD

Interes za motivaciju za rad, odnosno faktori koji organizuju, usmjeravaju i određuju intenzitet i trajanje radne aktivnosti, star je nesumnjivo koliko i sam ljudski rad. Kulminacija teorijskog, istraživačkog i praktičnog menadžerskog interesa za radnu motivaciju poklapa se sa naznakama koncepcije ljudskih resursa i zajedno se s njom razvijaju i mnogobrojne strategije za podizanje motivacije zaposlenih, koje se sve zajedno mogu podijeliti u dvije grupe, a to su materijalne i nematerijalne strategije

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motivacije.

Danas je dominantan problem pitanje ljudskih interesa i motivacije za rad. Više nisu toliko u pitanju ljudske mogućnosti i znanja, jer su nesumnjivo veliki, koliko motivisanje i podsticanje konstruktivne primjene tih mogućnosti, u funkciji ostvarenja organizacijskih ciljeva i razvoja [1].

Ono što predstavlja vječnu dilemu kod menadžera jeste pitanje da li isti faktori motivacije utiču na efikasnost i efektivnost zaposlenih u privatnom i javnom sektoru ili pak ne, što predstavlja i predmet istraživanja ovog rada.

2 MOTIVACIJA

Motivacija odgovara na pitanje zašto se neko ponaša na određeni način, postiže ili ne postiže radnu uspješnost određenog nivoa. Najjednostavnije određenje motivacije svakako je ono koje smatra da je ona traganje za onim što nedostaje ili što je potrebno osobi, odnosno traženje zadovoljenja potreba [1].

Takođe, motivacija predstavlja kompleks sila koje iniciraju i zadržavaju osobu na radu, u organizaciji i ona započinje i održava aktivnosti u zacrtanom smjeru.

Motivacije se odnosi na niz povezanosti nezavisnih i zavisnih promjenljivih, koje objašnjavaju smjer, veličinu i trajanje ponašanja pojedinca.

Menadžeri se, takođe, slažu da motivacija predstavlja zajednički pojam za sve unutrašnje faktore, koji konsoliduju intelektualnu i fizičku energiju, iniciraju i organizuju individualne aktivnosti, usmjeravaju ponašanje, te mu određuju smjer, intenzitet i trajanje [1].

Na motivaciju djeluje mnoštvo faktora, koji se mogu grupisati u 4 kategorije [1]:

1. individualne osobine,
2. karakteristike posla, koji pojedinac obavlja,
3. karakteristike organizacije, odnosno radne situacije u kojoj se pojedinac nalazi i
4. šira društvena okolina.

Individualne osobine podrazumijevalju sljedeće: percepcije, očekivanja, vrijednosti, stavove, potrebe, preferencije, te demografske i socijalne osobine.

Karakteristike posla se odnose na vještine koje isti zahtjeva, raznolikost, zanimljivost, autonomiju i feedback o rezultatima.

Karakteristike radne situacije predstavljaju skup faktora koji se mogu podijeliti u dvije grupe i to: organizacijska praksa (politika nagrađivanja, individualne nagrade, organizacijska kultura i klima) i neposredna radna okolina (saradnici, menadžeri, radni uslovi).

Sve strategije motivacije se mogu svrstati u dvije grupe i to: materijalne i nematerijalne strategije motivacije.

2.1 Materijalne strategije motivacije

Posmatrana u kontekstu motivisanja za rad, ali i raznolikih i specifičnih strategija, koje se unutar nje razvijaju u savremenim preduzećima, materijalna, odnosno finansijska stimulacija nije jednoznačan i jednodimenzionalan koncept, ona predstavlja složenu konstrukciju različitih oblika motivisanja, usmjerenih na osiguranje i poboljšanje materijalnog položaja zaposlenih i finansijskih kompenzacija za rad [1].

Ove strategije se odnose na [1]:

- isplate nadokanada,
- stimulacije i

- beneficije.

Isplata nadokanada podrazumijeva novu platu, sire grupisanje i nadoknade zasnovane na kompenzacijama i vještinama.

Stimulacije predstavljaju jedan od najčešće korišćenih alata motivisanja menadžera, a odnose se na: priznanja, dodatak na platu, plaćanje po komadu, timske podsticajne planove, podjelu profita, vlasništvo nad akcijama, te onlajn programme nagrađivanja.

Beneficije se odnose na tzv. povlastice koje zaposleni imaju u organizaciji i mogu biti: beneficije u vezi sa odsustvovanjem sa posla, beneficije u vezi sa osiguranjem, penzione beneficije i beneficije koje se odnose na usluge zaposlenima.

Materijalne nagrade se, može se slobodno pretpostaviti, djeluju slično na ponašanje većine ljudi u okviru iste kulture.

2.2. Nematerijalne strategije motivacije

Cjelovit motivacijski sistem, uz materijalne strategije, koje čine njegov temelj, mora uključivati i razgranatu nadgradnju ili infrastrukturu različitih nematerijalnih podsticaja za rad, koji zadovoljavaju raznolike potrebe ljudi u organizacijama. Temeljno polazište prakse motivacije u današnjim organizacijama jeste spoznaja da će motivacija za rad biti veća što čovjek može zadovoljiti više svojih raznolikih potreba. Pri tome, treba imati na umu da ljudi žele radom zadovoljiti više raznolikih potreba, a ne samo egzistencijalne ili one materijalnog standarda [1].

Kada se govori o nematerijalnim strategijama motivacije, misli se na sljedeće [2]:

- rotacija posla,
- proširivanje posla,
- obogaćivanje posla,
- particiracija zaposlenih,
- opunomoćivanje,
- fleksibilni oblici radnog vremena,
- redizajniranje organizacione strukture.

Rotacija posla podrazumijeva planirano i vremenski ograničeno mijenjanje posla zaposlenog i kruženje od jednog do drugog radnog mjesta, u skladu sa njegovom stručnošću i sposobnostima [2].

Proširivanje posla podrazumijeva dodjeljivanje srodnih poslova zaposlenom, čime se povećava odgovornost zaposlenog i njegova zainteresovanost za posao [2].

Obogaćivanje posla podrazumijeva davanje većih ovlašćenja zaposlenom, u smislu odlučivanja o metodama i načinu rada, povećanju odgovornosti zaposlenih, povećanju saradnje sa kolegama, sagledavanju uloge koju zaposleni ima u stvaranju dodatne vrijednosti kao cjeline [2].

Participacija zaposlenih uključuje zaposlene u process donošenja odluka [2].

Opunomoćivanje obuhvata podjelu moći sa drugima, tako da opunomoćeni zaposleni ima osjećaj odgovornosti, svjestan je povjerenja koje mu je dato, što ga dodatno motiviše da radi na još efikasniji način [2].

Fleksibilni oblici radnog vremena podrazumijevaju fleksibilne i skraćene radne sedmice, obavljanje posla kod kuće i sl. i oni ne samo da povećavaju produktivnost zaposlenih, već ih dodatno motivišu da rade na još efikasniji način [2].

Redizajniranje organizacione kulture kao faktora motivacije navodi se činjenica da će ovakvu ulogu odigrati samo organizaciona kultura koja ima određena obilježja, tj.

ona koja svojim osnovnim sredstvima smatra svoje zaposlene i znanje koje posjeduju, razvija klimu koja podstiče kreativnost i inovaciju, potencira nagrađivanje dobrog rada i dobih poslovnih praksi, pospješuje komunikaciju među zaposlenima, obezbjeđuje uslove u kojima se vreduje i cijeni svaka nova ideja, stvara i njeguje osjećaj zadovoljstva i uspjeha zbog visokog kvaliteta rada [2].

3 EKSPERIMENTALNA ISTRAŽIVANJA, REZULTATI I DISKUSIJA

Istraživanja, vezana za analiziranu problematiku ovog rada, vršena su anketnom metodom u dva različita tipa preduzeća i to Hotelu SL Panorama, koji spada u kompleks Grada Sunca, kompanije Swisslion (privatni sektor) i Hidroelektranama na Trebišnjici (državni sektor), oba sa područja grada Trebinja. Deskriptivna statistička karakteristika ispitanika prikazana je u tabeli 1.

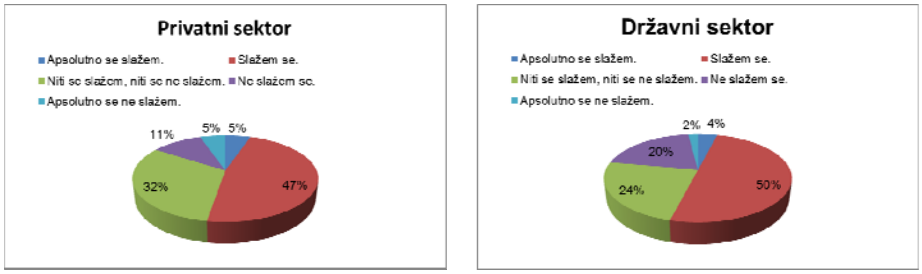
Tabela 1. *Deskriptivna statistička karakteristika ispitanika*

OPIS	BROJ ISPITANIKA			
	PRIVATNI SEKTOR		*DRŽAVNI SEKTOR*	
	APSOLUTNO	RELATIVNO [%]	APSOLUTNO	RELATIVNO [%]
POL:				
M	6	31,57	20	40
Ž	13	68,43	30	60
DOB:				
do 25	5	36,31	-	-
26-35	9	47,36	24	48
36-45	4	21,05	15	30
46-55	1	5,27	8	16
56-65	-	-	3	6
66 i više	-	-	-	-
NIVO OBRAZOVANJA:				
NKV	-	-	-	-
PKV	-	-	-	-
KV	-	-	-	-
SSS	15	78,95	9	18
VKV	-	-	2	4
VŠS	1	5,27	1	2
VSS	3	15,78	29	58
MR/MA	-	-	9	18
DR	-	-	-	-

Kao što se može primjetiti, na osnovu podataka iz Tabela 1, ženski pol je fleksibilniji za saradnju i pomoć pri istraživanju, prilikom korišćenja anketne metode.

U privatnom sektoru, budući da je hotel uslužna organizacija, preovladava mlađa radna snaga, uglavnom sa srednjim nivoom obrazovanja, dok je u državnom sektoru situacija drugačija. Zastupljene su gotovo sve životne dobi, a preko 80% ljudskih resursa je visokoobrazovano.

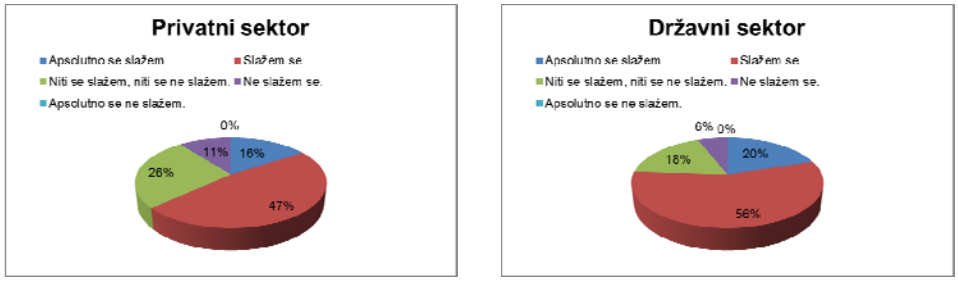
Na konstataciju „Glavni razlog mog rada jeste visina plate.“, ispitanici su odgovorili kako je prikazano slikom 1.



Slika 1. *Odgovori ispitanika na prvu konstataciju*

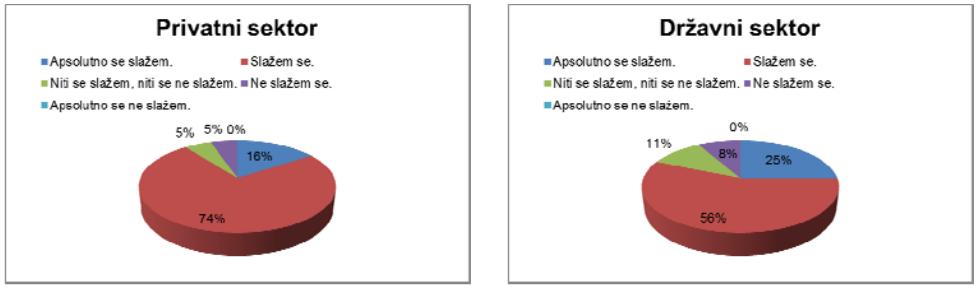
Kao što se može logički zaključiti, na osnovu slike 1, iako se analiziraju dva različita tipa organizacija, zaposleni imaju slično mišljenje u vezi sa postavljenom konstatacijom.

Uključivanje zaposlenih u proces zajedničkog rješavanja problema, svakako bi trebao da bude primarni cilj svake organizacije, budući da se na taj način zaposleni motiviše, stavljajući mu do znanja da se njegovo mišljenje cijeni. Kakvo je stanje u našoj privredi, vezano za prethodno pomenute situacije, ilustruje slika 2.



Slika 2. *Odgovori na konstataciju „Moj neposredni rukovodilac me podstiče i uključuje u zajedničko rješavanje problema”*

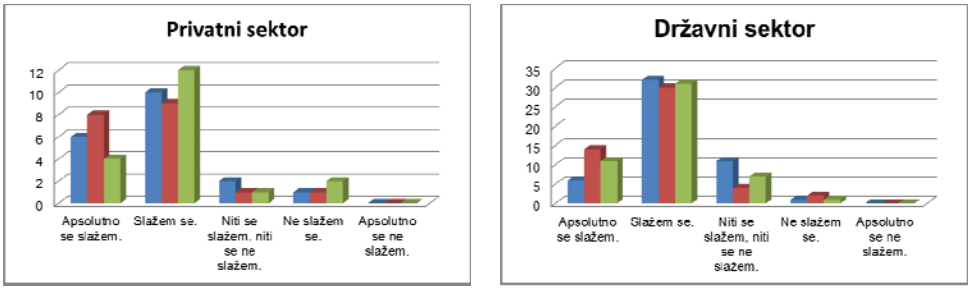
Da li menadžment i u kolikoj mjeri posvećuje pažnju motivaciji, najbolje oslikava sljedeća slika, koja predstavlja odgovor na konstataciju “Da bih davao/la bolje rezultate na poslu, trebam biti bolje motivisan/a.”



Slika 3. *Odgovori ispitanika na treću konstataciju*

Na motivaciju zaposlenih mogu da utiču individualne osobine, karakteristike posla, te karakteristike radne sredine. Koliko su prethodno pomenuti faktori bitni za

zaposlene, može se vidjeti na sljedećoj slici 4, gdje su faktori označeni bojama respektabilno.

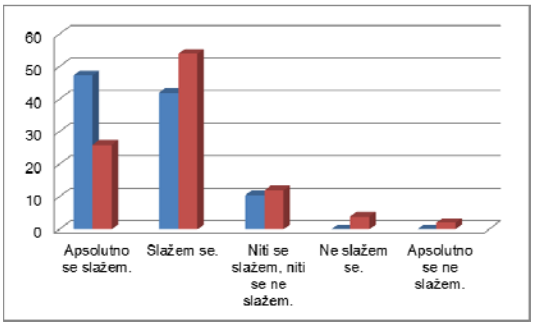


Slika 4. *Mišljenje ispitanika o faktorima motivacije*

Kako se može zaključiti sa slike 4, svi faktori motivacije su podjednako bitni za zaposlene i svi podjednako utiču na njih. U razgovorima sa ispitanicima, isti se slažu da je ipak najteže zadovoljiti faktore vezane za karakteristike radne sredine.

Od svih nematerijalnih strategija nagrađivanja, prethodno objašnjenim u teoretskom dijelu rada, ispitanici u oba sektora smatraju da su dvije najvažnije fleksibilni oblici radnog vremena i proširivanje i obogaćivanje posla.

Slika 5. daje prikaz odgovora na pitanje „Da li se slažete sa konstatacijom da je pohvala za dobro obavljen posao psihološki ček?" Plavom bojom su prikazani odgovori ispitanika iz privatnog, dok su crvenom bojom označeni odgovori ispitanika iz državnog sektora, izraženi procentualno.



Slika *5. Odgovori ispitanika na pitanje „Da li se slažete sa konstatacijom da je pohvala za dobro obavljen posao psihološki ček?"*

Tabela 2. prikazuje odgovore na pitanje „Koji bi Vas oblici ponašanja Vašeg menadžera, prema Vama, frustrirali i demotivisali, a koji bi Vas motivisali?". Prethodno pomenuto pitanje je otvorenog tipa, te stoga postoji i veći broj odgovora.

Na pitanje „Šta bi Vas dodatno motivisalo?", ispitanici su svoje glasove i primat dali usavršavanju, većoj plati, poštovanju i smanjenju stresa, dok su u drugom planu bili veća briga o zaposlenima, plaćen godišnji odmor i automobil.

Tabela 2*. Motivatori i demotivatori zaposlenih*

PRIVATNI SEKTOR		**DRŽAVNI SEKTOR**	
frustriralo i demotivisalo	*motivisalo*	*frustriralo i demotivisalo*	*motivisalo*
• kazne • neprofesionalizam nadređenih • nervoza • stres • nepoštovanje • negativna energija • nepovjerenje	• mjesec dana odmora • povišica • poštovanje • uvažavanje • povjerenje • pohvala • smirenost • profesionalizam	• loša organizacija posla • nestručnost • favorizovanje radnika • negativna atmosfera • bahatost • ponižavanje • omalovažavanje • mobbing • sebičnost • zloupotreba položaja • agresivnost	• dobra organizacija posla • razumijevanje problema • ljubaznost • uvažavanje stručnosti • poštovanje • pohvale • slobodni dani • razvoj karijere • participacija u odlučivanju • dobra komunikacija

Tabela 3 prikazuje odgovore na pitanje, otvorenog tipa, „Koje su posljedice nemotivisanosti zaposlenih?"

Tabela 3*. Posljedice nemotivisanosti*

PRIVATNI SEKTOR	**DRŽAVNI SEKTOR**
• otkaz • prijetnje • lijenost • veća mogućnost greške u radu • nezadovoljstvo • smanjena produktivnost • stres • negativna radna atmosfera • nervoza • loš kvalitet proizvoda • loši međuljudski odnosi • apsentizam • nemarnost prema imovini organizacije • loš poslovni rezultat	• loš radni učinak • apatija • osjećaj beskorisnosti • kraj preduzeća • loša atmosfera • odsustvo želje za stručnim usavršavanjem • slaba komunikacija • frustracije • smanjena efektivnost • stres • slab kvalitet • nezavršen posao • produženje roka isporuke • neispunjavanje radnih zadataka • nezainteresovanost • loši međuljudski odnosi • neodgovornost • gubitak volje za napredovanjem u karijeri • suzdržanost u pokazivanju svojih sposobnosti • nervoza

4 ZAKLJUČCI

Motivacija zaposlenih zasigurno bi trebala biti jedan od primarnih ciljeva menadžmenta svake organizacije, jer u koliko imamo motivisane zaposlene, sasvim je sigurno da će i ostali ciljevi preduzeća, profit, kvalitet, dobri međuljudski odnosi, produktivnost, efikasnost i sl., biti ispunjeni.

Sprovedeno istraživanje, u dva različita tipa organizacija, privatnom i državnom sektoru, pokazuje da, iako su svi ljudi različiti i iako je svako individua za sebe, kada se govori o motivaciji i motivacijskim faktorima, ipak su svi oni sličnog ili istog mišljenja.

Raduje podatak da naše organizacije u novije vrijeme ipak shvataju značaj ove problematike u preduzeću i posvećuju mu pažnju, ali još uvijek to nije na onom zavidnom nivou na kakvom bi trebalo biti.

ZAHVALNOST

Autori duguju posebnu zahvalnost zaposlenima preduzeća Hidroelektane na Trebišnjici i hotela SL Panorama, koji su prihvatili da se istraživanje sprovede u njihovim organizacijama.

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UNUSUAL APPLICATIONS, INTANGIBLE OUTCOMES: THE ERASMUS+ REBUS PROJECT AT VOLGA TECH

Alexey Fominykh[1], Eldar Kurbanov[2], Marina Kurdiumova[3]

Abstract: This paper reflects upon the practices and achievements of the Erasmus+ REBUS capacity building project (REady for BUSiness: Integrating and validating practical entrepreneurship skills in engineering and ICT studies) at Volga State University of Technology in 2016-2018. Being primarily a school of engineering, with a traditional special focus on Forestry, Environmental Studies and Nature Management, Volga Tech has chosen a group of undergraduate Master students as a piloting unit for testing the innovative teaching and learning approaches aimed at developing entrepreneurial skills and competences. The authors argue that the REBUS project was a success, even though some of its 'intangible outcomes' such as changes in attitudes and intercultural experience cannot be measured.

Key words: Capacity building, Erasmus+ programme, International mobility, Learning outcomes

1 INTRODUCTION

For Volga State University of Technology (or Volga Tech), the Erasmus+ REBUS project (REady for BUSiness: Integrating and validating practical entrepreneurship skills in engineering and ICT studies) was a logical continuation of series of international endeavors – predominantly EU funded – aimed at further integration into the European Higher Education Area, enhancing the quality of teaching, and gradual turn to the student-centered learning. Having a solid background of four implemented Tempus projects (since 2005) Volga Tech joined the REBUS consortium with a serious intent to widen the scope of applications of the European expertise and practices, as well as to expand the range of its international partnerships [1].

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2 HOW TO SOLVE A REBUS: STARTING THE PROJECT

Actually, the very first REBUS experiences showed that neither university, nor even the REBUS team at Volga Tech were quite REady for BUSiness. The intensity of communication with the European partners and project coordinators, stiff time and reporting management, along with a strong focus on students' engagement – all these factors made the REBUS project against Volga Tech previous, albeit successful Joint European Projects. Indeed, Volga Tech – or, at least, the REBUS team – has experienced a true capacity building, as during the course of the project all the teachers, administrators and students involved have increased their capacities in programme planning, course design, use of distance learning tools, foreign languages, to say nothing about intercultural communications. Some of the key REBUS elements, such as unique modes of (self) validation of entrepreneurial skills and competences, represented a novelty for Volga Tech, even though the Volga State University of Technology enjoys the reputation of one of the most advanced HEIs throughout the Russian Federation in using e-learning tools and technologies.

Among the first REBUS tasks and challenges were the in-depth desk research and expert interviews on the state of entrepreneurship in the country and entrepreneurial education. In fact, Volga Tech international office has never before experienced such en masse (in size of the university and the region) investigation of such kind; some past similar attempts were mostly concentrated on student feedback on some academic programmes and events. It was pretty difficult not only to find real active entrepreneurs and experts in the field, but also to make them share their visions frankly and freely. As a result, the Volga Tech REBUS team faced a challenge that was completely different from what had been expected before the beginning of the project. The desk research was, in fact, a detailed and precise needs analysis necessary for the implementation stage of the project.

So, all the interviewees replied that there was a great variety of formats and opportunities of entrepreneurship education in the Russian Federation. This is evidenced by high level of competition among the applicants in Russian universities, and the Volga Tech is no exclusion, for the programmes related to business and economics. The need for business education is even higher in large cities and big universities; it is also of high demand among those Russian nationals who apply to study abroad programmes. But, at the same time, the majority of university applicants and their parents are aimed at 'fundamental' higher education, thus choosing future careers of an engineer, doctor, lawyer, etc. The curricula of academic programmes in these profiles are rather mediocrely integrated with 'true' entrepreneurship. Responding to some of the REBUS objectives, several interviewees stressed on the necessity of technological entrepreneurship in the educational programs for the training of engineers, with more attention to be paid on 'practical' things, and not just the theory. Very few respondents mentioned their awareness on validation of competences; however, after gaining clear explanation of meaning of the process they agreed on crucial importance of such a procedure.

3 THE PILOTING PROGRAMME

Thank you very much for trying to format your paper in the way that this document describes. We are looking forward to seeing you in the Conference.

Volga State University of Technology was established in 1932 as a School of Forestry Engineering. turned into a modern multi-profile higher education institution,

however, forestry and environmental science have always been a special focus of the university, and in the early noughties became a subject of the first international, in fact, European projects, implemented with the EU funds within the Tempus programme. Therefore, there is no wonder that it was Forestry and Nature Management put in the focus of a new Erasmus+ capacity building project: a standing out application in comparison with the majority of other REBUS applications from Russia and Western Balkans.

The REBUS training component at Volga Tech became an integral part of the Master's degree study programme 'International Cooperation in Forestry and Nature Management', supervised by Prof. Dr. Eldar Kurbanov at the Department of Forestry (Institute of Forestry and Nature Management). The programme teaching staff also participate in the activities of the EU funded Jean Monnet Center of Excellence – SUFEX, the very first Jean Monnet CoE based at schools of engineering in the Russian Federation [2].

The core target group comprised 14 students of this particular programme (including 7 internationals). Being innovative in its didactic approaches, and more student centered, the programme was aimed at bringing the key elements of entrepreneurship and innovation from the REBUS agenda to the programme curricula, partly as 'regular mode' classes (lectures and seminars), and partly in e-learning format, using the computing equipment and software purchased and provided within the project. Worthy of note, the REBUS team at Volga Tech actually could not 'intervene' into already existing curricula of any Master's degree programme, it was only possible to offer the entrepreneurship related courses (or classes) only as electives; although, there was a good opportunity to incorporate some key issues raised within REBUS into the syllabi of several subjects, especially ones taught by the project team members.

Keeping in mind the focus of all three Master's degree programmes on Environmental Issues, Environment Protection, Forestry and Ecology, etc., the set of themes covered within REBUS should have include:

- Ecological tourism (eco-tourism)
- Sustainable urban forestry (urban-specific)
- Sustainable forest management (more generic)
- Monitoring of environment and natural resources
- Economics of forest complex (e.g. timber production, forest protection, forest infrastructure)
- International ecological certification (incl. one in forestry)
- Wildfires monitoring and protection
- Renewable energy sources (incl. bio fuel)
- ...and many more.

The project team has developed a didactic framework, which implied that by the end of the project students should be able to detect and assess the entrepreneurial opportunities in the field of forestry, nature management, landscape design and architecture. They should also obtain the skills necessary to implement their own entrepreneurship projects, such as needs analysis, strategic and operational planning, time management, financial issues, other 'soft skills' (proposal writing and presentation, communication skills (including command in English), team work); basics of copyright and patenting their innovative ideas and products. The successful implementation of students' entrepreneurial project implies they mastered their capabilities in the chosen fields of expertise (such as Forestry, Urban Ecosystems, etc.) during their Master's programme study. As for the attitudes, students were supposed to develop their personal motivation for entrepreneurship and innovation, readiness to risk in developing a new

product or service, ability to negotiate and debate on their project proposals, flexibility in decision making and finding compromises in troublesome situations.

Within REBUS a stronger accent was made on individual student projects, and incorporation of entrepreneurial vision and innovative approaches towards Forestry and Nature Management in students' Master's theses – for example, to consider the possible applications of their project as a core idea of a start-up; for those who took part in international study visit the latter condition was a must.

4 FOCUSING ON STUDENTS

Strategically, the REBUS project in its key dimensions follows the ideology of a student-centered learning (SCL) set by the European Higher Education Area. SCL, in a nutshell, is barely a pedagogical mindset, focusing on learners and their needs, rather than being centered around the teacher's input. This approach has many implications for the design and flexibility of curriculum, course content, and interactivity of the learning process and is being increasingly used at universities across Europe. The concept of SCL was initially a theoretical model defined as such by pedagogy and education researchers, though attempts at empowering the learner to enhance the educational process have probably always existed wherever educators have strived to improve and reform [3].

Needless to say that the use of e-learning tools within the REBUS project was already a good start for trying more student-centered approaches in teaching and learning. Personalization of students' profiles in Mahara and Level 5 platforms give the learners a degree of individual academic freedom and the educational environment for self-expression they could hardly obtain during regular classes at the Institute of Forestry and Nature Management. One should also take into consideration the orientation on an individual project (at the end of the course), and healthy competition for being included into the group for international study visit – in case of Volga Tech, to the University of Duisburg-Essen in Germany.

The international study visit was an intense and exciting enterprise that lasted for 10 days but actually became a life changing experience for eleven Volga Tech students. They worked in international teams (Russian-Bosnian-Albanian-Kosovar), studying various aspects of entrepreneurship, innovation and creativity in relation to their field of knowledge. The educational interaction within the groups and with the teaching coordinator was based on the principles of design thinking - the methodology of creative, rather than analytical solutions for engineering, business and other vitally important spheres.

Every day of the study week was devoted to one stage of design thinking: emphasize – design – ideate – prototype and test. Eventually, students presented their developed, elaborated and tested ideas. So, Volga Tech undergraduates participated in the preparation and public defense of three group projects, one of which, the "Eco-Museum", won a special prize in the nomination "The best project documentation".

According to the feedback from the participants, they learned a lot of new and interesting things that they would use in their further work and studies. The REBUS team members from Duisburg-Essen, Sarajevo, and Vienna have effectively projected their entrepreneurial mindset on students. As a result, something that initially seemed impossible or unrealistic for learners was gradually turned into real, almost ready-to-sell product.

Sharing their impressions on the REBUS study visit, Volga Tech students emphasize how international, multicultural environment and intense practical learning impact their vision of the study process and future careers.

R.M., female, age 31: “The study visit in Germany in the framework of the REBUS project impressed me by its nonstandard approach to training. Getting to know the design thinking method changed my attitude in entrepreneurship, as well as in everyday life. Daily brainstorming evoked a wide range of emotions. We were learning to think in a creative way, to work in a team, to react quickly to the tasks. The atmosphere was friendly, it seemed like a game, there was respect and understanding and no rivalry at all between the teams. I personally got great work and communication experience, obtained new knowledge and discovered new opportunities, made new friends and great memories.”

A.Z., female, age 26: “We have gained a great experience during this study visit – we looked at the world from another perspective, we got to communicate with international students. Participation in the REBUS project made me feel confident in everything I was doing; I felt I had the right capacity.

The project helped me understand what I wanted to achieve in the future and in what direction I should proceed in order to achieve my goals. I think that the ideating methodology that was used during the study visit may be used in various areas of our lives – in studies, at work, in everyday life. When I returned home, I realized that I became more focused, started setting clear objectives for myself and address them without any hesitation or delay. I began to analyze all my actions and draw conclusions - this is exactly what we learned in the classroom, and now I apply it in my everyday life and already see the positive results.”

B.A., male, age 23: “The study visit made a lasting impression on me. While communicating with different people, I learned their culture, language and traditions… I have gained valuable experience working in a team, when every team member fulfills his or her role in a group. At first, during the ideating stage we considered several projects. From a few projects originally initiated we gradually selected only one, which became the focus of our attention, and every team member contributed his or her fair share to project development”.

O.R., female, age 23: “Thanks to the project we were lucky to have our study visit in Germany, in a beautiful and quiet city of Essen. This expanded our horizons, we learned a lot of new and interesting things… We prepared presentations, elaborated models, were excited and worried to present them to other groups, as we wanted everything to be on top level. Each of us in this project opened up a new way, looked at oneself from an unexpected perspective... We made great friends with students from the University of East Sarajevo and Universum College of Pristina; we taught each other our traditions, customs and language”.

M. S., male, age 24: “The trip to Germany met my expectations. A new country, a new town, new knowledge, new acquaintances, different culture... Altogether it gave me a great life experience. Working in an international team together with students from Pristina and Sarajevo, we quickly found a common language and developed on our project during and even after our classes. We also exchanged contacts in order to continue our communication after the study visit is over. Now I understand how important is to know English at professional level. I also used my knowledge of German to communicate in the city… I had lifetime memories and experience from Essen”.

Z. A., female, age 33: “It was actually my first trip abroad! A lot of impressions and emotions, new knowledge and acquaintances! For me, this visit has become a special chapter of my life. A very interesting program that united several countries, taught teamwork and communication... By the end of my studies, I made certain conclusions for my future and realized my mistakes in the past.”

Hence, participation in REBUS allowed students to learn and put into practice new methods, technologies, approaches, but what is more important, interaction with

students from other countries, search for a common solution to the difficulties arising within co-working, operating in a team altogether contribute to the establishment of friendly relations between young people, and therefore, to some extent, between the countries involved. For 40 students who took part in the REBUS study visit (or three times more, taking into account visits to Graz and Palermo), the world will never be the same again – it has become brighter and friendlier.

5 DISSEMINATION: FAR BEYOND TARGET REGIONS

One of the less usual implications of the REBUS project at Volga Tech is that its dissemination, in fact goes far beyond Russia, or the Western Balkans. Due to the fact that half of the piloting group of Master students taking part in the project (and in international study visit) came from Uzbekistan, the projects geographic scope is not only Europe, but Eurasia.

In Uzbekistan, a country in Central Asia, with population of almost thirty million, domestic tertiary enrolment has not kept pace with the growing demand for higher education. As a result, many young people choose options of study abroad, and most of them go to Russia because of proximity, affordability of tuition, and the Russian as language of instruction, as it is still widely spoken throughout the former Soviet Union. As a result, in the last two decades Uzbekistan became one of the biggest transboundary markets for the Russian universities, and for Volga Tech as well. For many small and medium-sized universities in the Russian Federation, the reorientation of international marketing towards the former Soviet republics implied the beginning of cultural diversification on their campuses. For example, Volga Tech (about 9,000 students, of whom 900 are international) has started its international recruiting campaigns in 2008, until then having no foreign students at all. In 2015, Volga Tech became the second popular university (after Kazan Federal University at the first place) among applicants to Russian HEIs from Uzbekistan, attracting 161 students (out of 1,581 of Uzbekistanis entering Russian universities that year) [4].

The piloting Master's degree programme 'International Cooperation in Forestry and Nature Management' enrols seven Uzbekistani students; all of them Bachelors graduated from Tashkent Institute of Irrigation and Agricultural Mechanization Engineers – in fact, a strong and prestigious school, and alma mater of the country's President Shavkat Mirziyoyev. Having started political reforms and economic modernization in late 2016, Uzbekistan pays much attention to the development of entrepreneurship and innovations on its soil, and considers the European Union, along with the Russian Federation, to be important international partners. Therefore, engaging Uzbekistani students into the REBUS activities, Volga Tech promotes dissimination of the project ideas in Central Asia, contributing to the international understanding and development aid.

6 CONCLUSION

Implementing the REBUS project in a mid-sized Russian engineering university like Volga Tech has brought to light serious problems, albeit quite typical for a country, which higher education system is still in transition towards the EHEA. Previous Tempus experience of the university project team was of a great value when used in the newly designed Erasmus+ capacity building framework.

Placing students in the center of the REBUS teaching of entrepreneurship and innovation was probably the most challenging – both mentally and technically – and the most exciting part of the project. Strongly supported by the European partners, Volga

Tech has developed new patterns of interaction in the classroom, and new organizational models of student research and practice. At least eleven students used their opportunity to study in Europe, although for a short while. However, as student feedback shows, for many of them it was a life changing experience.

Thus, measuring the efficiency of the REBUS project should not only include formal outcomes such as statistics on mobility flows, number of new courses and publications, or units of technical equipment. A project focused on entrepreneurship and innovation must stress upon intangible outcomes: networking, development of a corporate or professional community culture, changes in attitude and mind set. This is what Erasmus+ has been designed and is working for.

ACKNOWLEDGMENT

This work was supported by the Erasmus+ Jean Monnet program (Project № 574894-EPP-1-2016-1-RU-EPPJMO-CoE) and REBUS (Project № 573664-EPP-1-2016-1-BA-EPPKA2-CBHE-JP) of the European Union. The European Commission support for the production of this publication does not constitute an endorsement of the contents which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

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EXPERIENCE IN FORMING ENTREPRENEURIAL COMPETENCES OF STUDENTS AT THE SIBERIAN STATE UNIVERSITY OF TELECOMMUNICATIONS AND INFORMATION SCIENCES WITHIN THE FRAMEWORK OF THE EUROPEAN ERASMUS+ PROJECT «REBUS»

D. Kaznacheev[1], B. Kruk[2], E. Meteleva[3], S. Plakidina[4]

Abstract: This paper summarizes the experience in developing and teaching the additional professional education course «Digital Entrepreneurship» within the framework of the ERASMUS+ project REady for BUSiness (REBUS), and also in organizing the Study Visit at the FH JOANNEUM University of Applied Sciences in Graz, Austria. It deals with the impact of the REBUS project in forming entrepreneurial and intercultural competences in engineering and ICT studies.

Key words: educational projects, entrepreneurial competences, intercultural competences, self-assessment, digital entrepreneurship

1 EUROPEAN INITIATIVES FOR RECOGNITION AND VALIDATION

The authors of the paper [1] note that «innovative development strategies of Russia require a new method of preparing specialists that allows to develop not only competences in particular professional fields built on the basic knowledge, but also managerial, entrepreneurial, leadership ones. The presence (availability) of developed entrepreneurial and leadership competences of specialists formed by the Universities should be in demand on the labor market. Consequently, a system of assessment of these competences with the possibility of the verification is to be created».

2 EXPERIENCE OF THE IMPLEMENTATION OF THE REBUS IN SIBERIA

Nowadays, in the HEIs (Higher Education Institutions) of Russia increased

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attention is paid to the development of entrepreneurship education as well as entrepreneurial and leadership competences of students [2, 3]. In the frames of the implementation of the ERASMUS+ project REady for BUSiness (REBUS) at SibSUTIS the enrolment of students for the additional professional education course «Digital Entrepreneurship» was realized. The main goal of this course consisted in identifying and developing the entrepreneurial and intercultural competences in engineering and ICT studies. All material of this course was delivered in English.

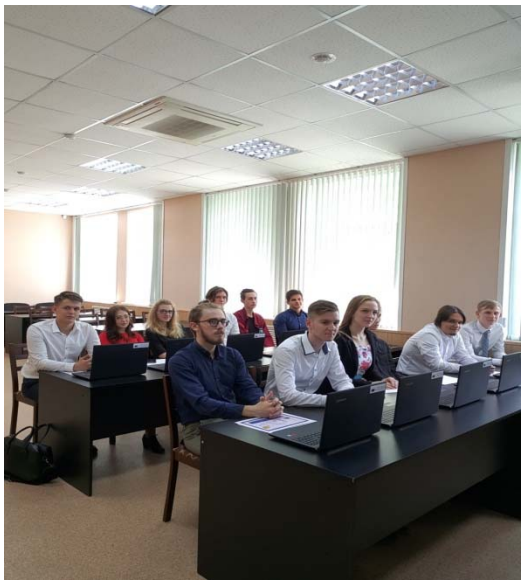


Figure 1. *Face-to-face lectures in SIBSUTIS on unit Basics of Digital Entrepreneurship*

2.1 Description of the learning pathway of students

The course, for duration of 72 hours, included the following units: Basics of Digital Entrepreneurship [4], Tools of Digital Entrepreneurship, E-Commerce, Online shop, SMM, Digital marketing, Digital communication in business, Effective communication being a component of entrepreneurship competence, Feedback in digital communication.

Training consisted in three main stages, each of which was realized in the form of blended learning [5, 6]. Thus, phase 1 “Introduction and theory” implied the face-to-face lectures (Fig. 1) with the use of video material, webinars, discussions, group work, distance learning in the learning environment Moodle [7] as well as testing. Phase 2 “Practical work” included primarily the work with cases and examples using the learning environment Moodle, collection and analysis of information in open sources, screening and discussion of video material, completion of practical tasks, selection of project themes, project development. Phase 3 “Feedback” involves the presentation of projects, their justification and evaluation of student performance, final assessment and attestation paperwork.

The key component of the course at SibSUTIS was the project design of applications, sites and business-process management projects. According to the standard of project management PMI PMBOK the preliminary presentation of projects was made through executive summaries. The final presentation involved the use of

executive summaries from the methodical REBUS kit with the following uploading on the Mahara platform.

The only students who had successfully completed all theoretical units, done practical work, passed the tests as well as completed profiles and portfolios on the Mahara platform were allowed to present their projects. When presenting projects the students highlighted their competitive advantage, market relevance, potential commercial benefit, and also showed their ability to work with PowerPoint and speak English publicly (Fig. 2). The qualified assessment of all students' projects was made by the members of the REBUS project as well as outside experts-practitioners in the fields of marketing, digital technologies, life quality.

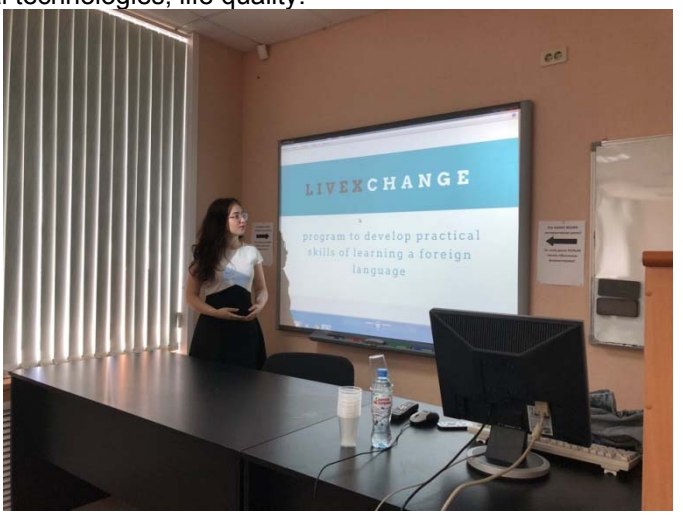


Figure 2. *Presentation of the project in SIBSUTIS*

2.2 The study visit to FH JOANNEUM

In accordance with the final score 13 best students who would continue their training at FH JOANNEUM University of Applied Sciences, Austria, were chosen.

This training was held from 17 to 28 September, 2018, at the FH JOANNEUM University of Applied Sciences. There, all students were divided into mixed study groups: the representatives of Albania, Kosovo and Russia teamed up with students from Austria (Fig. 3).

The event was opened by the International projects Coordinator at FH JOANNEUM Rupert Beinhauer who explained to students the substance of the following work with cases of real companies, such as Nuki (speaker Clarissa Morales), EPUmatch (speaker Rainer v. Leoprechting), FH Zwickau (video introduction). A preliminary work plan was developed as well as teamwork objectives that were formulated by the second day of training.

Training at the FH JOANNEUM University was combined with a well-designed cultural program: a visit to the Museum and City Hall of Graz, sightseeing tours of Graz and its surroundings.



Figure 3.*The students from Albania, Kosovo* and Russia at FH JOANNEUM University*

In the first week, students went to the neighboring town Kapfenberg, where they had an interesting opportunity to visit an experimental laboratory - Smart Lab of FH JOANNEUM. After a short overview, students engaged in analytic investigation: they were to define the prospect of implementing the latest technologies in traditional spheres of human activity. At the end of the first training week the students worked in teams on the case study research (Fig. 4).

The whole following week was dedicated to the case study teamwork, the outcomes of which are actually available on the Mahara platform. The students' investigations resulted in case solutions that were presented by each study group on September 28. Finally, the winners were selected and awarded with special certificates.

Another significant point in student training at the home university as well as at the host university consists in students' self-assessment of two important competences: intercultural teamwork competence and competence to spot ideas and opportunities. The assessment technology is based on the use of the LEVEL5 program (tool) that allows to rate on a five-point scale the following parameters: "Knowledge", "Skills", "Attitude and emotions". Self-assessment was made as at the beginning of the training at SibSUTIS as upon completion of the Study Visit at FH JOANNEUM University. Diagrams reflecting the evolution of these parameters during the participation of SibSUTIS students in the ERASMUS+ project REBUS are represented in Figures 5 and 6.

Figures 5 and 6 show that for "Knowledge" parameter at the beginning of the course students with level 1 and 2 prevailed (7 people out of 13) whereas after the successful completion of the whole training respondents with level 4 have become the prevailing part of the student group (8 people out of 13). For "Skills" parameter level 3 is still the most frequent as at the start (5 people out of 13) as at the end of the training, but quantitatively it almost doubled (9 people out of 13). Regarding the "Attitude and emotions" parameter, also there is a certain progress: initially, 8 students out of 13 assessed their subjective perception of the REBUS program at level 2, but right after the Study Visit in FH JOANNEUM University and experience in international team working the highest level became the most popular (6 people out of 13), and also 5 students

assessed their attitude at level 4.



Figure 4. *The case study teamwork of Russian students at FH JOANNEUM University*

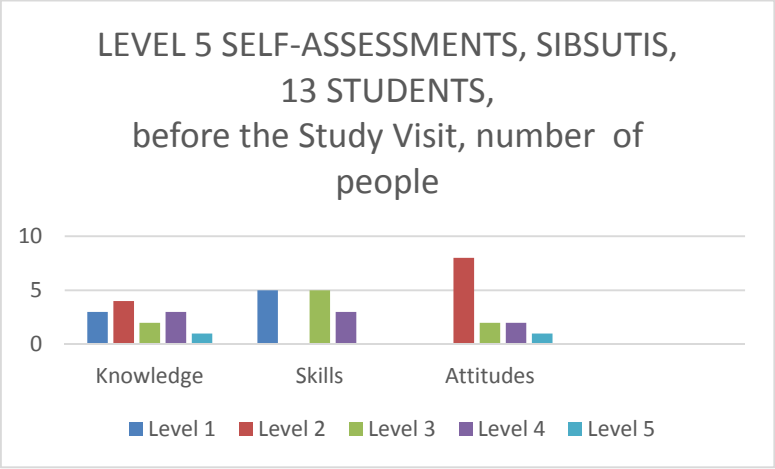


Figure 5. *Values of the LEVEL 5 parameters at the beginning of the course*

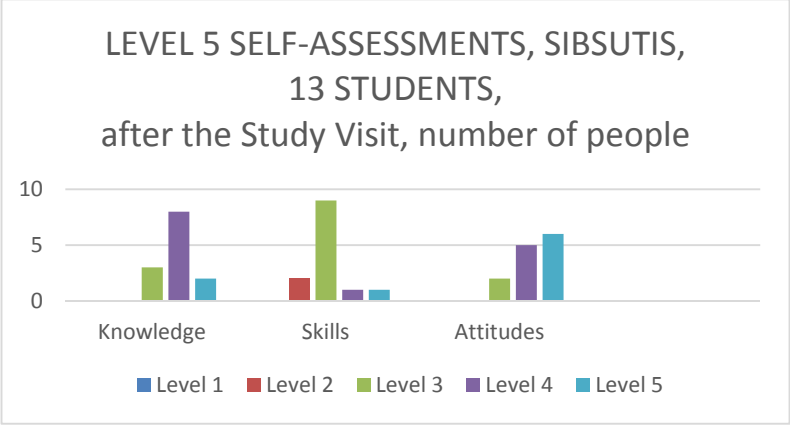


Figure 6. *Values of the LEVEL 5 parameters after the Study Visit*

3 CONCLUSION

Therefore, 13 students of the Siberian State University of Telecommunications and Information Sciences participated in the REBUS project Study Visit and were awarded by certificates authorizing the professional activity in the field of entrepreneurship in EU States. According to the results of the final stage of training the positive students' reviews of the program were collected; above all, students note the opportunity to improve skills in developing and promoting startups in an innovative environment with the use of the latest technologies, as well as possibility of socio-cultural interaction in English as the principal language of communication.

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DA LI JE TRANZICIONI MENADŽMENT U SRBIJI NA POČETKU XXI VEKA OPRAVDAO NADANJA STANOVNIŠTVA

Predrag Petrović[1]

Rezime: Raspadom SFRJ, Srbija se suočila sa velikim privrednim teškoćama. Isrpljena ratovima na teritorijama gde su živeli Srbi, sankcijama UN, NATO Agresijom, sudom u Hagu i drugim zahtevima inofaktora i mnogim drugim problemima, Srbija nije imalu potrebnu materijalnu i kadrovsku osnovu da uđe u novi vid reindustrijalizacije.

Na samom početku XXI veka u Srbiji je zavladao veliki optimizam u pogledu najavljenih tranzicionih privrednih promena i očekivanja opšteg poboljšanja uslova života.

U prvim tranzicionim fazama zapadni kapital je pod veoma povoljnim uslovima kupovao srpska preduzeća koja su i do tada dobro radila, imala savremenu opremu, kadrove, tržište i sve drugo što je potrebno (cementare, fabrike duvana, lekova i prehrambenih proizvoda, šećerane, pivare i dr.

Drugi ciljevi planirani u okviru tranzicionih postupaka i promene vlasništva preostalih preduzeća nisu mogli da se ostvare u mnogim oblastima industrije i poljoprivrede iz objektivnih i subjektivnih okolnosti, koje su delimično razmatrane u ovom radu.

Ključne reči:menadžment, privreda, poljoprivreda, stanovništvo, tranzicija

IS THE TRANSITION THEIR MANAGERS IN SERBIA AT THE BEGINNING OF XXI CENTURY JUSTIFY HOPES POPULATION

Abstract:The disintegration of Yugoslavia, Serbia was faced with major economic difficulties. Been exhausted by wars in the territories where Serbs lived, UN sanctions, NATO aggression, the court in The Hague and other requirements inofactora and many other problems, Serbia did not have the necessary material and personnel basis to enter into a new form of re-industrialization. At the beginning of XXI Ages in Serbia has taken over a great optimism regarding the upcoming transition of economic change and the expectations of the general improvement of living conditions.

In the early transition stages of Western capital under very favorable conditions to buy Serbian companies that were by then well done, had modern equipment, personnel, market and everything else you need (cement factories, tobacco, drugs and food products, sugar refineries, breweries and etc.

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Other objectives planned in the context of transitional processes and change of ownership of the remaining companies were not able to achieve in many areas of industry and agriculture of objective and subjective circumstances, which are partially discussed in this paper.

Keywords:Managemen, Industry, Agriculture, Population, Transition

1. UVOD

Za razvijene države nikada nije bila dilema, da li treba ulagati i podizati na viši nivo privrednu delatnost. Malo je struka koje tako određuju suštinski budućnost svakog društva, kao što je inženjerstvo i bez dobrog inženjerstva nema snažne i konkurentne privrede. Globalne prilike dovele su tradicionalno inženjerstvo u Srbiji u podređeni položaj, dok na početku trećeg milenijuma inženjerstvo u Evropi doživljava svoj uspon.

Prvi talas industrijalizacije povezuje se sa izgradnjom prve srpske fabrike, Kragujevačke topolivnice, 1853., koja je inicirala dalji industrijski razvoj.

Drugi talas industrijalizacije povezuje se za period između dva svetska rata kada je u Srbiji izgrađeno pet fabrika samo za proizvodnju aviona, Rakovički (IAM, sada IMR), Ikarus, Fabrika vagona Kraljevo, Rogožarski i Zmaj, fabrika za proizvodnju avionskih motora, kasnije i vozilskih motora i kamiona (IMR), zatim železara u Smederevu, rudnik u Boru i dr.

Treći talas industrijalizacije u Srbiji odvijao se posle Drugog svetskog rata i praktično sve do početka raspada SFRJ, do kada su se na domaće i inostrano tržište plasirali sofisticirani/finalni proizvodi (traktori, motori, kombajni, automobili, autobusi, tekstilni, poljoprivredni, građevinski, prehrambeni, farmaceutski, hemijski i mnogi drugi proizvodi.

Četvrti talas pod nazivom *„Industrijalizacija 4.0“*, danas se u Srbiji odvija pod patronatom zapadnog kapitala. [6]

Prema izjavama ekonomskih stručnjaka Srbiji je potreban rast BDP-a od 5-7% nekoliko godina uzastopno, što je u evidentnim teškoćama u kojima se Srbija nalazi, praktično nemoguće. Prognoze su da će se 2018. završiti sa 3,5-4%, što bi bio najveći rast u regionu.

2. EFEKTI INDUSTRIJSKE TRANZICIJE U SRBIJI U XXI VEKU

Postsocijalističke privredne transformacije srpskog društva i tranzicioni prelazak iz komandno-planske u tržišnu privredu, uslovljavao je opšte korenite i strukturne promene u svim privrednim sektorima. Tržišno poslovanje, oblikovano novoliberalnom ideologijom, zahtevalo je sasvim drugačiju strukturu vlasništva, organizacionih uređenja, načina upravljanja i komunikacija unutar i izvan preduzeća, u odnosu na ono koje je bilo dominantno u eri samoupravnog socijalizma.

Srpska privreda je počela da se urušava raspadom SFRJ, ratovima koji su vođeni na teritorijama, gde su živeli Srbi, sankcijama UN, pogrešnom tranzicijom, odnosno privatizacijom, agresijom i bombardovanjem NATO-a, pa posle demokratskih promena ponovo pogrešne privatizacije i...

U takvim okolnostima država je često pribegavala uvođenju stečajnih postupaka u mnogim preduzećima, da bi nakon prestanka agresije NATO-a, ranije planirani isti bili stornirani, a u preduzećima u stečaju počele su pripreme za njihovo ukidanje, s namerom učešća i većeg interesa stranog i domaćeg kapitala, u transformacijama vlasništva.

Da bi kontrolisala i sačuvala preduzeća od loše transformacije vlasništva, država osniva Agenciju za privatizaciju koja putem tenderske i akcijske ponude, nudi industrijska preduzeća na prodaju. Taj proces se odvijao po Zakonu o svojinskoj transformaciji i Zakonu o privatizaciju, uz mnogobrojne anekse koji su se vremenom donosili u zavisnosti od stanja privrednog ambijenta. Prvo su prodata, tada profitabilna preduzeća: cementare, pivare, fabrike lekova, hemijskih proizvoda, pneumatika, duvana, prehrambenih i farmaceutskih proizvoda i dr. [4]

U tim tranzicionim periodima metalski kompleks je bio u najtežoj situaciji, interes prodaje je bio slab, a država za njih nije imala rešenje pa je njihov dalji opstanak egzistirao kroz tzv. „*restruktuiranje*“, sa dodatnim subvencijama. U takvim uslovima, za neka preduzeća zapadni kapital nudi svoje investicije, a u nekim slučajevima i uz pomoć domaćih tzv. tajkuna, koji na taj način uvećavaju svoj kapital, često ne poštujući ugovorne obaveze.

Ako bi se analizirali okvirni faktori koji su uticali na relativno slab učinak i očekivani rezultat tranzicionih promena, mogu se navesti neki:

- podsticaj privredi se uglavnom odvijao iz budžeta, preko fonda za razvoj, agencija za finansiranje i osiguranja, raznih ministarstava, trezora i dr.
- instrumenti su bili u vidu subvencija, kredita (domaćih i stranih), garancija, obuka, formiranja klastera, poslovnih inkubatora i nekim drugim vidovima.
- efekat takvog finansiranja, kroz potrošena sredstva, bio je veoma loš, bez vidljive produktivnosti, ali vidljivim socijalnim programima i bezuspešnom pokušaju u čuvanju postojećih radnih mesta, kroz isplate minimalnih nadoknada i dr. [10]

Takvom ishodu, su svakako doprineli:loša kadrovska politika i suvišni uticaj partokratije, nesavesno i protivzakonito poslovanje i poslovanje iz neznanja, stvaranje fiktivnih uslova za stečaj u cilju smanjenja prodajne cene, zloupotreba položaja i ovlašćenja u poslovanju, zaključivanja štetnih i fiktivnih ugovora, nedopuštene trgovine, utaje plaćanja poreza, doprinosa, taksi i drugih izdvajanja, raznih prevara i pronevera, falsifikovanja službenih dokumenata, primanja i davanja mita, korupcije, izbegavanja carinskog nadzora i dr. [1]

Takvi postupci su doprineli da se u javnosti često potencira preispitivanje legalnosti i dokumentacije 24 preduzeća iz Srbije, po nalogu Evropske unije, koje je Evropski parlament označio kao sporne, baš iz razloga koji su navedeni.

3. UTICAJ GLOBALNE POLITIKE NA TRANZICIJU U SRBIJI

Globalna politika koja se vodi utiče značajno i na Srbiju. Dinamika globalizacije kapitalizma zasniva na integraciji slobodnog kretanja konflitnog kapitala i pretvaranja čitavog sveta u novac i robu. Danas se u multipolarnom svetu koji predstavlja novu realnost globalnog kapitalizma, može očekivati smanjenje i ravnoteža sila moći u međunarodnim odnosima, ali do smanjenja klasnih razlika sigurno neće doći.

Savremeni predatorski kapital u multipolarnom svetu neće imati onu vrstu straha koja je postojala u bipolarnom svetu, a dolazila je od organizovanog klasnog protivnika. Danas nema klasne borbe koja bi obuzdala kapitalizam u njegovoj težnji za povećanjem profita i osvajanjem novih tržišta. Intenzivan je rast nejednakosti u savremenom svetu, pri čemu preti i potvrđena činjenica da 1% najbogatijih u svetu poseduje više nego ostatak sveta.

Globalni kapitalizam je zasnovan na eksploataciji kao ekonomskoj formi tlačenja, koji reprodukuje klasne nejednakosti, otuđeni život, ekološku dominaciju, rodnu, porodičnu i nacionalnu dezintegraciju i sl.

U Srbiji je radnička klasa dezorjentisana i dezintegrisana, pretvorena u prekarijat (povremeno zaposleni, slabo plaćeni, bez klasne solidarnosti sa velikim strahom i nepoverenjem prema poslodavcu). [3]

Privredna globalna aktivnost koja se uvodi u Srbiji, svodi se na izabranu transformaciju vlasništva profitabilnih preduzeća ili koriste velike povlastice firmama (doplata svakog radnog mesta iz budžeta (10.000-20.000 evra i više), pretvaranje poljoprivrednog zemljišta u građevinsko, oslobađanje od svih vrsta poreza, doprinosa, dobiti, opštinskih taksi i drugih beneficija), koje otvaraju pogone za izradu pojedinih komponenata za automobilsku, tekstilnu, građevinsku, prehrambenu i drugu industriju.

3.1. Trend stanja i perspektiva privrednog ambijenta u Srbiji

Srpska industrija se decenijama izgrađivala posle Drugog svetskog rata, da bi se raspadom SFRJ, preko noći gurnula u proces tranzicije pri čemu joj je nametnuto od strane zapadnih zemalja model najsurovijeg liberalnog kapitalizma u kome su za većinu preduzeća važila nemilosrdna tržišna pravila. Deo poslovne i političke svetske elite otkupio je preduzeća izmorena dugogodišnjim iscrpljivanjem, sankcijama, varvarskim bombardovanjem NATO alijanse konkurentskih preduzeća, pre svega u vojnoj oblasti sa ciljem što većeg slabljenja, a istovremeno osmatrajući atraktivna građevinska zemljišta i poslovne prostore za izgradnju tržnih centara kako bi plasirali svoju robu.

Povlašćeni status su imali zainteresovani strateški kupci, odnosno velike svetske kompanije koje su na brzinu pokupovala, već ranije planirana najuspešnija srpska preduzeća, odnosno tržišta koje su one pokrivale (duvan, cement, šećer, pivo, lekovi, naftni derivati, prehrana, mobilna telefonija, televizija...). Intenzivna je gradnja tzv,. šoping molova, preko kojih zapadni kapital plasira svoju novu robu nižeg kvaliteta, a visokih cena, kao što su odeća, obuća, prehrambeni, konditorski i poljoprivredni proizvodi, dečije igračke, nameštaj, automobili i svi vidovi motornih vozila i građevinskih mašina, građevinski materijali, bela tehnika i TV aparati, satovi i mnogi drugi proizvodi. Plasira se u velikom obimu i polovna roba, kao što su: automobili, odeća, obuća, nameštaj, poljoprivredna mehanizacija i mnogi drugi proizvodi. I ne samo to, realizuje se: intenzivna prodaja i višedecenijsko davanje u zakup poljoprivrednog zemljišta pod veoma povoljnim uslovima koji se graniče sa besplatnim. Nameću se: sumnjivi marketinzi, prajd parada, rialiti programi, kladionice, ulična brza hrana, mobilna telefonija, naftni i gasni proizvodi, i ...

Sektor usluga je došao do izražaja (zapošljavanje u tržnim centrim, pekarama, brzoj hrani, kafićima i mnogim drugim neproduktivnim, nekvalitetnim i slabo plaćenim radnim mestima...), što je za kreatore novog svetkog poretka bila često izgovarana foskula „*Srbija je na dobrom putu*“.

To su uglavnom neprofitna ili niskoprofitna radna mesta za izradu napr. pojedinih vrsta kablova i delova za automobile, konfekcijske i obućarske delove, trikotažu, elektronske komponente, određene prehrambene proizvode i sl. Slična situacija je i u sektoru usluga u kojoj je globalni kapital takođe doneo nova niskoprofitna radna mesta u objektima brze hrane, kafeima, buticima i prodavnicama nove i polovne odeće i obuće, poslovnim stranim bankama, i dr. Svetski trgovački lanci, uz pomoć banka, Srbiju su preplavili bofl i nekvalitetnom robom iz celog sveta. Pri tom se nude veoma „povoljni krediti“ kako bi srpskom stanovništvu bilo prividno sve dostupno, kupovina i stana i nameštaja i garderobe i automobila i letovanje i ...

Uvertira pri stvaranju neoliberalnog poretka pogubna za srpske radnike je donošenje Zakona o radu 2010. koji ju vlasnicima kapitala dao sva moguća prava, pri

čemu efikasnost proizvodnje podrazumeva smanjenje svih vrsta troškova, pa i plata radnika. Ali ne tako retko, podrazumeva se i prećutno odobrenje na rad na crno, bez adekvatne zaštite, nedeljom, praznikom, bez plaćenih doprinosa, čestim prekovremenim, a ne plaćenim radom, kašnjenjem i onako minimalnih plata, rada na određeno i ... Za većinu radnih mesta nije potrebna visoka kvalifikacija, naprotiv, veoma niska, koja se ostvaruje kroz kratke obuke, kurseve, radionice i slično.

Kada je u pitanju strani poslodavac, visoka sprema se uglavnom zahteva u preduzećima koja se bave IT tehnologijom i delimično u stranim bankama. To je veoma mali broj, u odnosu na godišnji broj svršenih studenata na svim državnim i privatnim fakultetima u Srbiji. Kada je u pitanju i celokupno školstvo, mnoge deklaracije i reforme koje su dolazile sa zapada, nisu donele ništa novo, naprotiv donele su degradaciju znanja na svim nivoima.

Međutim u Srbiji nije sve tako loše. Na Duing listi Svetske banke nalazi se na 48 poziciji u odnosu na 190 zemalja sveta, što je relativno dobra pozicija za deset oblasti koje se rangiraju,bez obzira što je u ovoj godini pala za pet mesta.

Srbija ima prostor za dalji napredak bez obzira što ne može da planira neki vid reindustrijalizacije na predhodnim kapacitetima, jer jednom uništena fabrika teško se vraća na predhodno stanje. To se uglavnom odnosi na uništene gigante koji nisu više u prilici da izrade visoko vredne sofisticirane finalne proizvode.

Prema političkim statističkim podacima koji se iznose u javnost, Srbija beleži dobre rezultate, ali realnog poboljšanja nema, jer se godinama okrećemo oko trećine prosečnog iznosa BDP po glavi stanovnika Evropske unije. Da li stvarno industrijaska proizvodnja raste, proceniće građani, kroz poboljšanje standarda.

Neuspeh tranzicije se odigravao u pogrešnom pravcu, čiji je negativni trend zadržan i danas i to iz više razloga:

- zasnivanju procesa tranzicije isključivo na prilivu inostranog kapitala,
- zasnivanje na prihodu od prodaje i privatizacije preduzeća,
- ogromnom uvozu robe široke potrošnje i jačanja uvozničkog lobija,
- intenzivnog razvoja sektora usluga,
- likvidacija domaćih banaka, a dovođenje stranih,
- skrojena je država po meri dela političke, poslovne, uvozničke i delom intelektualne elite,
- uništenja srednjeg sloja građanstva,
- neadekvatno školovanje svih kadrovskih vidova i svođenje radnika koji su u radnom odnosu na nivo tehnološkog roblja,
- velikih migracija stanovništva/kadrova i oslanjanje na priliv deviznih doznaka naših građana koji žive i rade u inostranstvu (2017., priliv je iznosio 3,588 mlrd. USD),
- sve veće prisustvo prekarizacije rada, uz nemogućnost međusobnog povezivanja zajedničkih interesa zaposlenih,
- pridobijanje i očuvanje što većeg uticaja u vlasti i uživanja u privilegijama,
- i suviše prisutan značaj partokratije preko koje profitiraju nestručni „kadrovi“,i dr.

4. MOGUĆNOSTI I STANJE RESURSA U TRANZICIONOM CIKLUSU SRBIJE

Danas se u javnosti često pominje nova svetska kriza, koja je prema ocenama stručnjaka neminovna. Setimo se svetske krize od pre deset godina kada su kompetentni političari izjavljivali kako je svetska kriza izazov za Srbiju, a iskoristila je tako što joj je zbog neznanja i nespremnosti za radikalne reforme, ali i same krize, bilo potrebno deset godina da se dostigne pred krizni BDP, što je Srbiju primaklo samom

začelju jugoistočne Evrope. Očekuje se, mogući rast BDP u ovoj godini oko 4% i vraćanja javnih finansija iz budžetskog deficita u suficit, smanjenje javnog duga, kao i veći prilivi od stranih investicija i deviznih doznaka, prodaje preduzeća, zemljišta i dr. Međutim nije baš sve tako optimističko, jer i pored direktnih stranih i javnih investicija njihov priliv je još uvek nedovoljan da bi u dužem periodu obezbedio rast BDP od 4%, koliko je neophodno za priključenje zemljama jugoistočne Evrope.

Danas je u Srbiji priliv uglavnom od stranih investicija, sa veoma malim prilivom domaćeg kapitala. Takve okolnosti doprinose promeni vlasničke strukture privrede, padu kvaliteta zapošljavanja i migraciji najvitalnijeg i stručnog dela populacije, pa zbog neoganizovasti i siromaštva više se oslanja na uzimanje kredita, što može biti veoma opasno, jer može se otvoriti prostor za stvaranje uslova dužničke krize i nemogućnosti otplate kredita. Ako kojim slučajem dođe do najavljene nove svetske krize, ona će najviše pogoditi najzaduženije zemlje i zemlje koje se u svom razvoju nedovoljno oslanjaju na sopstvene resurse, a Srbija je školski primer takve zemlje.

Srbija mora raditi na adekvatnom obrazovanju u novim tržišnim i globalnim tendencijama uz razvijanje preduzetničkih veština i sposobnosti, što je imperativ svake nove privrede. Poslodavci su uglavnom nezadovoljni znanjem novih generacija, pa su ponekad primorani da sami vrše obuku za određene poslove, a opet u mnogim delatnostima nisu im ni potrebni, jer nove ideje uglavnom donose iz svojih matičnih zemalja.

U svakom slučaju pred Srbijom su kompleksni i politički i ekonomski problemi koje u načelu treba rešavati kroz: usmeravanje ekonomske politike ka proizvodnji robe za domaće i strano tržište, kontrolisanje inflacije i fiskalne politike, smanjivanje državnih troškova, regulisanje poreza i parafiskalnih nameta, kontrolisanje spoljošnjeg i unutrašnjeg duga, smanjivanje korupcije na minimum, stvaranje odgovornije i efikasnije državne administracije, kao u mnogim zemljama EU i dr.

5. ZAKLJUČAK

Srbija je do raspada SFRJ imala veoma jaku plansku privredu, da bi NATO agresijom 1999., mnoge konkurentske fabrike bile uništene, a druge iscrpljivanjem svele na nisku prodajnu vrednost. Fabrike koje su i u predtranziciono doba dobro radile, po niskoj ceni su od strane srodnih preduzeća sa zapada otkupljene (pivare, cementare, šećerane, fabrike lekova, duvana, hrane, naftna industrija, telekomunikacije i dr.)

Globalni kapital doneo je Srbiji nova niskoprofitna i najmanje kvalitetnih radnih mesta i za takva se iz budžeta izdvaja 10-20.000 i više evra, pod pogrešnim nazivom „*fabrika*“, otvaraju se samo „*pogoni*“ sa neinventivnim, prostim, jednostavnim i monotonim, slabo plaćenim, niskoprofitnim, haotičnim, neizvesnim, nepredvidljivim radnim mestima i..., za izradu pojedinih komponenata za automobilsku, tekstilnu, građevinsku, IT tehnologiju i druge delatnosti. Takav pristup je tipičan primer formiranja nove svetske klase, prekarijata. Pored navedenih beneficija poslodavci takvih preduzeća oslobađaju od plaćanja poreza i doprinosa, poreza na dobit i građevinsko zemljište, opštinske i takse na nezaposlenost i druge fiskalne zakonske obaveze.

Indentična je situacija i u uslužnim delatnostima, u kojima se zapošljavaju mladi naraštaji, čak i sa visokom stručnom spremom, po tržnim centrima, prodavnicama, buticima u extra zonama i drugim objektima u većim gradovima Srbije u kojima se plasira roba isključivo sa Evropskog tržišta i drugih zemalja gde je radna snaga još slabije plaćena nego u Srbiji, nižeg ili srednjeg kvaliteta, pa i kao takva za srpske standarde, sa relativno visokim cenama.

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CROWDFUNDING PLATFORME KAO PRILIKA ZA FINANSIRANJE INOVACIONOG RAZVOJA

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Rezime: Finansiranje projekata inovacionog razvoja je problem koji je prisutan u svim savremenim društvima. U posljednjoj deceniji došlo je pojave oblika finansiranja pod nazivom crowdfunding, odnosno grupnog finansiranja projekata. U ovom radu su date definicije pojma crowdfundinga, kao i osnovne karakteristike prve regionalne crowdfunding platforme.

Ključne riječi: crowdfunding, finansiranje, inovacija, platforma, projekat

CROWDFUNDING PLATFORMS AS OPPORTUNITY FOR FINANCING OF INNOVATION DEVELOPMENT

Abstract: Funding of innovative development projects is a problem that is present in all modern societies. In the last decade there have been occurrences of financing forms called crowdfunding, or group financing of projects. This paper presents definitions of crowdfunding as well as basic characteristics of the first regional crowdfunding platform.

Key words: crowdfunding, financing, innovation, platform, project

1 UVOD

Problem obezbjeđivanja sredstava za finansiranje projekata inovacionog razvoja prisutan je u svim modernim društvima.

Razvojem informaciono-komunikacionih tehnologija, kao i evolucijom savremenog društva i privrede stvorili su se uslovi za pojavu crowdfundinga, koji se nametnuo kao uspješan alternativni način finansiranja.

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2 POJAM CROWDFUNDINGA

Riječ crowdfunding je novija složenica u engleskom jeziku, koja se prvi put spominje 2006. godine. Na srpskom jeziku nema odgovarajući prevod, a najprihvatljiviji prevod na naš jezik bi bila sintagma grupno finansiranje.

Takođe, ne postoji precizna odrednica ili definicija riječi. U dosadašnjem istraživanju fenomena crowdfundinga došlo se do definicija prikazanih u tabeli 1.

Tabela 1. *Definicije crowdfundinga* [1]

Ramsey, Y. A. (2012)	Proces prikupljanja novca s ciljem da ideje postanu uspješni poslovni poduhvati povezivanjem nosioca ideja sa potencijalnim finansijerima.
Lynn, D. M. (2012)	Relativno novi alat društvenih medija namjenjen prikupljanju sredstva za razne poduhvate.
Bechter, C., Jentzsch, S., Frey, M. (2011)	Pristup prikupljanju kapitala potrebnog za projekat ili kompaniju animiranjem velikog broja pojedinaca da doniraju manje iznose ($1-$100).
Sigar, K. (2012)	Strategija uvećanja kapitala prikupljanjem manjih novčanih svota od velike grupe ljudi putem onlajn kanala.
European Crowdfunding Network (2012-2013)	Crowdfunding je mehanizam okupljanja velikog broja pojedinaca, najčešće preko interneta, spremnih da malim ulaganjima podrže određeni projekat u zamjenu za učešće u projektu, finansijsku dobit ili drugu nenovčanu nagradu.
Wheat, R. E., Wang, Y., Byrnes, J. E., Ranganathan, J. (2012)	Nova metoda prikupljanja sredstava putem interneta kojom pojedinci traže podršku za svoje projekte na specijalizovanim crowdfunding platformama.
Lynn, D. M., Sabbagh, H. (2012)	Inovativni alat društvenih medija koji predstavlja novi izvor finansiranja poduhvata.
Powers, T. W. (2012)	Finansijski mehanizam koji startap kompanijama omogućava prikupljanje sredstava od javnosti preko internet posrednika.

Prilikom definisanja pojma crowdfundinga autori su pristupali problemu iz različitih uglova, ali ono što je zajedničko u definisanju pojma crowdfundinga je, da je to prikupljanje novčanih sredstava, najčešće putem interneta, koje daje grupa ljudi sa namjerom ostvarenja određenog cilja, koji je postavio neki pojedinac ili grupa [2].

2.1 Vrste crowdfundinga

Vremenom su se razvile različite vrste crowdfundinga, koje možemo podijeliti u četiri osnovne grupe, koje su formirane na osnovu povrata investicije, odnosno onoga što investitor dobija za uložena sredstva. Tako razlikujemo:

- donatorski (engl. *donation-based*),
- nagradni (engl. *reward-based*),
- investicioni (engl. *equity-based*) i
- kreditni (engl. *lending-based*) crowdfunding.

Donatorski crowdfunding je baziran na dobročinstvu i donatori ne očekuju zauzvrat bilo kakvu materijalnu korist, nagradu ili naknadu.

Kod nagradnog crowdfundinga investitori dobijaju određenu nagradu u zavisnosti od iznosa uplate. Najčešće su to robne nagrade ili usluge koje su vezi sa projektom koji se finansira. Ova nagrada ne uključuje bilo koji dio učešća u vlasništvu projekta.

Za razliku od ova dva prethodna principa, kod investicionog crowdfundinga investitori za svoja uložena finansijska sredstva zauzvrat dobijaju dio vlasništva u

projektu, tako što postaju vlasnici akcija projekta ili kompanije.

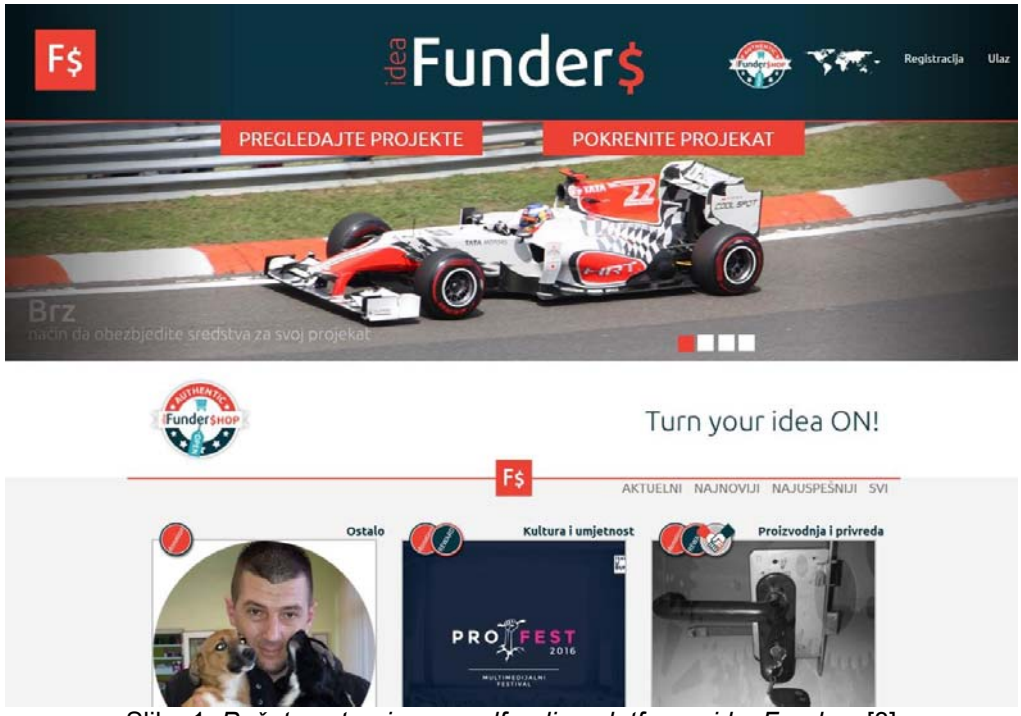
Kod kreditnog crowdfundinga vlasnici projekta prijavljuju projekat na platformu, gdje se potom automatizovanim sistemom određuje kreditni rizik i odgovarajuća kamatna stopa. Ovdje investitori kupuju akcije platforme i novac se prosljeđuje vlasnicima projekta. Investitori u ovom slučaju zarađuju od kamate na pozajmicu.

3 PRVA REGIONALNA CROWDFUNDING PLATFORMA

Prve crowdfunding platforme su počele da se pojavljuju u posljednjoj deceniji. U svijetu je su prisutne različite vrste crowdfunding platformi, od opštih platformi za sve vrste projekata, odnosno kampanja, do usko specijalizovanih platformi za određene oblasti.

U regiji Zapadnog Balkana je prisutno više platformi koje djeluju unutar pojednih država. Kao prva regionalna platforma koja djeluje na području Srbije, Bosne i Hercegovine i Hrvatske, radom domaćih stručnjaka kreirana je platforma ideaFunders. Crowdfunding platforma ideaFunders počela je sa radom 2015. godine.

Izgled početne stanice ove crowdfunding platforme prikazan je na slici 1.



Slika 1. *Početna stranica crowdfunding platforme ideaFunders* [3]

Budući da je platforma bazirana na projektima koji se objavljuju na njoj, na početnoj stanici je napravljena jasna podjela na logičke cjeline u zavisnosti od toga da li korisnici žele da pregledaju postojeće projekte ili pokrenu vlastiti novi projekat.

3.1 Osnovni principi

Svi projekti na crowdfunding platformi su podijeljeni po kategorijama i pripadajućim potkategorijama. Podjela je prikazana u tabeli 2.

Tabela 2. *Kategorije projekata na platformi ideaFunders*

Humanitarni projekti	Nekomercijalni projekti	Komercijalni projekti
Liječenje Socijalno ugroženi Prirodne nesreće Ostalo	Obrazovanje Sport Kultura i umjetnost Zajednice Ostalo	Inovacije IT softver i hardver Energija Ekologija Medicina i zdravlje Preduzetništvo i usluge Proizvodnja i privreda Poljoprivreda i hrana Turizam i ugostiteljstvo Mediji i produkcija Ostalo

Kategije prikazane u gornjoj tabeli predstavljanju aktuelno stanje na platformi. Ukoliko se ukaže potreba, ove kategorije se mogu ažurirati u skladu sa novim zahtjevima.

3.2 Vrste projekata

Pored gore navedene podjele na kategorije, u zavisnosti od načina na koji se prikupljaju sredstva, projekti se dijele na sljedeće vrste [4]:

- rezultatski uslovljene „Sve ili ništa“ – kada po završetku projekta titular (vlasnik/autor) dobija prikupljena sredstva pod uslovom da je do završetka projekta prikupljen traženi iznos ili više tj. ostvaren finansijski cilj - u protivnom sredstva se ne povlače sa računa finansijera (fandera),
- rezultatski neuslovljene „Daj šta daš“ – kada po završetku projekta titular (vlasnik/autor) dobija prikupljena sredstva, bez obzira da li je projekat ostvario finansijski cilj.

4 ZAKLJUČAK

Crowdfunding platforma predstavljena u ovom radu je pionirski korak u kreiranju crowdfunding mreže u regionu Zapadnog Balkana. Ponuđeni mehanizam za finansiranje projekata predstavlja veliki potencijal za obezbjeđenje finansijskih sredstava, kako za projekte inovacionog razvoja, tako i za ostale vrste projekata.

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ASSESSING THE NEED FOR VALIDATION TOOLS IN THE ICT SECTOR IN KOSOVO

Uran Rraci[1],**Armend Berisha**[2]

Abstract: This paper aims to shed light in the practices and mechanisms that organizations in Kosovo utilize to recognize and validate education, training and in-formal education. Moreover, the paper analyzes the need of ICT employers in Kosovo for validation based on the level of skills and knowledge required for the job position – whether there is a higher need for validation for low-skills positions or for high-skills positions. In addition, this piece seeks to provide an insight if the current instruments for validation in Kosovo meet the employers demand for recruitment purposes. The paper uses mixed-methods – a brief analysis of the European Union trends of policies and documents in regards to the documentation and validation of education and a context description of Kosovo's mechanisms for recognition – which will serve as a basis for hypothesis testing. The second method of the paper will test the proposed hypothesis for ICT employers needs for validation and recognition in Kosovo.

1 EUROPEAN INITIATIVES FOR RECOGNITION AND VALIDATION

The European Union agenda for skills validation derives by the need to enable the mobility of worker within the member states, increase the skills levels in Europe as a means to better lives and jobs, and boost competitiveness and support fair and balanced growth reaping the full benefits of digital and technological advancements (Hawley, J., Souto Otero, M., & Duchemin, C. (2010). The EU is increasing activities and commitment toward homogenizing practices for validation and recognition in all member states. Yet, it remains a greater need for coordination in order to reduce the differences of standards and qualification frameworks within the member states in order to achieve the initial goal for validation and recognition; however, there is a substantial progress of member states towards addressing the need for validation and recognition. According to the European inventory on validation of non-formal and informal learning (2014), in 2010 half of the member states did not have in place a comprehensive national strategy for validation, whereas in 2014 more than two-thirds of the members states have in place or are in the midst of developing a national strategy. The strategies for validation and

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*This designation is without prejudice to positions on status, and is in line with UNSC 1244 and the ICJ Opinion on the Kosovo declaration of independence."

the National Qualification Frameworks among these countries are linked to the European Qualifications Framework, which is a common European reference framework whose purpose is to make qualifications more readable and understandable across different countries and systems (European Center for the Development of Vocational Training, 2018).

The department for Education and Training under the European Commission measures the progress and the application of good practices by the member states for validation and provides a record on how validation is being used at national, regional and local level in Europe (Košmrlj, 2016). According to the country reports, there is a high development among the member states in terms of providing opportunities for validation across the different sectors of education and in the labor market. In addition, there is a sufficient and accessible guidance and counseling for how to maximize the benefits of validation by the individuals, also there are reliable and credible agencies that assure the quality of assessments (Košmrlj, 2016). There is a need for improvement for the member states to provide skills audit for the people who are unemployed or for the one who are at risk of losing jobs. Currently, less than half of the countries report to integrate skills audit in their inventory of tools for validation (Košmrlj, 2016). The most pressing need in regards to validation for the member states is to ensure for the disadvantaged groups to benefit.

The most prominent tools and mechanisms that EU has developed to utilize for validation of education, training and informal education, besides the European Qualification Framework (EQF), include Europass, the credit systems (ECTS), and the quality arrangements in higher education and vocational education and training. The Europass is a set of five standardized documents and a skills passport available in 26 languages, designed to enable citizens to communicate their skills and qualifications effectively when looking for a job or training, and help employers to understand the skills and qualifications of the workforce (Europass, 2018). The credit system, ECTS for higher education and ECVET for vocational education and training, is a central tool of Bologna Process, which enables students to transfer in between universities and countries and have their diplomas recognized by the host countries. Quality Assurance arrangements in higher education and vocational education and training, is a tool that provides extensive data available to the public and other stakeholder in order to keep colleges and universities accountable.

2 THE STATE OF VALIDATION AND RECOGNITION IN KOSOVO

Kosovo, although is not an EU member state and nor part of the European Higher Education Area (EHEA), adopted all the education reforms and principles that derive with the Bologna Process. As e result, all higher educations in Kosovo implement the three-cycle degree system, ECTS credit system, and the quality assurance system. In 2012, the Kosovar government established the National Qualification Authority, which is an independent public body aiming to oversee and develop the National Qualification Framework in the context of lifelong learning. In terms of validation of education and training, the authority plays an important role in country's endeavors to harmonize the standards of qualification with the European Qualification Framework in order to promote and enable the mobility of students and workers within Kosovo and the European countries. The NQA, despite the limited human resources, has validated 19 qualification standards and has verified more than 40 standards of profession (KESP, 2017). Despite this, according to the dvv international (2013), the qualifications requirements in the VET sectors are not sufficiently linked with those of general and higher education. There are no sufficient data or report indicating the progress towards the validation or recognition

of non-formal and informal learning. However, the Kosovo Progress Report by the EU Commission (2014) notes the efforts that the authority has made in modernizing vocational training institutions, in particular to harmonize learning outcomes with the labour market demands.

The Kosovo Accreditation Agency in Kosovo is another entity that emerged due to the embracing the education reforms in the past decade. The Kosovo Accreditation Agency (KAA) is entitled to conduct institutional and programmatic accreditation for higher education providers in the Republic of Kosovo. The standards and guidelines upon which the KAA evaluates colleges and universities in Kosovo derive from the Standards and Guidelines for Quality Assurance (ENQA) in the European Higher Education Arena (EHEA) (Kosovo Accreditation Agency, 2014). The KAA evaluates institutional study programs on whether an institution meets the minimum criteria of quality based on prior evaluation by the accreditation experts. The agency plays a major role in the country for validating higher education programs for all professions. The agency has evaluated all the study programs in the country so far and is the key stakeholder to the country's for formal education recognition and validation endeavors.

3 ASSESSING THE NEEDS OF ICT SECTOR

In order to test whether businesses have different necessities regarding the validation of skills depending on job level, authors conducted interviews with local ICT companies, and in total 17 senior level representatives responded to the questionnaire. All of the representatives are part of the decision-making process within their companies, and are specifically involved in recruitment. The number of employees within these companies ranges from 8 – 45. Almost 90% of the companies work with local and international markets, while 10% conduct business activities exclusively with international markets. As it has become the case in most countries, the ICT sector in Kosovo has also undergone a radical transformation, becoming an important economic factor. Moreover, because growth in this sector has increased exponentially, companies have continuously faced challenges when recruiting new employees. The interviews aim at inquiring about these challenges, and the results of the questionnaire are presented below.

The recruitment channels used by the companies do not differ from the selection process used by other sectors in Kosovo. In 11.76% of companies, traditional vacancy advertisements is the most frequent channel of recruitment. Recruiting perspective employees through universities is seldom (5.88%) used by ICT companies, while no companies use employment agencies to recruit employees. The most frequent recruitment channel is through internships (35.29%), while recruitment through professional networks is the second most popular channel at 29.41%. Companies have begun to utilize social networks to fill vacancies, however, this channel is used most frequently in 17.67% of the cases.

One of the main challenges faced by ICT companies is the skills gap, which continues to limit the growth, thus, hindering the scale process which is very important for these companies. Companies have identified numerous skills/abilities that perspective employees lack. The most important skills/abilities they lack are: multitasking and prioritizing, innovation, self-initiative, communication, foreign language (German/English), teamwork, creativity, critical thinking, independent thinking, loyalty, flexibility, entrepreneurial thinking etc. These skills/abilities that prospective employees lack are in direct correlation with what companies expect from new employees in order to be successful within the organization. Because some of the aforementioned skills/abilities are considered soft-skills, there are no existing tools, other than formal

education, that could adequately validate them. There is an exception with an Erasmus + Capacity Building Project called Ready for Business – Integrating and validating practical entrepreneurship skills in engineering and ICT studies. As part of this project, students from the engineering and ICT studies are able to undergo trainings and validate their skills using LEVEL 5 software. This is why companies often rely on university degrees to measure the skill level of prospective employees. Furthermore, these obstacles are also the reason why the most frequent recruitment channels used by companies are internships and professional networks. This confirms that companies are more inclined to trust personal relationships rather than conventional recruitment methods.

4 HOW IMPORTANT IS IT FOR PERSPECTIVE EMPLOYEES TO HAVE THEIR SKILLS VALIDATED?

As mentioned previously, there are not enough programs in Kosovo that conduct adequate skill validation. Naturally, higher education institutions in Kosovo offer a variety of academic programs that develop the skills/abilities mentioned above, however, most of the teaching is conducted using conventional teaching methods and curriculums are seldom based on labor market needs, thus, assessment methods lack the sophistication to validate the skills which would satisfy the needs of companies. When asked about the importance of skills validation, 70.56% of the companies responded that this is very important, while 29.44% said it is important. Their response shows there is a need for a comprehensive national approach to develop validation tools that would satisfy the needs of the labor market, which would ease the recruitment process for the companies.

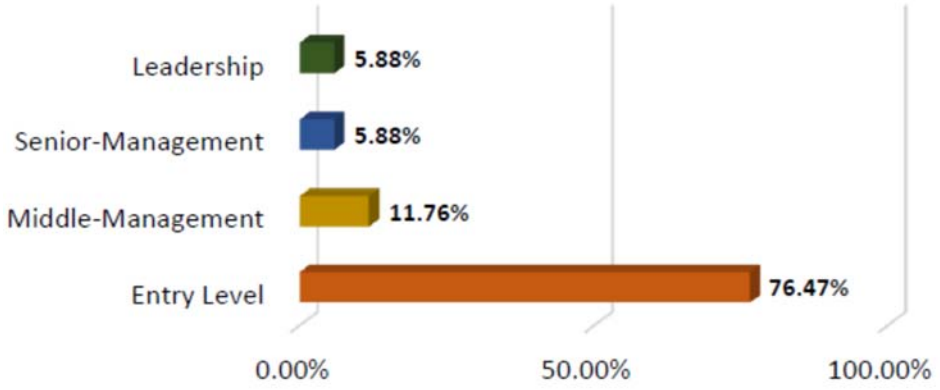


Figure 1. *What job level is most important to have their skills validated?*

The research revealed an important element regarding the need for skills validation. Company representatives, while emphasizing the importance of skills validation, stated that the need for validation differs between job levels. According to the research, validation is more important for entry-level positions, because prospective employees who apply for entry-level positions do not have enough experience to showcase their skills, thus, proof of their skills/abilities is very important. This question provides an answer to the hypothesis that validation differs between job levels within the company. Figure 1 shows that validation is most important at entry-level positions. Companies stated that skills validation is imperative for entry-level jobs (76.47%), while 11.76% of the companies stated that skills validation is important for middle-

management. According to the questionnaire, senior-management and leadership level are less needed, 5.88% respectively, to have their skills validated. In principle, validation should be required for high-level officials who are responsible for the fate of the company, however, according the questionnaire, employers find it more difficult to assess the skills of entry-level employees since their previous experience is limited.

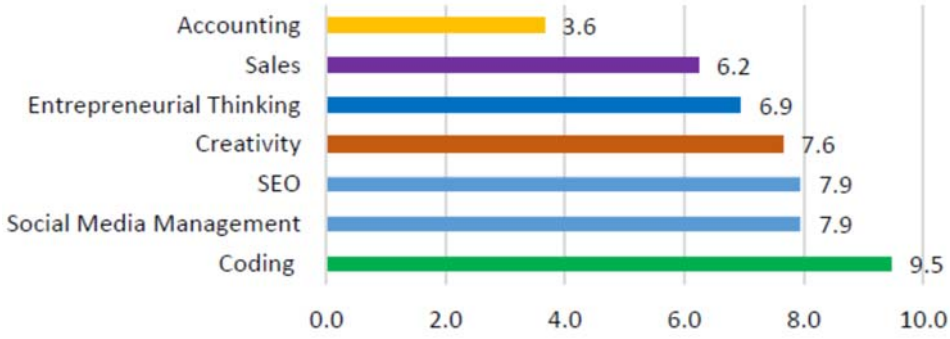


Figure 2. *Skills where validation is needed in the future.*

Besides job levels, it is profoundly important to validate skills/abilities in different fields as well, especially those acquired through informal education which is very common in Kosovo. Through the questionnaire, this paper aims to explore whether ICT companies were able to assess the labor market and whether there are fields where validation is required. According to companies, validation for coding is the most important. Moreover, because the majority of ICT companies in Kosovo work with international customers, prospective employees that are able to demonstrate social media management skills are more likely to get hired. A list of other fields where validation is needed is presented on Figure2.

5 CONCLUSIONS

The process of validating formal education, informal education and training continues to pose challenges for ICT companies in Kosovo. The current system does not meet their needs, therefore, it is incumbent upon educational providers to develop a system for validating skills that are important for the companies, thus, reducing the skills gap. There is a positive outlook since higher educational institutions in Kosovo are cooperating with educational institutions in EU to develop validation tools that will allow students and perspective employees to demonstrate their skills. This is very important for entry-level jobs, since the majority of companies face difficulties hiring individuals in this level because their skills are not validated through proper channels. Their answers substantiated the hypothesis that the need for validation differs between job levels and it is important to provide validation opportunities especially for informal education. Because growth in the ICT industry is exponential, the need to hire competent individuals will continue to remain apparent for many years, therefore, developing a comprehensive validation system is not only important for the industry, but for the future of the workforce as a whole.

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STUDENT SESSION

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SIMULACIJA PROCESA OBRADE PRIMJENOM CAD/CAM PROGRAMSKOG SISTEMA OPŠTE NAMJENE CATIA

Dušan Josipović[1], Nikola Kurdulija[2]

Rezime: U ovom radu prikazan je način izvođenja simulacije procesa obrade i generisanja NC koda primjenom CAD/CAM programskog sistem opšte namjene CATIA. Postupak podrazumijeva izradu 3D modela pripremka i obratka u CATIA programskom sistemu opšte namjene, odabir mašine alatke u virtualnom okruženju modula Machining, Prismatic Machining, odnosno Machining, Lathe Machining, definisanje strategija obrade, izvođenje simulacija procesa obrade, te na posljetku automatizovano generisanje G koda. Na osnovu dobijenog G koda, izrađen je fizički model postupcima glodanja i struganja na CNC strugu EMCO Concept Turn 450 sa upravljačkom jedinicom Siemens Sinumerik 840D.

Ključne riječi: automatizovano generisanje G koda, obrada glodanjem, obrada struganjem, simulacija procesa obrade

SIMULATION OF THE CAD / CAM PROGRAMMING PROCESS SYSTEM FOR CATIA GENERAL PURPOSE

Abstract: This paper shows cutting process simulation end G code generation using CAD/CAM software CATIA. The procedure means 3D model of workpiece generation in CATIA software, selection of machine tool in virtual environment in Prismatic Machining Module, i.e. Lathe Machining module, then strategic of production selection, performing of simulation, and at the end automated G code generation.
Based on generated G code, physical prototype has been produced on Turning Machine Emco Concept Turn 450, with Siemens Sinumerik 840D control unit. Both milling and turning processes were used during production, using driven tools.

Key words: automated generation of G code, milling processing, turning processing, simulation of the cutting process

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1 UVOD

Računarom podržana proizvodnja (Computer Aided Manufacturing – CAM) obuhvata sve funkcije proizvodnje u kojima se koristi računar. Akronim CAM ima široko značenje, ali se najčešće podrazumijeva skup računarskih programa koji podržavaju pripremu i upravljanje proizvodnim procesima putem direktne ili indirektne veze procesa i računara. CAM tehnologija počela se razvijati iz tehnologije numerički upravljanih mašina alatki početkom pedesetih godina prošlog vijeka. U to vijeme, radom numerički upravljanih alatnih mašina upravljano je pomoću kodiranih naredbi sa bušene trake. Automatizovano generisanje programa za upravljanje CNC mašinama alatkama danas predstavlja najviše područje primjene CAM sistema.

Današnji CAM sistemi imaju na raspolaganju čitav niz funkcija, kao što su: generisanje i optimizacija putanje alata, razvoj i primjena odgovarajućih baza podataka, simulacija i vizuelizacija proizvodnih procesa itd., čime se neposredno utiče na smanjenje manuelnih aktivnosti u okviru programiranja, te na povećanje ukupnih izlazinih tehno - ekonomskih efekata. Programiranje NUMA primjenom CAM sistema predstavlja osnovni trend savremenog inženjerstva, koji je u potpunosti potisnuo sve ostale metode programiranja [1]. Dubovska [2] i Majerik [3] prikazuju upotrebu CAD/CAM programskog sistema CATIA za simulaciju procesa obrade i automatizovano generisanje programskog koda, pri izradi dijelova postupkom visokobrzinske obrade glodanjem (High Speed Machining, HSM) i struganjem. Prema [4] CAD/CAM sistemi su veoma važni u proizvodnom procesu izrade dijelova složenog oblika za automobilsku i vazduhoplovnu industriju. Takođe upotreba CAD/CAM sistema smanjuje mogućnost nastajanja grešaka u toku proizvodnog procesa.

2 CAD/CAM SISTEM CATIA V5

Softverski paket CATIA (*Computer Aided Three-dimensional Interactive Application)* je program opšte namjene koji, između ostalog, sadrži module za simulaciju procesa obrade i automatizovano generisanje upravljačkog programa, odnosno G koda. CATIA je komercijalni programski paket razvijen od strane francuske kompanije Dassault Systemes. Kompanija Dassault Systemes je uvođenjem programa CATIA V5 postavila novi standard, donoseći značajna poboljšanja u arhitketuri sistema i korisničkom radnom okruženju. CATIA V5 Machining nudi najkvalitetnije proizvode i rješenja koja proizvođačima omogućuju planiranje, simulaciju i optimizaciju procesa obrade. Upotreba ovakvog CAM sistema može značajno da smanji ukupno vrijeme proizvodnje, osigura visok kvalitet i efikasnost proizvoda. Zahvaljujući jednostavnom korisničkom interfejsu, upotreba CATIA sistema zahtjeva dosta kraći proces učenja u poređenju sa drugim komercijalnim CAM sistemima. Moduli Lathe i Prismatic Machining omogućavaju izvođenje simulacije i generisanje G koda za obradu glodanjem i struganjem.

Programiranje u CAD/CAM softverskim sistemima se zasniva na modelu gotovog dijela koji treba izraditi, definisanju tehnologije izrade, režima obrade, optimizacije putanja alata na osnovu kojih će se generisati upravljački program za određeni upravljački sistem.

3 SIMULACIJA PROCESA OBRADE I GENERISANJE NC KODA

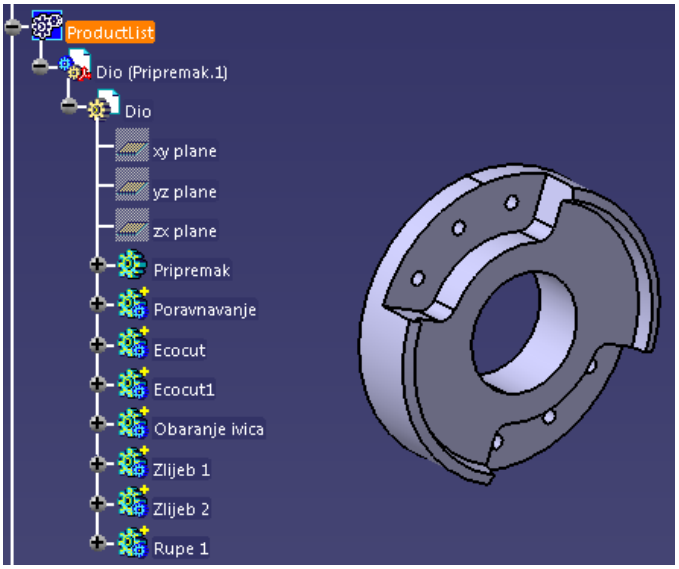
Postupak automatizovanog generesanja upravljačkog programa se sastoji od sljedećih koraka:

1. Definisanje pripremka i obradaka po operacijama
2. Izbora mašine i nulte tačke radnog predmeta W
3. Definisanje operacija i strategije obrade dijela
4. Simulacija procesa obrade i generasanje NC koda

3.1 Definisanje pripremka i obradaka po operacijama

U ovom koraku definiše se pripremak i obradak po operacijama. Takođe, potrebno je definisati tačku koja će biti izabrana kao nulta tačka radnog predmeta W, te tačke START POINT i END POINT. Pri tome START POINT je tačka u koju će alat doći u brzom hodu, a END POINT tačka u kojoj se vrši izmjena alata.

Potom, potrebno je nacrtati pripremak u SKETCH-u, u sekciji PART DESIGN, korišćenjem alatki PROFIL i OPERATION, nakon čega se vrši izrada modela pripremka korišćenjem alatki SKETCH - BASED FEATURES. Nakon modelovanja pripremka, slijedi crtanje i modelovanje obradaka po operacijama, istim alatkama kao i za pripremak.



Slika 1. *Obradak*

Na kraju, potrebno je definisati nultu tačku obratka W, te tačke START POINT i END POINT korištenjem alatke POINT.

3.2 Izbor mašine i nulte tačke radnog predmeta W

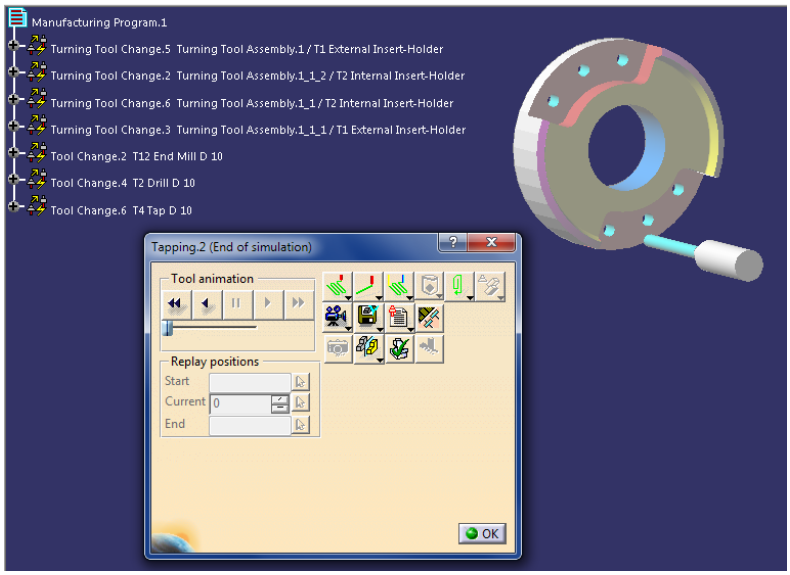
U ovom koraku potrebno je izabrati modul LATHE ili PRISMATIC MACHINING u zavisnosti od toga koji je postupak obrade u pitanju, struganje ili glodanje. Nakon toga slijedi izbor mašine i nulte tačke, kao i selektovanje pripremka i obratka u sekciji PART OPERATION. Kod izbora mašine, potrebno je u kartici NUMERICAL CONTROL izabrati POST PROCESSOR, odnosno upravljačku jedinicu Sinumerik, Fanuc, itd.

3.3 Definisanje operacija i strategij obrade dijela

Kod definisanja operacija potrebno je odrediti putanju alata, izabrati geometriju, alat, režime obrade, kao i način prilaska i odmicanja alata. Kod određivanja putanje alata, zavisno od operacije, kretanje može biti pravolinijsko, koncetrično, spiralno itd. Alati i režimi obrade se biraju iz baze podataka. Način prilaska i odmicanja alata može biti radijalni, aksijalni ili kombinovani.

3.4 Simulacija procesa obrade i generasanje NC koda

Simulacija procesa obrade podrazumijeva prikaz obrade dijela prema operacijama. Simulacija se izvodi korišćenjem opcije TOOL PATH.



Slika 2. *Simulacija procesa obrade*

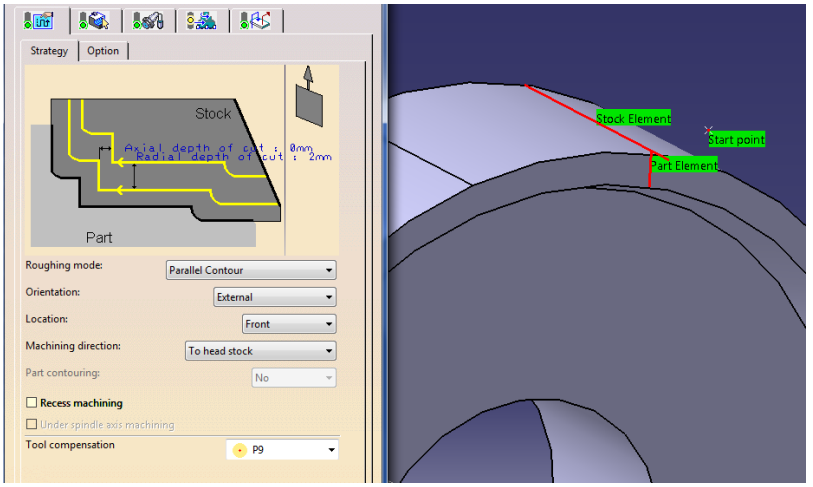
Prije nego što se pristupi generisanju koda, potrebno je definisati POST PROCESSOR (CENIT, ICAM ili IMS) i ukucati ekstenziju koja odgovara upravljačkoj jedinici. S obzirom da je upravljački sistem mašine na kojoj se vrši obrada (EMCO Concept TURN 450) Siemens Sinumerik 840D, potrebno je odabrati postprocessor CENIT.

Generisanje NC koda se izvodi korišćenjem opcije GENERATE NC CODE INTERACTIVELY. U kartici IN/OUT, potrebno je sa kartice NC Data Type odabrati NC code, te lokaciju na kojoj će kod biti sačuvan. Generisanje G koda izvršava se selektovanjem EXECUTE opcije.

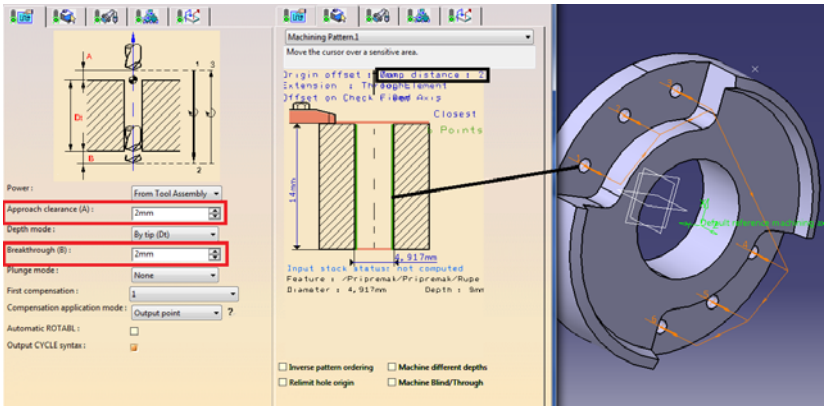
4 SIMULACIJA OBRADE STRUGANJEM U CATIA V5

Za obradu struganjem potrebno je izabrati modul LATHE MACHINING, pri čemu je potrebno izvršiti prilagođavanje koordinatnog sistema pripremka sa koordinatnim sistemom mašine. Za operacije struganja koriste se alatke TURNING OPERATIONS u paleti MACHINING OPEARTIONS. Pri definisanju operacija struganjem, obrada može biti spoljašnja ili unutrašnja, te poprečna ili uzdužna. Izbor putanje alata i alata zavisi od tipa obrade. Kod definisanja geometrije potrebno je izabrati konturu profila na površini obratka i pripremka. Za operacije bušenja i izrade

navoja koriste se alatke DRILLING koji se nalaze na paleti MACHINING OPEARTIONS. Operacije bušenja i izrade navoja se mogu izvoditi u modulu LATHE ili PRISMATIC MACHINING. Pri operacijama bušenja i izrade navoja, kod definisanja putanje alata moguće je postaviti vrijednosti APPROACH i BREAKTROUGH. Pri tome APPROACH CLEARANCE označava udaljenost od obratka, odnosno vrijednost na koju će alat doći u brzom hodu. BREAKTROUGH označava koliko alat treba da prođe van obratka, i definiše se u mm. U kartici za definisanje geometrije moguće je postaviti vrijednost JUMP DISTANCE, kako ne bi došlo do kolizije alata i obratka.



Slika 3. *Okruženje za definisanje geometrije kod obrade struganjem*

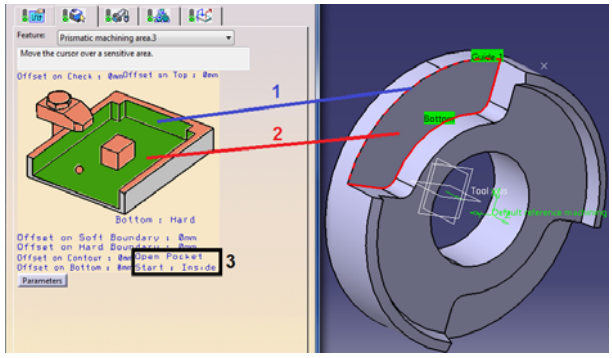


Slika 4. *Okruženje za definisanje geometrije kod bušenjem i izrade navoja*

5 SIMULACIJA OBRADE GLODANJEM U CATIA V5

Za obradu glodanjem potrebno je izabrati modul PRISMATIC MACHINING. Za operacije glodanja koriste se alatke MILLING koje se nalaze u paleti MACHINING OPEARTIONS. U kartici za definisanje putanje alata definiše se strategija obrade, što podrazumjeva definisanje načina kretanja alata, broj prolaza i dubinu po jednom prolazu. Na slici 5. prikazan je način na koji se definiše geometrija pri obradi

glodanjem. Na slici 5, brojem 3. označen je način obrade koja može biti otvorena ili zatvorena.



Slika 5. *Okruženje za definisanje geometrije kod obrade glodanjem*

6 ZAKLJUČAK

Cilj ovog rada je da se prikaže mogućnosti savremenog CAM programskog sistema CATIA V5 u smislu izvođenja simulacije obrade, automatizovanog generisanja G koda, sa posebnim osvrtom na upravljanje gonjenim alatima. U tom cilju odabran je radni predmet složene geometrije, za čiju izradu je potrebno primjeniti postupke struganja i glodanja. Kompletna obrada dijela izvodi se u jednom stezanju, na CNC strugu, pri čemu se zahvati obrade glodanjem izvode primjenom gonjenih alata.

Automatizovano programiranje podrazumijeva programiranje geometrijskih i tehnoloških informacija, uz podršku računara. Izradom G koda na ovaj način skraćuje se vrijeme i troškovi programiranja, što je posebno bitno pri obradi dijelova složene geometrije, gdje se lakše i brže dolazi do upravljačkog programa u odnosu na ručno programiranje. U radu je najprije prikazan proces obrade struganjem, odnosno proces definisanja putanje alata, strategije obrade, odabir režima obrade te način prilaska alata konturi pripremka i odmicanja alata od obratka.

U drugom dijelu prikazan je proces obrade glodanjem na istom radnom komadu, u istom stezanju, upotrebom gonjenih alata. Da bi se mogla izraditi dva kružna džepa, potrebno je preći iz modula LATHE MACHINING u modul PRISMATIC MACHINING.

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UTICAJ KOEFICIJENTA TRENJA KOČIONOG SISTEMA KOD TERETNIH MOTORNIH VOZILA I PREVENTIVNI TEHNIČKI PREGLED DISK KOČNICE

Njegoslav Đokić[1]

Rezime: U ovome radu je data analiza odnosa tangencijalne sile i stezne sile tj. koeficijenta kočenja. Prikaz realnog i teorijskog dijagram za promjenu sile na pedali kočnice. Pokazano je i kako koeficijent trenja zavisi i od uslova na kolovozu, i prikazani su i iznosi koeficijenata trenja za različite podloge. Izvršena je i provjera kočionog sistema teretnog motornog vozila SCANIA R410.

Ključne riječi: kočioni sistem, tehnički pregled, teretno vozilo, trenje

INFLUENCE FRICTION COEFFICIENT OF THE BRAKING SYSTEM AT FREIGHT MOTOR VEHICLES AND PREVENTIVE TECHNICAL INSPECTION OF DISC BRAKE

Abstract: In this work gives an analysis ratio tangential force and clamping force it is braking coefficient. Presentation of the real and theoretical diagram to change the force on the pedal brake. It also shows how the friction coefficient depends on the conditions on road, and amounts of the friction coefficient for different substrates. A check of the braking system of a freight motor vehicle SCANIA R410 was also performed.

Key words: brake system, tehnical inspection, freight vehicle, friction

1 UVOD

Kočioni sistem ima zadatak da obezbjedi usporavanje i zaustavljanje vozila sa usporenjima koja odgovaraju potrebama i raspoloživom prianjanju uz stabilno kretanje vozila za vrijeme kočenja. Kod konvencionalnih sistema za kočenje (frikcione kočnice) vozilo se zaustavlja tako što se kinetička energija prevodi u toplotnu energiju trenjem kočnih obloga i kočionih doboša ili diskova. Toplotna energija se rasipa u okolinu.

Velika promjena koja se već sada odvija, i to ne samo na teretnim vozilima, je sve veća primjena elektronike u tzv. *by wire* sistemima (*engl. brake by wire, steer by wire, itd.*). To su sistemi gdje uređaji za upravljanje vozilom (pedala kočnice, upravljač) nisu izravno povezani sa izvršnim dijelovima sistema (točkovi, disk kočnice), već se naredba vozača prvo prenese do računara koje upravlja vozilom. Tako se povećava

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sigurnost prilikom samog procesa kočenja.

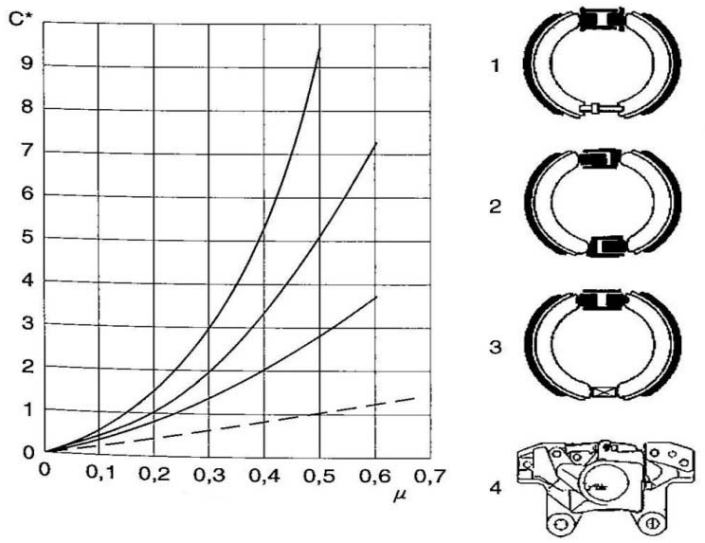
2 FORMIRANJE SILE KOČENJA

Osnovni način formiranja sile kočenja kod teretnih vozila je primjena kočnica na principu trenja (frikcione kočnice). Ova vrsta kočnice stvara moment kočenja koji pretvara kinetičku energiju vozila u toplotu. Frikcione kočnice mogu biti izvedene kao disk ili bubanj kočnice.

Karakteristična veličina kod frikcionih kočnica je vrijednost tangencijalne sile stvorene na bubnju ili disku i stezne sile. Ta se vrijednost naziva koeficijentom kočenja B_C ili *(engl. C – star value (C*))*. Taj je faktor određen konstrukcijom, geometrijom i koeficijentom trenja kočionih obloga. Bubanj kočnice mogu ostvariti veće sile kočenja pri istim steznim silama od disk kočnica, pa je i njihov koeficijent kočenja mnogo veći. Variranje koeficijenata trenja kočionih obloga mnogo je izraženije kod bubanj nego kod disk kočnica što ima veliki uticaj na moment kočenja (slika 1).

Prednost disk kočnica nad bubanj kočnicama odnosi se prvenstveno u daleko manjoj osjetljivosti na variranje koeficijenta trenja i većoj toplotnoj stabilnosti. Disk kočnice su počele zamjenjivati bubanj kočnice pojavom pojačivača sile kočenja 1960-ih godina. Danas se bubanj kočnice mogu naći samo na stražnjim osovinama putničkih vozila, te na teretnim vozilim.

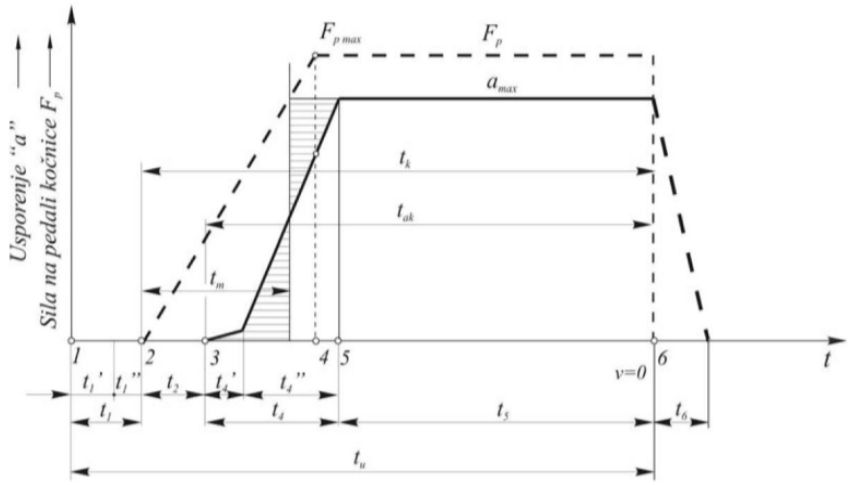
Osim frikcionim kočnicama, vozilo se može usporiti momentom kočenja motora sa unutrašnjim sagorijevanjem čija snaga može iznositi do 7 kW po litri zapremine.



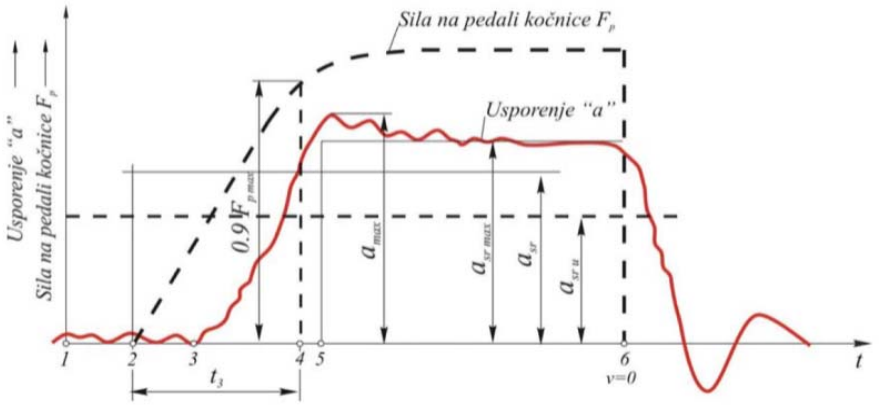
Slika 1. *Koeficijent kočenja C*: 1) Duo servo bubanj, 2) Duplex bubanj, 3) Simplex bubanj, 4) Disk kočnica* [2]

2.1 Teorijski i realni dijagrami promjene sile

Prikaz realnog i teorijskog dijagram za promjenu sile na pedali kočnice slika 2 i slika 3.



Slika 2. *Teorijski (idealizovani) dijagram promjene sile na pedali kočnice*



Slika 3. *Realni dijagram promjene sile na pedali kočnice*

Upoređivanjem ova dva dijagrama vidi se da u praksi (realnom dijagramu) je a < a_{max}, takođe se vidi da je u tački 4 sila na pedali kočnice u praksi manja za otprilike 10% i da faktor prianjanja u opštem slučaju nije u potpunosti iskorišten.

U opštem slučaju: puno usporenje je bilo koje usporenje za određenu silu aktiviranja, dok u graničnom slučaju: najveće usporenje je ono koje vozilo može postići sa određenim uslovima prianjanja i parametrima kočionog sistema.

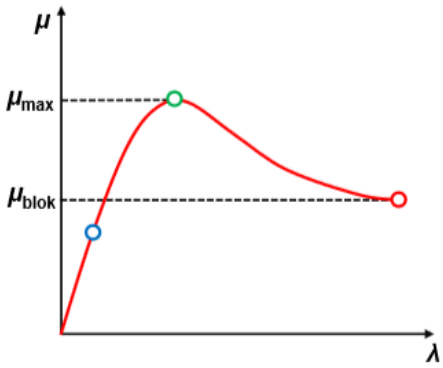
Od trenutka djelovanja sile kočenja do trenutka zaustavljanja vozila, vozilo se kreće usporeno, a put koji ono za to vrijeme prijeđe naziva se put kočenja.

U slučaju trenutnog djelovanja sile kočenja u punoj veličini, cijelo vrijeme kočenja, kretanje vozila će biti jednoliko usporeno, a nagli prirast i prestanak djelovanja sile izazvat će uzdužni udar. Veličina uzdužnog udara biće veća ako je vrijeme iniciranja sile kočenja kraće, tj. ako je pritisak na papučicu kočnice bio nagliji. Takvo kočenje se naziva intenzivno odnosno forsirano kočenje.

Ako je na početku kočenja postepen prirast sile, a na kraju postepeno opadanje sile kočenja, veličina usporenja vozila je promjenjiva na početku i na kraju kočenja dok je u sredini konstantna. Kod takvog načina kočenja put kočenja je duži, ali je vožnja udobnija. Takav način kočenja naziva se slobodno kočenje.

Kočenje vozila je proces koji se vrši sa ciljem da se vozilo uspori ili zaustavi. Sistem za kočenje je ujedno i uređaj bezbjednosti vozila, tako da se kočne osobine vozila mogu da posmatraju i sa tog aspekta.

Na slici 4 prikazan je dijagram iskorišćenosti prianjanja, tako da razlikujemo potpuno iskorišćenje, nedovoljno iskorišćenje i nedovoljno iskorišćenje gubitak upravljivosti (stabilnosti).



Optimalno kočenje → potpuno iskorištenje raspoloživog prianjanja

Nedovoljno kočenje → nedovoljno iskorištenje prianjanja

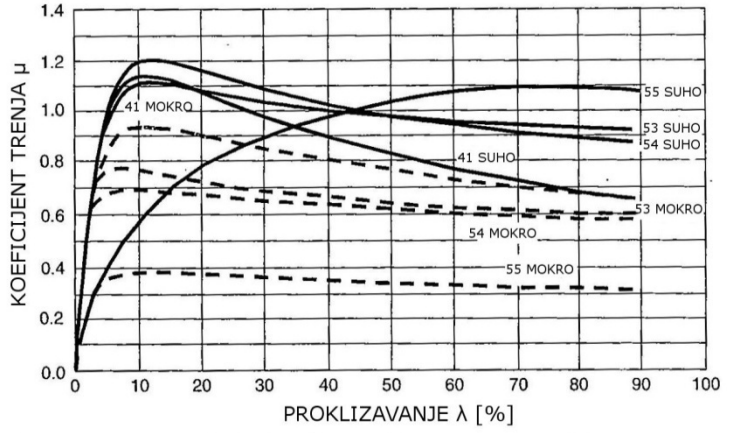
Suvišno kočenje → nedovoljno iskorištenje prianjanja, gubitak upravljivosti/stabilnosti

Slika 4. *Dijagram iskorišćenosti prianjanja*

2.1.1 Zavisnost o koeficijentu trenja

Koeficijent trenja μ između kolovoza i pneumatika ima presudni uticaj na usporenje vozila, a samim time i na put kočenja. Opterećenje točkova može biti optimalno iskorišteno samo u slučaju kada koeficijent trenja postigne dovoljno visoku vrijednost što na kraju rezultira dovoljno velikim usporenjem. Koeficijent trenja μ, koji se još naziva i omjerom prianjanja, funkcija je proklizavanja λ između točka i kolovoza.

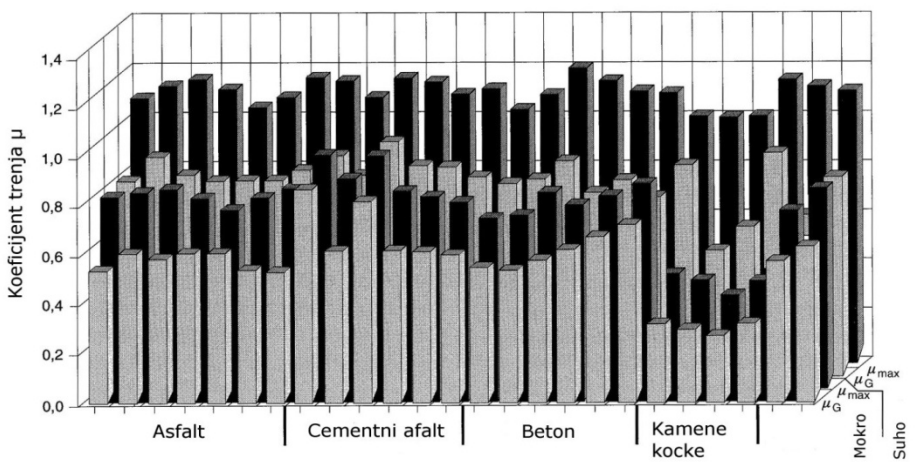
Oblik μ-λ krive pneumatika zavisi od uslova na kolovozu, ali i od materijala kolovoza. Slika 5. pokazuje tu zavisnost o uslovima na kolovozu. Maksimalni koeficijent trenja modernih pneumatika je kod proklizavanja između 8% i 25%.



Slika 5.*Zavisnost koeficijenta trenja od uslova na kolovozu* [2]

Slika 6. prikazuje dijagram maksimalnog mogućeg koeficijenta trenja μ_{max} kao i vrijednosti koeficijenata koji se javljaju u blizini područja blokiranja točkova na različitim podlogama i atmosferskim uslovima jednog te istog pneumatika pri brzini od 30 km/h. Ovaj dijagram pokazuje da koeficijent trenja može poprimiti vrlo različite vrijednosti. Maksimalna vrijednost koeficijenta trenja između 1,0 i 1,2 može se postići na svim suhim kolovozima.

Ako su kolovozi mokri učinak je potpuno drugačiji. Kolovozi popločeni kamenim kockama imaju vrijednost koeficijenta trenja od samo 0,4, dok kolovozi od asfalta i betona variraju između 0,7 i 0,8. Samo posebne površine, kao one na trkaćim stazama ili pistama imaju visoke vrijednosti koeficijenta trenja od 0,9 do 0,95, čak i kada su mokre.



Slika 6. *Iznosi koeficijenata trenja na različitim podlogama* [**2**]

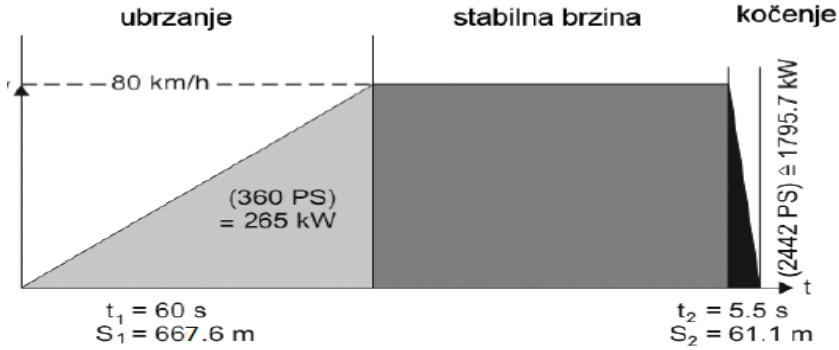
3 PROVJERA KOČIONOG SISTEMA TERETNOG VOZILA SCANIA R410

Činjenica je da se proces kočenja u opštem slučaju odigrava ukupnim otporima koji se javljaju u procesu kočenja: kočenje kočnicama, otporom u ležajevima točkova, otporom vazduha, otporom kotrljanja i otpor klizanju točkova.

Parcijalni udio pojedinih otpora je različit i približno iznosi:

- Udio kočnica 90% od ukupne snage,
- Otpor u ležajevima točkova 1-2%,
- Otpor kotrljanju do 1%,
- Otpor klizanju točkova do 4%,
- Otpor vazduha 3-6% (zavisno od brzine).

Kod proračuna kočnica svjesno se svi otpori zanemaruju, tako da ukupnu energiju kočenja preuzimaju kočnice vozila.



Slika 7. *Snaga kočenja teretnog vozila* [4]

Iz slike 7. se može vidjeti da je snaga motora koji za 60s ubrza teretno vozilo do brzine od 80 km/h 265 kW, a snaga kočnice koja to isto vozilo sa 80 km/h zaustavi za vrijeme od 5,5s je 1795,5 kW. Jasno je da je kočioni sistem ovako velike snage neophodan ako želimo da se vozilo zaustavi za kratko vrijeme pri čemu neće preći veliki put.

3.1 Tehnički pregled teretnog vozila SCANIA R410

U ovom poglavlju je data procedura odvijanja tehničkog pregleda kočnice na primjeru navedenog teretnog vozila. Pregled je izvršen u tehničkom servisu Kompanije a.d Boksit Milići. Predmetno teretno vozilo je opremljeno vazdušnim (pneumatskim) kočionim sistemom i spada u grupu teretno-vučnih vozila.

Cilj periodičnog tehničkog pregleda jeste da se korišćenjem određenih instrumenata i metoda utvrdi ispravnost vozila i njihova usaglašenost sa normativima i tehničkim uslovima koji se zahtijevaju da bi vozilo moglo saobraćati na putu.

Tehničkim pregledom teretnog vozila SCANIA R410 obuhvaćena je preventivna kontrola pojedinih dijelova kočionog sistema i provjera mehaničkih dijelova predne disk kočnice koja je definisana pravilnikom o tehničkim pregledima vozila.

3.1.1 Kočioni disk

Pregledano vozilo opremljeno je disk kočnicama. Vizuelnim pregledom utvrđeno je da disk (slika 8.) nije pretjerano izbrazdan, odnosno istrošen, niti zauljen. Istrošenost diska provjerava se upoređivanjem debljine radne površine diska sa neistrošenim dijelom vijenca oboda diska. Pretjerana istrošenost diska dovodi do rasta pritiska vazduha u kočionoj instalaciji. Trošenje diskova ne smije premašiti 1 mm na svakoj strani, bez obzira na njihovu debljinu.



Slika 8. *Kočioni disk*

3.1.2 Kočiona obloga

Na predmetnom vozilu kočiona obloga (slika 9.) mora biti takve debljine da osigurava pouzdano kočenje. Neki proizvođači stavljaju oznake po kojima je moguće prepoznati stepen istrošenosti kočione obloge. Kočione obloge moraju biti postavljene na način da se omogući vizuelna provjera njihove istrošenosti bez demontaže dijelova vozila. Navedeno teretno vozilo to ispunjava. Na osnovu zvanične dokumentacije pri provjeri kočionog sistema SCANIA-e definisano je sljedeće:

Table 1. Tehničke specifikacije

Disk kočnica, debljina	*Minimalna debljina kočione obloge*
>40 mm	*2 mm*
37-40 mm	*4 mm*

Većina novih teretnih vozila opremljena je senzorom istrošenosti kočionih obloga pa se njihovo stanje može provjeriti indikatorom u vozačevoj kabini. (SCANIA R410 to posjeduje). Pregledano vozilo je bilo opremljeno indikatorom istrošenosti kočionih obloga i koji nije bio uključen, te se može zaključiti da kočione obloge nisu pretjerano istrošene.



Slika 9. *Kočiona obloga*

4 ZAKLJUČAK

Kočnice kao izvršni element kočionog sistema predstavlja njegov i najvažniji dio. Kočnice treba da obezbijede potrebnu snagu za brzo i efikasno zaustavljanje, ali i odgovarajuće energetske kapacitete za preuzimanje i dalji transfer toplotne energije koja se razvija tokom kočenja.

U radu je izvršena konstatacija prednosti disk kočnice u odnosu na doboš kočnice na prednjoj osovini kod teretnih motornih vozila sa aspekta analize koeficijenta kočenja i različitih uticaja koeficijenata trenja. Prianjanje između podloge i točka vrlo je složen problem koji se pojednostavljeno može objasniti pomoću navedenog uticaja koeficijenta trenja. Tako da koeficijent trenja najviše zavisi od kolovoza tj. da li je mokar kolovoz itd. Dat je i praktični primjer potrebne snage kočenja pri zadatim uslovima kod teretnih motornih vozila.

Da bi se izvršio postupak preventivnog tehničkog pregleda potrebno je prvo upoznavanje sa pravilnicima koji definišu navedeni postupak, a u cilju provjere mehaničkih dijelova prednje disk kočnice teretnog motornog vozila.

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DETEKCIJA CURENJA VODE U VODOVODNOJ MREŽI UPOTREBOM AKUSTIČNIH UREĐAJA

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Rezime: Ovaj rad opisuje realne gubitke vode i njihovu detekciju upotrebom akustučnih uređaja. U radu je dat konkretan primjer otkrivanja curenja na vodovodnoj mreži grada Trebinja. Primjena ovog načina otkrivanja curenja ima niz pogodnosti u pogledu smanjenja gubitaka vode kao, smanjenja troškova popravke i izbjegavanje oštećenja infrastrukture kroz rane intervencije.

Ključne riječi: geofon, korelator, loger šuma, realni gubici, šum curenja

DETECTION OF LEAKAGE OF WATER IN THE WATER NETWORK USING ACOUSTIC DEVICES

Abstract: This paper describes the real losses of water and their detection using acoustic devices. This paper presents a concrete example of leak detection on the water supply network of Trebinje. The application of this leak detection method has a number of benefits in terms of reducing water losses, reducing repair costs and avoiding damage to infrastructure through early intervention.

Key words: correlator, geophones, leakage noise, logger noise, real losses

1 UVOD

Vodovodni sistem je skup objekata i opreme funkcionalno povezanih tako da se omogućava realizacija tehnološkog procesa, kojima se ostvaruje snabdijevanje potrošača vodom prema zahtjevima pojedinih vrsta potrošača. Ti zahtjevi obuhvaćaju osiguranje dovoljne količine vode, te osiguravanje njenih kvaliteta vezanih uz specifičnu namjenu.

Jedan od glavnih problema vodovodnih sistema su gubici vode. Javljaju se duž čitavog vodovodnog sistema, od vodovodnog izvora pa do poslednjeg hidranta na mreži, kao npr.: curenja na glavnim cijevovodima, na rezervoarima, spojevima, pumpama, priključcima i sl. Takođe postoje gubici vode koje se javljaju kod ilegalnih priključaka na objekte koji troše vodu. Kod neispravnih kućnih instalacija i vodomjera nastaju gubici koji izazivaju neracionalno trošenje vode, što može štetno uticati na

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naselja u kojima postoje mjere štednje vode zbog nestašice. Neracionalan može biti i fiksan način plaćanja vode koji se zbog nedostatka vodomjera može zateći u manjim selima. Gubici vode iz distribucijskih sistema su problem svih zemalja širom svijeta, a kod zemalja koje oskudijevaju vodom taj problem je i vrlo ozbiljan. Zato je od velike važnosti uočiti i sanirati gubitke [1].

Fizički gubici mogu se podjeliti na fizičke i prividne. Fizički gubici su logična posljedica starenja sistema i njegovih dijelova, slabog i neredovnog održavanja, grešaka i lošeg izvođenja, kao i uticaja okoline. Dijelovi vodovodnog sistema (posebno brtve na spojevima) podložni su starenju, propadanju i stvaranju šupljina i pukotina kroz koje voda iz sistema ističe u okolinu. Loše izvođenje rezultira propuštanjem sistema, a ugradnja nekvalitetnih i neprimjerenih dijelova ubrzanim starenjem, propadanjem i propuštanjem. Korištenje puteva, izvođenje građevinskih radova u okolini i slične aktivnosti neprestano utiču na cjevovode, ubrzavajući negativne procese. Nezaštićeni dijelovi sistema ubrzano propadaju i gube vododrživost (posebno spojevi, koji su najosjetljiviji na vibracije i pomicanje tla). Prividni gubici nisu posljedica nekontrolisanog isticanja vode iz sistema, nego nekontrolisanog i neovlaštenog korištenja vode (krađa vode, netačno mjerenje i obračunavanje potrošnje itd.). I ovi gubici su prisutni u svakom sistemu, jer je praktično nemoguće svu potrošnju izmjeriti i naplatiti.

Glavni akcenat rada će biti na fizičkim gubicima u vodovodnoj mreži, kao i na njihovom otkrivanju i otklanjanju.

2 MJERNE ZONE I DETEKCIJA CURENJA

2.1 Mjerne zone – sektorizacija sistema vodosnabdjevanja kao neophodan element u cilju smanjenja gubitaka

Mjerna zona je dio sistema vodosnabdijevanja, koja je od ostatka sistema odvojena definisanom i stalnom granicom. Sektorizacija sistema vodosnabdijevanja je podjela sistema na mjerne zone I u tu svrhu potrebno je dobro poznavanje sistema. Mjerenjem mjernih zona se postiže tačan proračun ukupnih gubitaka u mjernoj zoni, pomaže se lociranje gubitaka, smanjuje se potreban broj zatvorenih ventila, i smanjuju se neophodna odstupanja od postojećih hidrauličkih parametara, i parametara vezanih za kvalitet vode u mreži.

Najjednostavnije prikazano, gubici u mjernoj zoni predstavljaju razliku između ulaza i potrošnje. Ulaz se može mjeriti precizno, međutim, kvantifikovanje potrošnje se ne može izvršiti direktno, čak i ako su svi kućni priključci snabdjeveni mjeračem, zbog faktora kao što su greške u mjerenju i ilegalna potrošnja. Ovi problemi se najbolje prevazilaze kvantifikovanjem gubitaka tokom minimalne potrošnje, koja se obično dešava noću. Obzirom da je noćna potrošnja veoma mala, njen najveći dio će biti posljedica curenja. Minimalna noćna potrošnja je najniži protok u mjernu zonu tokom svake noći. Noćna potrošnja se računa kao srednja vrijednost tokom određenog vremena, koje se najčešće definiše kao jedan sat. Međutim, protok izmjeren kao minimalna noćna potrošnja, a koji je praktično vrijednost ukupnih gubitaka, se ne može direktno povezati sa dnevnom vrijednošću gubitaka, jer je pritisak noću uglavnom najviši, dok tokom dana varira. Ekstrapolacijom vrijednosti noćnih gubitaka tokom 24 sata će se dobiti prevelike dnevne vrijednosti gubitaka, zbog čega se uvodi „Noćno-dnevni faktor“ (NDF), koji je obično između 18 i 24 [2].

2.2 Teorija detekcije curenja

Postoje tri glavne metode za rano otkrivanje novih curenja koje efkasno smanjuju vrijeme curenja. Te metode su: praćenje protoka, praćenje pritiska i praćenje šuma curenja.

Lomovi i pukotine na cijevima prouzrokuju više ili manje naglo povećanje protoka, koje može biti otkriveno stalnim praćenjem dotoka vode u vodovodni sistem ili u mjernu zonu. U tu svrhu, protok treba pratiti neprekidno ili najmanje jedan sat tokom minimalnih noćnih protoka i treba ih uporediti sa prethodno izmjerenim referentnim vrijednostima. Ako povećani protok ostaje stabilan više od tri dana, promjena je vjerovatno uzrokovana curenjem, a ne velikom potrošnjom korisnika [3].

Pritisak koji se prati na mreži može otkriti samo velika curenja, jer male stope curenja neće značajno smanjiti pritisak. Informacije dobijene praćenjem pritiska se mogu koristiti za određivanje prioriteta rada: preporučljivo je započeti otkrivanje curenja na mjestu gdje je izmjeren maksimalni pad pritiska [3].

U otkrivanju curenja, koja mogu biti vidljiva na površini zemlje, u podzemnim distributivnim sistemima za vodu, najčešće se koriste akustične (zvučne) metode. Prilikom isticanja fluida iz unutrašnjosti cijevi pod pritiskom dolazi do formiranja mehaničkih vibracija koje se prenose duž cjevovoda. Pomoću piezokeramičkih senzora moguće je izvršiti njihovu detekciju i uporedjivanjem kašnjenja priliva vibracija od jedne do druge tačke definisati precizno tačku pucanja cijevi. Voda koja curi iz cijevi pod pritiskom emituje zvuk različitih frekvencija, koje se najlakše opisuju kao „šuštanje“. Glavni cilj pretrage za curenjem je da se čuje šum curenja. Korišćenjem opreme teži se da se čuje najglasniji šum curenja i tačno odredi tačka curenja. Zvuk se transportuje preko zida cijevi brzinom koja takođe zavisi od materijala cijevi i prečnika cijevi. Čvrstina materijala zida cijevi direktno utiče na kvalitet prostiranja mehaničkih vibracija, što znaci da kod cijevi sa tvrđom strukturom materijala (metalne cijevi) imamo daleko bolje i dalje dopiranje mehaničkih vibracija u odnosu na cijevi mekše strukture materijala (plastične cijevi) [4].

Frekvencija zavisi od faktora kao što su veličina curenja, materijal cijevi, prečnika cijevi, pritiska, okoline cijevi. Kod cijevi manjeg prečnika formira se izrazit i jak šum koji je visokih frekvencija, dok kod velikih prečnika šum može biti slabijeg intenziteta i nižih frekvencija. Uticaj pritiska unutar cijevi direktno utiče na kvalitet formiranja šuma curenja s tim da kod većih pritisaka šum je izražajan i upečatljiv, dok kod nižih pritisaka šum može biti teško uočljiv i na nižim frekvencijama. Najbolje vrijeme za izvođenje akustičnih pretraga je kada su svi parametri na minimumu osim pritiska koji je najbolji da teži maksimumu.

Na osnovu navedenih činjenica može se doći do zaključka da ja najbolje vrijeme za vršenje akustične detekcije curenja period umirenja mreže koji se najčešće dešava u noćnim satima.

Za kvalitet šuma je najbitnije da je snažan i da se jasno čuje, a pri slabo uočljivim šumovima koriste se filteri za izolovanje šuma, jer ako je šum slab ili prigušen samim tim je i slab za slušanje.

Kao metode za smanjenje curenja u određenom dijelu mreže ili u određenom dijelu cijevi koriste se logeri šuma curenja, korelator i ispitivanje geofonom.

Nakon dobijanja tačke curenja pomoću korelacije izmedju logera, potrebno je izvršiti akustično potvrdjivanje tačke pucanja cijevi slušanjem kvara na površini zemljišta iznad te tačke pomoću uredjaja za mikrolociranje kako bi se precizno odredilo mjesto za vršenje iskopa [4].

3 PRIMJER RADA OPREMA ZA SISTEMSKO ISPITIVANJE OBLASTI I PRECIZNO LOCIRANJE CURENJA

Kako bi na što efikasniji način postojeći skriveni kvarovi, koji još nisu vidljivi na površini i ne predstavljaju komunalni problem, bili locirani Vodovod Trebinje je u proteklom periodu nabavio opremu jednog od renomiranih svjetskih proizvođača Gutermann Švajcarska. Komplet opreme se sastoji od uređaja koji omogućavaju detekciju curenja u određenoj oblasti distributivne mreže (Zonescan 820), i instrumenata za precizno potvrđivanje tačke pucanja cijevi (korelator - Aquascan 620L i geofon - Aquascope 550).

3.1 Primjena Zonescan 820 na vodovdoj mreži grada Trebinja

Zonescan 820 je profesionalni alat za analizu, snimanje i detekciju curenja u cijevima za distribuciju vode za piće a uz sve to je i veoma lak za upotrebu. Sastoji se iz malih, pametnih jedinica (logera) koji su postavljeni širom mreže kako bi prikupljali podatke za analizu kao i komunikacijske jedinice koja interaktivno kontroliše i prebacuje podatke na pokretni računar (laptop).

Kao primjer rada i funkcionisanja logera u ovom radu biće prikazana ulica Obala Mića Ljubibratića u kojoj su uočeni veliki problemi sa potrošnjom vode (Slika 1).

Nakon uočenih probema sa rastom potrošnje logeri se raspoređuju i postavljaju u mjernu oblast u kojoj su se pojavili problemi. Logeri se postavljaju u šahtove i prilikom postavljanja logera treba voditi računa da se ostvari dobar i čvrst kontakt za osnovu ventila ili hidranta. Logeri se programiraju tako da u periodu kada je mreža umirena, što je najčešće od 02:00 do 04:00 sata iza ponoći vrše mjerenje jačine šuma. Ovi logeri imaju mogućnost korelacije mogu snimiti zvučni signal čim će uporedjivanjem biti definisana tačna tačka pucanja cijevi. Jedan dio ulice je pokriven sa cijevima od livenog željeza Ø100, a u drugom dijelu su polietilenske cijevi (PEHD100).

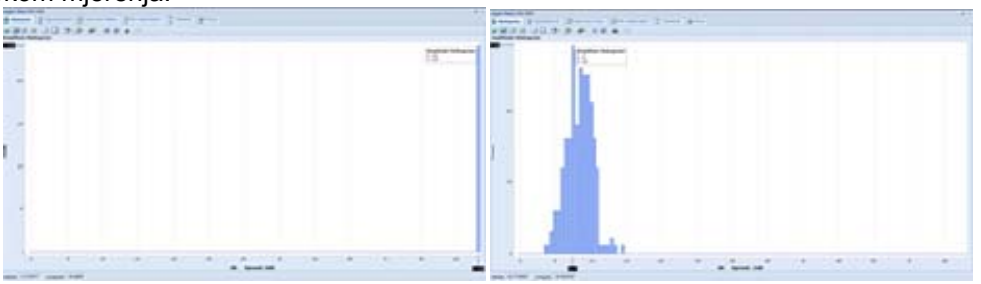


Slika 1. *Primjer postavljanja logera na mreži*

Na slici 1 se vidi da su 4 logera detektovala kvarove na mreži, sto je označeno sa crvenom bojom. Logeri označeni zelenom bojom govore da u tom dijelu mreže nema problema i da je taj dio mreže ispravan, dok loger označen žutom bojom predstavlja moguće curenje.

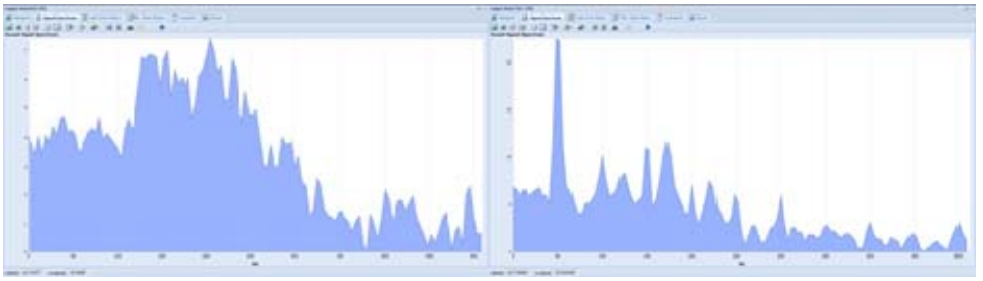
Jedan od prvih pokazatelja da na mreži postoji mogućnost prisustva problema jeste mjerenje jačine šuma, pri čemu kod logera koji je bio u blizini kvara šum kvara nadmašuje sve okolne šumove dok kod logera koji je bio na mreži gdje nema prisustva

curenja curenja okolni šumovi formiraju histogram buke okoline. Na slici 2 prikazan je histogram logera sa kvarom (lijevi dio slike) i bez kvara (desni dio slike). Na histogramu logera sa kvarom može se uočiti da je tokom svih 240 mjerenja jačine šuma izmjerena vrijednost šuma 63 dB što daje do znanja da je kvar daleko nadjčao sve šumove okoline. Na desnoj strani slike može se uočiti veoma nizak nivo zabilježene okolne buke, što znači da nema prisustva kvara koji bi je nadjačao i bio konstantne jačine tokom mjerenja.



Slika 2. *Histogram logera sa kvarom i bez kvara*

Pored toga što se prisustvo curenja cijevi detektuje pomoću jačine buke, logeri šuma curenja sa korelacijom omogućavaju i pregled spektra (Slika 3) za svaku tačku mjerenja gdje se tačno može uočiti popunjenost spektra u tačkama gdje ima problema i prazan spektar zabeležen na logerima bez prisustva kvara.



Slika 3. *Spektar logera sa kvarom i bez kvara*

Pregledom histograma i spektra može se steći znanje samo o prisustvu problema, samo u oblasti mjerenja, ali se ne može još uvijek reći precizna tačku pucanja cijevi. Kako bi bili u mogućnosti da tačno definišemo tačku pucanja cijevi, program za rad sa logerima je opremljen automatskim izračunavanjem korelacija između svi mjernih tačaka u oblasti mjerenja (Slika 4). To znači da će se između logera koji su čuli isti kvar formirati korelacija i pomoću nje definisati tačno mjesto pucanja cijevi. Bojom je definisan kvalitet korelacije (žuta od 40 - 70%, crvena od 70 - 100%) koji većim brojem iskazuje bolju preciznost definisanja tačke pucanja.

Pored određivanja tačke pucanja između dva logera program ima i mogućnost da ukoliko dva logera čuju kvar koji se ne nalazi između njih odredi smjer pucanja izvan opsega korelacije, što se grafički prikazuje strelicama.



Slika 4. *Izračunavanje korelacije između svih mjernih tačaka u mjernoj oblasti*

Na slici 5 prikazan je dijagram korelacije sa definisanim kvarom između dva logera (desni dio slike) i slučaj kada se kvar nalazi izvan opsega koreliranja dva logera (lijevi dio slike).



Slika 5. *Dijagram korelacije sa definisan kvarom između dva logera i izvan opsega koreliranja dva logera*

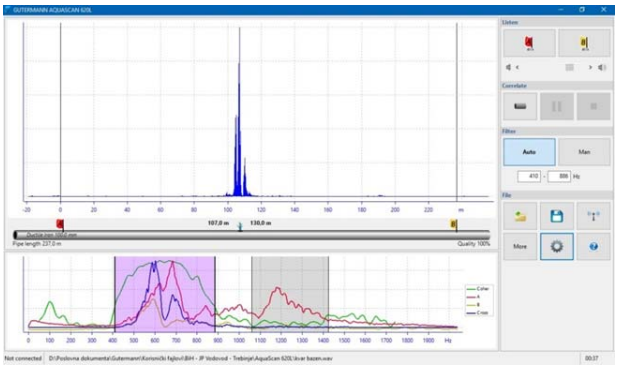
3.2 Rezultati vršenja korelacije u realnom vremenu na dijelu cjevovoda sa dijagnostikovanim problemom

Nakon dobijanja potencijalnog mjesta pucanja cijevi pomoću korelacionih logera šuma curenja potrebno je izvršiti potvrđivanje prisustva kvara i precizno lociranje za potrebe vršenja sanacije. Kako bi se potvrdilo prisustvo kvara u trenutku dolaska na lokaciju koristi se korelator šuma curenja – Aquascan 620L.

Detekcija se zasniva na brzini kojom zvuci curenja putuju dužinom cijevi. Zvuci curenja se mjere na dvije lokacije dionice. Mikrofon postavljen bliže curenju prvi će registrovati zvuk curenja. Izmjereni zvuci se bežično prenose do prenosnog korelatora koji određuje poziciju isticanja. Vrši se ukrštena korelacija evidentiranih zvučnih signala u cilju računanja vremenskog intervala između zvučnih signala koji su emitovani iz istog izvora. Korelator analizira strukturu zvukova i mjeri vremenski interval Δt sve dok se na drugom mikrofonu ne evidentira zvuk identične strukture

Sonde korelatora su postavljene u šahtove u dio ulice Obala Mića Ljubibratića koja je problematična i na kojoj postoji potencijalno pucanje cijevi. U program korelatora unešeni su podaci o materijalu cijevi, dužina cijevi i prečnik cijevi u mm. Rezultati dobijeni korelacijom prikazani su slikom 6 na kojoj se može vidjeti prisustvo

kvara na 107 metru od sonde A i 130 metru od sonde B. Oštar vrh (pik) nam govori da je curenje detektovano sa velikom preciznošću, odnosno što je vrh uži preciznost je veća. Pouzdanost curenja je 100%. Korišten je automatski filter, a može se koristiti i ručno podešavanje filtera. Svrha korištenja filtera je poboljšanje oblika pika i demaskiranje curenja koje korelator nije otkrio sa standardnim podešavanjem.



Slika 6. *Rezultati korelacija*

3.3 Akustično potvrđivanje curenja metodom kontaktnog slušanja i površinske verifikacije iznad tačke puknuća cijevi

Nakon potvrde kvara logerima i korelatorom koristi se ručni mikrofon za kontaktno potvrđivanje mjesta pucanja cijevi i geofon za površinsku verifikaciju iznad puknuća cijevi. Prema podacima dobijenih od logera i korelatora moguće mjesto pucanja cijevi je okolina hidranta, pa je kritični hidrant podvrgnut slušanju ručnim mikrofonom i okolina hidranta zemnim mikrofonom. Korišten je Aquascope 550 kojeg od drugih lokatora curenja razlikuje posjedovanje četiri filtera za uklanjanje okolnih šumova i zvukova niskih frkvencija za preciznije odeđivanje mjesta puknuća cijevi. Na osnovu spektra (Slika 7) na kontrolnoj jedinici za ručni mikrofon možemo zaključiti da se kvar nalazi na hidrantu ili u okolini hidranta.



Slika 7. *Spektar kvara ručno mikrofona*

U nastavku je izvršena potvrda kvara geofonoskom glavom pomjerajući se 30cm oko hidranta. I geofonska glava je potvrdila da se kvar nalazi na hidrantu što je prikazano na spektru (Slika 8).



Slika 8. *Spektar kvara geofonskog ispitivanja*

Na slici se može vidjeti da je mjesto kvara označeno sa najvećim brojem (30) i kako se odaljavamo od kvara da se vrijednost šuma smanjuje.

4 ZAKLJUČAK

U radu su prezentovani uređaji za detekciju curenja vode u vodovodnoj mreži koji se koriste u gradu Trebinju. Uređaji se zasnivaju na akustičnim metodama otkrića puknuća cijevi za skrivene kvarove, odnosno za curenja koja nisu izbila na površinu zemlje.

Na osnovu terenskog rada može se zaključiti da su se uređaji pokazali kao pun pogodak i da se teži da se čitav grad pokrije uređajima, tkz. ZoneScan ALPHA sistemom za stalno praćenje curenja.

Ugradnjom sistema za stalno praćenje curenja ostvarile bi se znatne operativne i finansijske benificije, kao što su:

- Smanjenje trajanja curenja i smanjenje nivoa nefakturisane vode,
- Smanjenje radnih sati operatera utrošenih na pretragu curenja,
- Popravka curenja prije nego da ih korisnik uoči i izbjegavanje prekida snabdijevanja,
- Smanjenje troškova popravke i izbjegavanje oštećenja infrastrukture kroz rane intervencije,
- Unapređenje javne slike i nivoa usluge servisa samog vodovoda.

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NUMERIČKA SIMULACIJA EKSPERIMENTALOG ISPITIVANJA APSORBERA UDARA

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Rezime: Konstrukcije koja trebaju apsorbovati veliku količinu energije tokom sudara su predmet istraživanja velikog broja istraživača u autoindustriji i van nje. Za potrebe studentskih formula koriste se razni apsorberi udara kvalitativno definisani pravilnikom FSAE takmičenja. Kako bi se smanjili troškovi razvoja i testiranja novog apsorbera, podobno je sprovodjenje numeričke analize udara metodom konačnih elemenata. Time se dobija jasnija slika o ponašanju apsorbera pri apsorbciji udara. U radu je sprovedena numerička simulacija eksperimentalnog ispitivanja apsorbera udara za potrebe studentske formule Zastava 2017. Svi ulazni parametri simulacije su definisani prema postavci eksperimenta, odnosno prema pravilniku. Sprovođenjem simulacije za odabranu vrstu apsorbera, izrađenu od stirodura, dobijeni su zadovoljavajući rezultati.

Ključne reči: apsorber udara, eksperiment, formula student, numerička simulacija...

NUMERICAL SIMULATION OF EXPERIMENTAL EXAMINATION OF IMPACT ATTENUATOR

Abstract: Structures that are supposed to absorb a large amonut of energy during impact are subject of great number of researches both in auto industry and beyond. For the purpose of student formulas various impact attenuators that are being used, are qualitatively defined by the FSAE competition rule book. In order to reduce the cost of development and testing of the new attenuator, it is convenient to conduct numerical analysis of impact by using finite element method. By doing so, a clearer image of attenuator's behaviour during impact absorption is obtained. In this study, numerical simulation of experimental testing of impact attenuator, for the purposes of Zastava 2017 student formula, is conducted. All entry parameters of the simulation are defined by the experimental setup, i.e. by the rule book. By conducting the simulation for the chosen type of attenuator, made of styrodur, satisfying results are obtained.

Key words: Experiment, Formula Student, Impact Attenuator, Numerical Simulation…

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1 INTRODUCTION

Structure that serves to turn a certain amount of kinetic energy of the vehicle during front impact, into it's own deformation work, is called an impact attenuator [1]. By the Student Formula 2017 competition rule book [2], each vehicle is obliged to have an impact attenuator built in, which is not allowed to be smaller than 200×200×100 mm and which has to bring mass of 300 kg to a halt at the speed of 7 m/s, which has to be experimentally confirmed. Besides set requirements, maximum deceleration should not go over 40 g and average deceleration should not go over 20 g.

According to already existing impact attenuators [3-15] and economical and technological abilities, concept of impact attenuator made of mutually glued layers of styrodur, thickness 50 mm, in shape of a truncated pyramid (Figure 1). The use of polymer foams for the purpose of constructing absorption structures is very common [16-20].

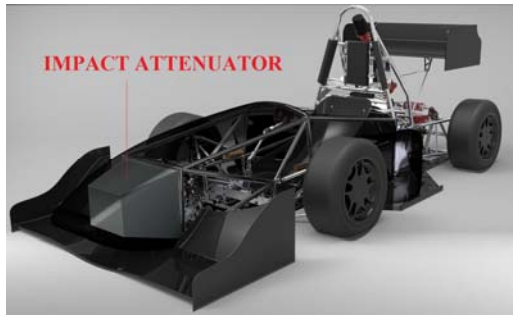


Figure 1. *Three-dimensional model of a formula with the chosen impact attenuator*

Design, optimization and quality assurance of attenuator is being dealt with by large number of researchers [1-15]. Numerical simulation [21-27], along with experimental researches [28-33] is an integral part of attenuator construction.

The aim of this paper is examining the quality of the chosen attenuator, for the purposes of experimental testing, by conducting numerical simulation using finite element method. As a result, additional money costs are prevented, in case of not meeting attenuator quality criteria, set by the rule book [2].

2 EXPERIMENT PLAN

By the propositions of the competition and the regulations [2], there are few ways to conduct an experiment. Two main ways to examine an attenuator's behaviour in the event of an impact are: crash test and „Drop Test". Having considered economical and technological conditions and according to [28-33], drop test represents an optimal solution. Therefore, to execute a crash test a very expensive experimental equipment [29] is necessary, that is not affordable. The potential energy (E_p) of weight mass (m) elevated on height (h), that needs to be achieved, is equal to kinetic energy of vehicle (E_k) in a given moment of impact (1).

$$E_k = m \cdot V_{impact}^{\ 2} / 2 = E_p = m \cdot g \cdot h \tag{1}$$

Schematic view of „*Drop Test*" plan is shown in Figure 2.

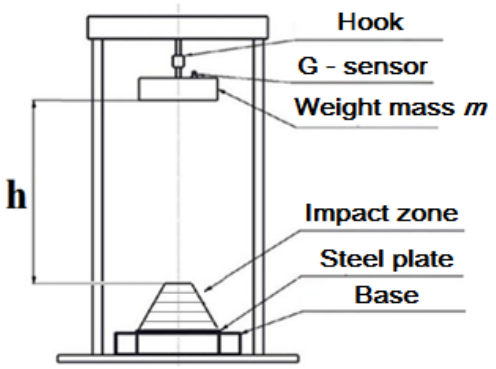


Figure 2. *Schematic view of „Drop Test" experiment plan.*

3 NUMERICAL SIMULATION OF EXPERIMENT

To a conceived three-dimensional model of attenuator, with previously generated grid in FEMAP software, after importing into software for pre and postprocessing (LSPP - Livermore Software Pre Post), suitable restraints and characteristics are added additionally. The grid is defined so that the nodes are equally arranged along the geometry and joined (merged) in places where glue is used, i.e. between styrodur layers. Additionally, in LSSP geometry is created in shape of a cylinder with loose grid that represents weight mass (*m*). In order to reduce calculation time, a weight is set in position promptly before impact (Figure 3). In the moment of impact velocity of the weight is set to 7 m/s and the effect of gravitational acceleration is taken into account. End time of the simulation is controlled. According to analytical calculations, it is limited to 0,08 s.

Suitable material formulation is chosen (Fu Chang - MAT_83) and all the parameters that it requires are entered [34, 35], formerly attained by quasi-static testing of styrodur to pressure [36]. In fact, by quasi-static testing of styrodur to pressure on servo-hydraulic pulsator (Figure 4), engineering stress-strain curves for chosen deformation rates are obtained.

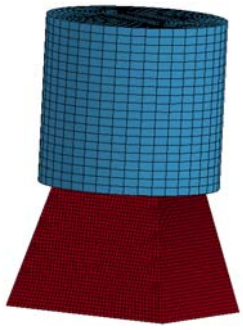


Figure 3. *Geometry setup*



Figure 4. *Servo-hydraulic pulsator/testing machine SHIMADZU type EHF-EV101K3-070-0A*

With the help of them, LSPP calculates coefficients that are used to define Fu Chang material formulation [34, 35, 39], for quasi-static processes, as well as dynamic ones. Curves obtained by the experiment have confirmed characteristic behaviour of polymer foams [34, 35, 38]. Due to physics of process alone, the weight is defined as a rigid body, so for it, material formulation MAT_20 (RIGID) is chosen.

4 RESULTS

After preprocessing, simulation is preformed, whose results are entered back in LSPP for postprocessing, i.e. visualization. Figure 5 shows animation of compacting process in steps at the impact velocity of 7 m/s.

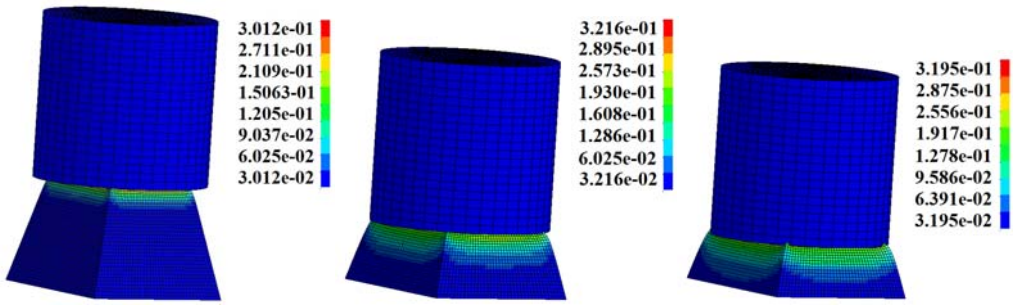


Figure 5**.** *Steps of compacting process animation during impact with graphic view of stress values measured in GPa*

As one of the main results of the simulation, Figure 6 shows diagram of deceleration during impact. The whole process of deforming lasts 0,02 seconds, in which weight travels nearly 203 mm, which is 80% of overall attainable velocity of the attenuator.

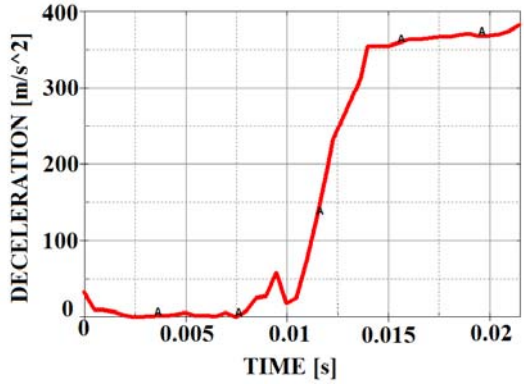


Figure 6. *Diagram of deceleration during impact*

From the diagram from Figure 8. it can be concluded that the attenuator meets conditions regarding maximum deceleration, which does not go over 40 g. The average deceleration obtained is 161 m/s^2 which is less than maximum average deceleration allowed, that is 192 m/s^2 (20 g).

4 CONCLUSION

According to the all already mentioned, using numerical analysis, it is concluded that adopted geometry of impact attenuator satisfies, i.e. that it is within the boundaries of all set constraints. Hence, based on the numerical simulation, manufacturing of the attenuator for the purposes of experimental testing is approved.

Certainly, further optimization of the attenuator is always welcomed. Foams are often used in combination with other materials [16, 41, 42], in order to transform kinetic energy into deformation work as much as possible. The ideal case of energy absorption would be if the total impact energy was transformed into deformation work of an attenuator, with linear increase of deceleration value, in time intervals that are as large as possible. Further researches and numerical analyses could be performed in order to optimize existing attenuators.

5 ACKNOWLEDGMENTS

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SINHRONIZACIJA ROBOTA MITSUBISHI I CNC OBRADNOG CENTRA EMCO CONCEPT MILL

Aleksandar Reljić[1]

Rezime: Cilj ovog rada jeste objediniti znanja iz modernih mehatroničkih sistema i kreirati proces automatizacije proizvodnih sistema u kome će glavni zadatak biti sinhronizovati rad MITSUBISHI robota i CNC obradnog centra. Kao rezultat navedene sinhronizacije, procesom glodanja, iz rotacionog pripremka dobije se mašinski dio koji se naziva "kandžasta spojnica".

Ključne riječi: Automatizacija, CNC, CIROS, Robotika, Sinhronizacija

SYNCHRONIZATION OF MITSUBISHI ROBOT AND CNC MACHINING CENTER EMCO CONCEPT MILL 105

Abstract: The purpose of this paper is to unify knowledge from the modern mechatronic systems and create a process of automation of production systems in which the main task will be synchronization of MITSUBISHI robot and CNC machining center. As a result of the mentioned synchronizaton, with the milling process, a design part called "claw coupling" is made out of the rotary stock.

Key words: Automation, CNC, CIROS, Robotics, Synchronization

1 UVOD

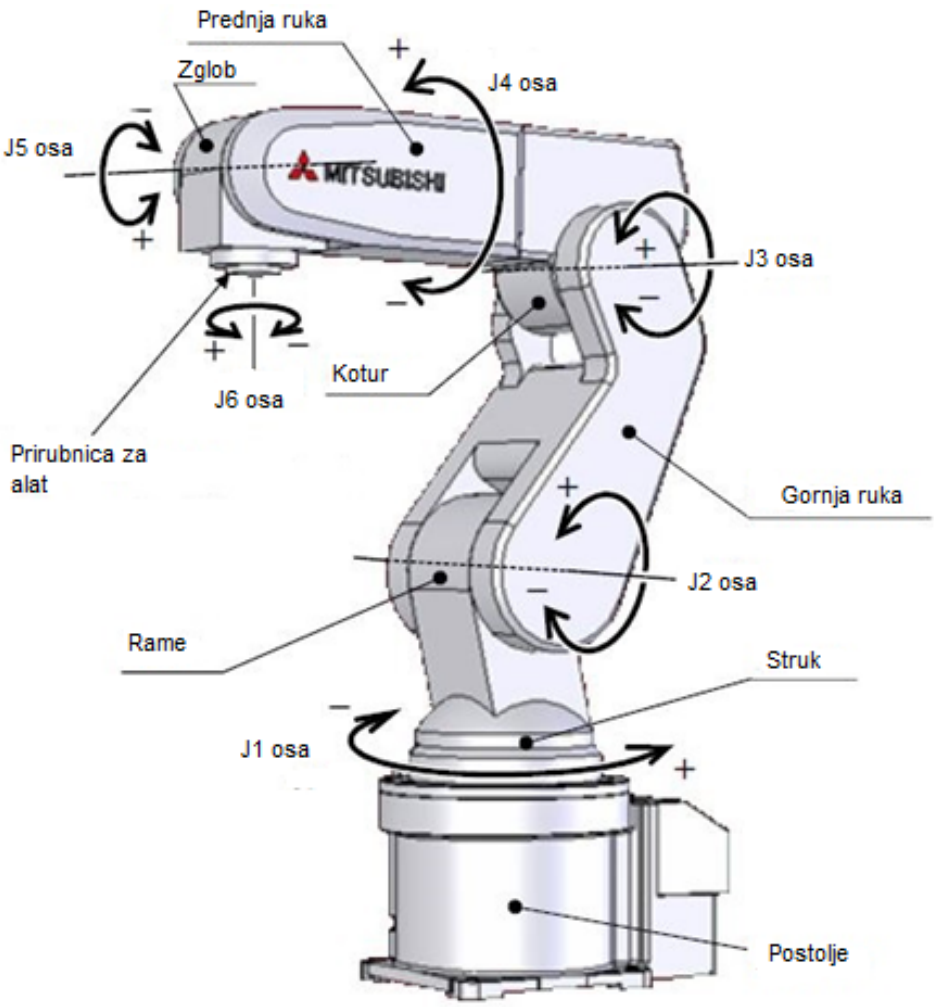
Laboratorija Elektrotehničkog fakulteta Univerziteta u Istočnom Sarajevu posjeduje uslove za realizovanje praktičnih zadataka iz oblasti automatizacije proizvodnih sistema, odnosno modernih mehatroničkih sistema, uzimajući u obzir CNC mašine i robote koje ista posjeduje. Osnovna zamisao jeste objediniti rad CNC mašine i robota koristeći multidisciplinarna znanja iz više oblasti, među kojima se najviše ističu kompjutersko upravljanje mašinama alatkama i znanje iz oblasti programiranja robota. Programiranje CNC obradnog centra izvršeno je automatski, kao rezultat postprocesorske operacije nekog od CAM alata (u ovom slučaju pomoću softvera CATIA), a programiranje robota obavljeno je u softveru koji se naziva CIROS, čiji je proizvođač Festo Didactic. U savremenoj industriji primjena robota je sve učestalija iz razloga visoke preciznosti i ponovljivosti u radu, mogućnosti rada u agresvinim

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sredinama opasnim po čovjekovo zdravlje, zatim mogućnost izvedbe pojedinih operacija poput zavarivanja, lijepljenja, farbanja i slično. Primjena robota u proizvodnji opravdana je samo u slučaju masovne proizvodnje, gdje je proizvodni proces kontinualan i gdje se ostvaruje visoka ekonomičnost proizvodnje.

2 ROBOT MITSUBISHI

Robot koji je korišten u ovom radu pripada grupi zglobnih vertikalnih robota PUMA i njegov izgled dat je na slici 1:



Slika 1. *Robot MITSUBISHI RV-2SDB [2]*

Robot se sastoji iz nekoliko modula, to su:

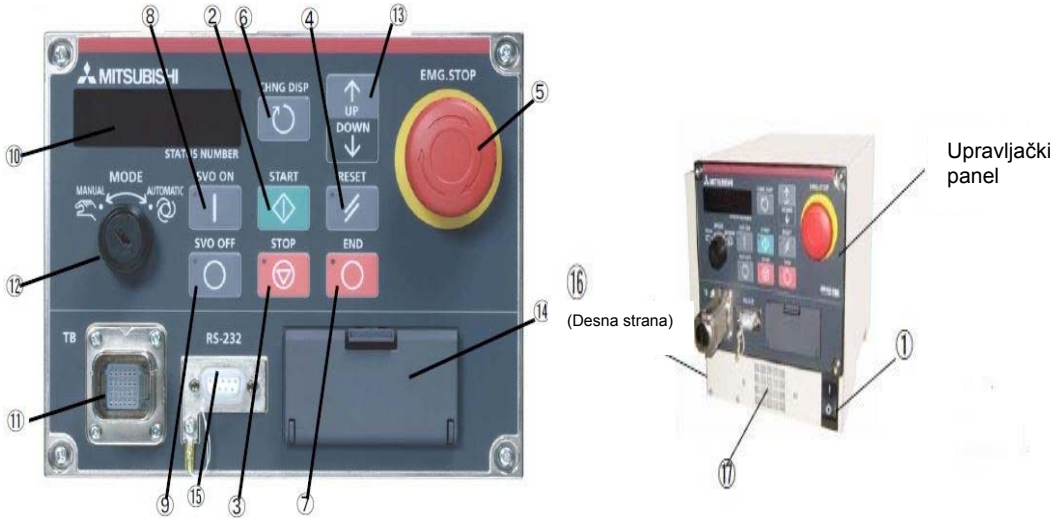
- Mehanički modul: postolje robota, mašinski dio sa prenosnicima i pogonima, robotski alati, hvataljke, ruka robota, stanica robota
- Elektronski modul: kontroler robota, senzori, mjerni sistemi, modul napajanja, operator panel, kontroler za upravljanje pogonima
- Softverski modul: sistemski softver kontrolera robota, softver za programiranje robota, obrada podataka, procesiranje senzorskih signala

Proces progamiranja robota, osim koda koji se mora napisati u softveru CIROS, obuhvata i programiranje pozicija robota u skladu sa predviđenim zadatkom. Programiranje pozicija vrši se pomoću uređaja kojim se ručno upravlja robotom i naziva se Teaching Pendant.



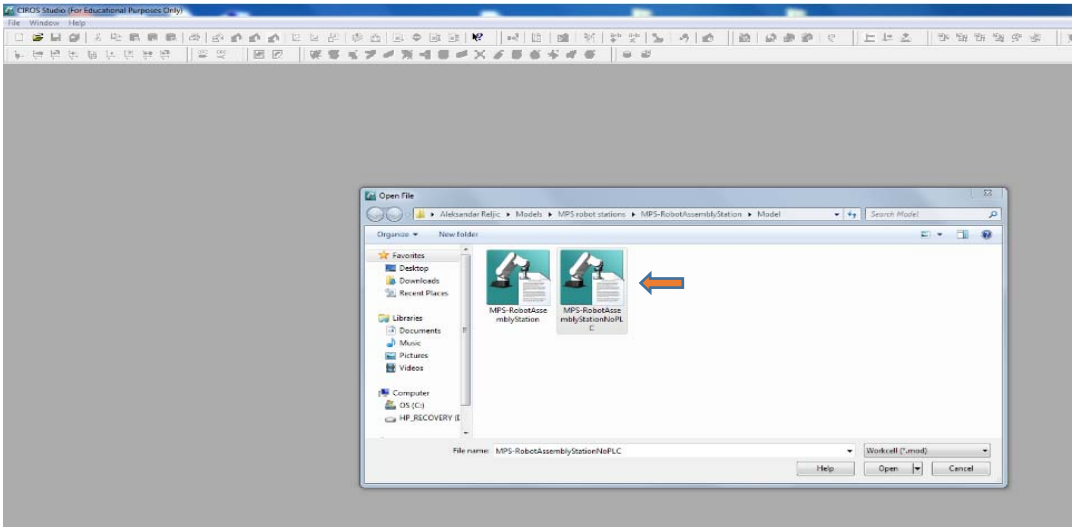
Slika 2. *Izgled Teaching Pendant uređaja [3]*

Za ostvarivanje procesa rada robota, podešavanje automatskog ili ručnog režima rada, odabir aktivnog programa koji robot izvršava odgovoran je uređaj koji se naziva kontroler robota. Izgled takvog uređaja dat je na slici 3:



Slika 3. *Kontroler robota CR1DA-777 [3]*

Softver CIROS koji je osmislila kompanija Festo Didactic, sastoji se od nekoliko cjelina. Za proces sinhronizacije robota i CNC obradnog centra koristi se CIROS Studio. U ovom dijelu softvera moguće je upravljati radom robota (programiranje kretanja robota, uključivanje/isključivanje pogonskih servomotora, aktiviranje G-koda CNC mašine, itd.) U dijelu CIROS Studio-a u ovom slučaju koristi se model koji se naziva "MPS-RobotAssemblyStationNoPLC" i njegov izgled dat je na slici 4:



Slika 4. *MPS-RobotAssemblyStationNoPLC model u okviru CIROS Studio softvera [1]*

3 CNC OBRADNI CENTAR EMCO CONCEPT MILL

EMCO CONCEPT MILL 105 je posjeduje jedno glavno vreteno po Z osi, sa standardni revolverskim magacinom alata i nizom dodatnih modula i tehnoloških funkcija za razne vrste obrade skidanjem strugotine. Uspješnp se koristi za sve vrste glodanja, bušenja, izradu navoja. Pripremci koji se mogu obrađivati na ovom obradnom centru mogu biti prizmatični ili cilindrični (ograničenog prečnika). Izgled ovog obradnog centra dat je na slici 5:



Slika 5. *Izgled EMCO CONCEPT MILL 105 obradnog centra [1]*

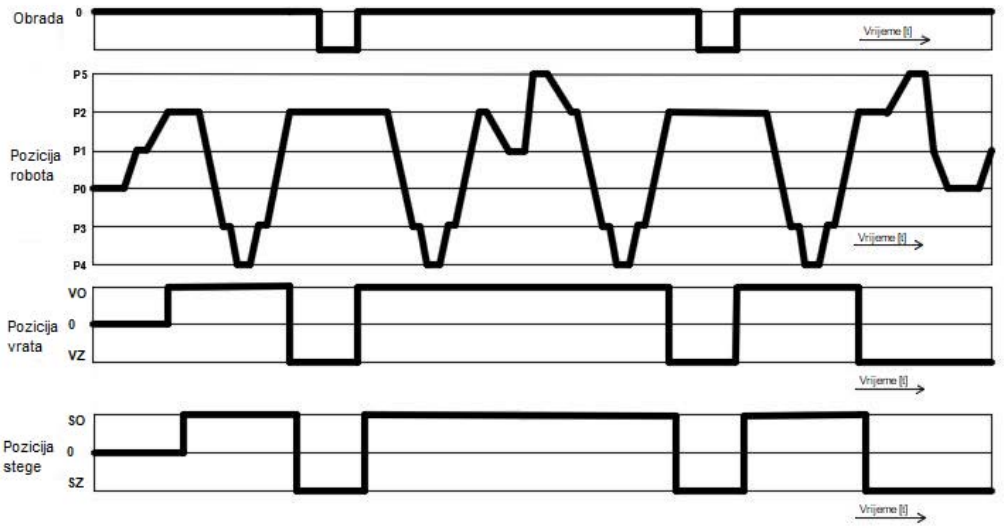
4 PROCES SINHRONIZACIJE

Sam proces sinhronizacije robota i CNC obradnog centra, u ovom slučaju, osmišljen je za mini-seriju od dva cilindrična radna komada. Oni čine reprezentativni primjer masovne serije dijelova koji se izrađuju u industrijskim uslovima. Proces čine sljedeći koraci:

- Robot je u početnoj poziciji
- Robot dolazi u poziciju prvog pripremka i hvata ga svojim alatom
- Robot odnosi pripremak u poziciju ispred vrata obradnog centra i tu se zaustavlja
- Vrata obradnog centra se otvaraju
- Nakon što su vrata upotpunosti otvorena (javi se signal), robot unosi pripremak unutar prostora radne mašine i ostavlja ga u stegu mašine

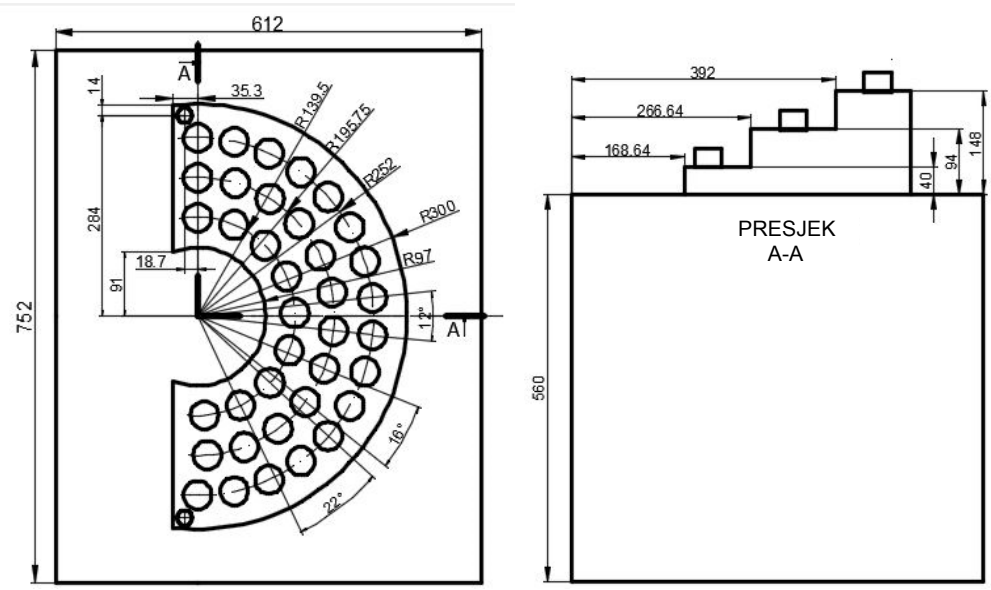
- Robot odlazi u poziciju ispred vrata obradnog centra, vrata se zatvaraju i stega steže radni komad, potom počinje CNC obrada i robot miruje
- Nakon CNC obrade, pneumatski se uklanja strugotina sa radnog komada, vrata i stega se ponovo otvaraju, robot ulazi u radni prostor mašine, uzima obradak i nosi ga u poziciju odakle ga je uzeo sa palete
- Vrata mašine i stega i dalje su otvorene, robot uzima drugi pripremak i proces se ponavlja. Nakon dobijenog drugog obratka, robot ga uzima iz stege, napušta radni prostor obradnog centra, vrata i stega se zatvaraju,a robot vraća drugi obradak u poziciju na paleti odakle ga je uzeo, te se potom vraća u početni položaj.

Za proces simhronizacije kreiran je poseban dijagram stanja u zavisnosti da li je aktivan proces CNC obrade, u kojoj poziciji se nalazi robot, da li su otvorena/zatvorena vrata/stega obradnog centra, i dat je na slici 6:



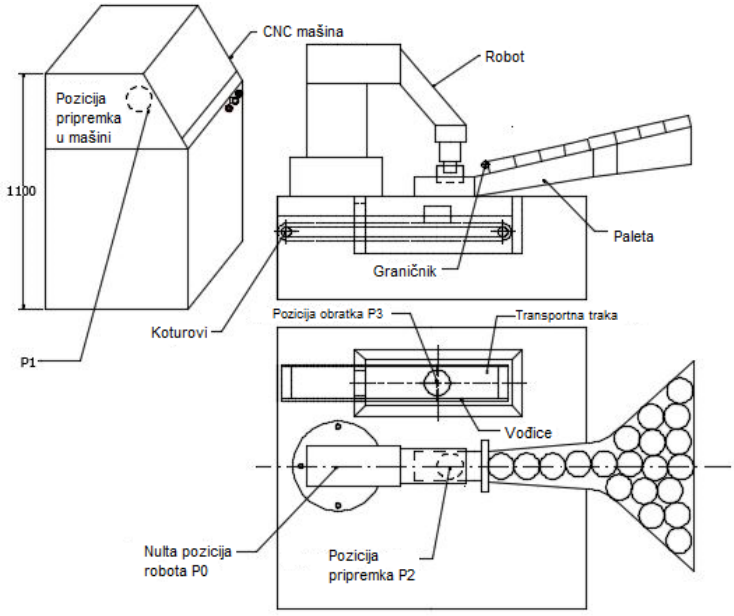
Slika 6: *Dijagram stanja procesa sinhronizacije robota i CNC obradnog centra [1]*

Takođe, u radu su navedene dvije moguće varijante rasporeda dijelova pri manipulaciji. U prvom slučaju, robot uzima pripremke sa palete u obliku prstena. Paleta se na odgovarajući način pozicionira i fiksira i na mjestu svakog pripremka napravi se otvor dubine 1mm kako bi se mogao postaviti pripremak. Izgled palete dat je na slici 7:



Slika 7. *Izgled palete u obliku prstena [1]*

U drugom slučaju, robot uzima pripremka sa samo jedne pozicije. Paleta se postavi pod određenim uglom u odnosu na radni sto i na njoj se napravi samo jedno udubljenje, jer će na jedno mjesto dolaziti pripremci. Graničnik se postavi kako bi obezbjedio prolaz samo jednog komada svaki put kada senzor očita da nema prisustva pripremka. Takođe, kada senzor javi da je pozicija pripremka prazna, aktivira se i uređaj koji obezbjeđuje vibriranje palete, kako bi se pokrenuli statični pripremci. Izgled jedne takve palete dat je na slici 8:



Slika 8: *Prihvatanje pripremaka sa jedne pozicije [1]*

5 ZAKLJUČAK

Ovaj rad objedinio je znanja elektro-struke iz oblasti robotike i mehatronike,a sa druge strane znanja ponajviše iz oblasti automatizacije proizvodnih sistema, zatim fleksibilnih tehnoloških sistema, kompjuterski upravljanih mašina alatki, obrade rezanjem, alata i pribora, i slično. Takođe je važno pomenuti da bez znanja iz oblasti CAM programiranja ne bi bilo moguće ostvariti specifičnost obrade rotacionog pripremka (kružno kretanje alata koji zahvata materijal sa 5% prečnika alata). Osnovni problem komunikacije između robota i CNC obradnog centra je prevaziđen. Opisani su uređaji koji čine mehatronički sistem, dat je princip njihovog rada. Proces sinhronizacije robota i CNC obradnog centra obuhvatio je kompletnu proceduru upravljanja fleksibilnom tehnološkom ćelijom i kao takav predstavlja osnovu za buduće kompleksnije radove iz oblasti automatizacije proizvodnih sistema. .

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PRESENTATIONS OF COMPANIES

KOLEKTOR

Kolektor CCL je savremeno proizvodno preduzeće koje na području Republike Srpske postoji i uspješno se razvija već 14 godina.
Preduzeće je dio slovenačke grupacije Kolektor Group u okviru koje ravnopravno egzistira sa 35 ostalih fabrika-članica. Kolektor CCL bavi se proizvodnjom komutatora i elektro-komponenti, a svoje proizvode plasira širom svijeta. Značajan dio proizvodnog programa ove firme čine dijelovi i komponente za autoindustriju, dok se preostali dio odnosi na dijelove za elektro uređaje najpoznatijih svjetskih proizvođača.
Strateški cilj kojem teži Kolektor CCL je da bude kompetentni centar za razvoj i proizvodnju komutatora odakle i potiče sam naziv firme CCL (kompetentni centar Laktaši). Kolektor je usmjeren ka zapošljavanju, razvoju i usavršavanju novih kadrova o čemu svjedoči konstantan rast broja novo zaposlenih visoko obrazovanih kadrova, a savremene tehnologije i oprema koju Kolektor posjeduje idealna su podloga za to.
Danas, na tri svoje lokacije, Kolektor CCL zapošljava preko 500 radnika od kojih više od 40 čine mladi visoko obrazovani inženjeri. Trenutno je u izgradnji nova proizvodna lokacija u Prijedoru, a u bliskoj budućnosti planira se značajno povećanje obima proizvodnje i broja zaposlenih.

АН Инжењеринг

Kompanija AN Inženjering osnovana je 2012. godine u Moskvi, nakon decenijskog iskustva na projektima grijanja, hlađenja i ventilacije širom Ruske Federacije.
Kompanija je u Trebinju sa radom počela 2017. godine, sa ciljem da postane regionalni lider u oblasti grijanja, klimatizacije, ventilacije, sa jakom servisnom mrežom na području cijele države. Sjedište kompanije je na adresi Republike Srpske bb u novoizgrađenom poslovno-stambenom kompleksu Dom Sunca.
Cilj kompanije je da sa timom mladih i kreativnih stručnjaka, te resursima sa kojima kompanija raspolaže, ponudi kompletan spektar usluga, **od ideje do realizacije** i da stvaraju energetski efikasna i tehnički prilagodljiva rješenja, te da pružaju odgovor na sve potrebe koje pred njih postavljaju klijenti.

UNIS Fabrika gasnih aparata d.o.o. (UNIS FAGAS d.o.o.) Sarajevo je osnovana 1997. godine. Osnovna djelatnost je projektovanje, proizvodnja opreme za mjerenje i regulaciju gasa, kao i njena ugradnja prema zahtjevu kupca. Osim plasmana na tržišta bivše Jugoslavije, UNIS FAGAS izvozi na tržišta Srbije, Sjeverne Amerike, Skandinavije, Njemačke, Makedonije, kao i na tržišta Bliskog i Srednjeg Istoka.
UNIS FAGAS ima uveden Sistem kvaliteta ISO 9001 od decembra 2001. godine te u svojoj poslovnoj politici nastoji da sve svoje proizvode sertificira kod nadležnih institucija prema važećim BAS EN standardima.
Pored sertificiranja proizvoda od strane domaćih institucija, UNIS FAGAS sertificira svoje proizvode i od strane njemačkog udruženja za zrak, gas i vodu DVGW-a, kao i kod kanadsko - američkog udruženja za gas, a naše proizvode za regulaciju gasa ispitujemo u laboratorijama Instituta za gasnu tehniku - Gas Werme Instituta (GWI) u Essen-u.
Takođe, pored regulacione i mjerne opreme za gas, UNIS FAGAS vrši projektovanje, proizvodi, montira na objektu i pušta u pogon sve tipove gasnih stanica, kao što su GRMS (glavne regulaciono mjerne stanice), RMS (regulaciono mjerne stanice), MS (mjerne stanice), BS (blok stanice), PČGS (prijemno čistačke gasne stanice) i sl., a za pritiske do i uključujući 100 bar.
UNIS FAGAS je ovlašteni zastupnik grupacije Honeywell (ELSTER-INSTROMET) za područje BiH. Honeywell (ELSTER-INSTROMET) je prepoznatljiv više od 170 godina kao kvalitetan i inovativan proizvođač opreme za mjerenje i regulaciju gasa.
UNIS FAGAS je zastupnik i firme PREMATLAK za područje BiH koja se bavi proizvodnjom manometara i termometara.

OMD

VUKA KARADŽIĆA 28
ISTOČNO SARAJEVO
066/132-443

Firma ”OMD” osnovana je početkom 2017.godine i bavi se obradom mašinskih dijelova od aluminijuma i drugih lakih metala. Firma vrši izradu različitih dijelova po narudžbi za automobilsku industiju u Kanadi. Ono što izdvaja firmu od ostalih srodnih u okruženju, jeste mogućnost izrade različitih varijanti virtuelnih konstrukcija i mašinskih dijelova po želji kupca, na osnovu čega se izrađuje dokumentacija za izradu u proizvodnim pogonima. Cilj kompanije jeste da sa vlastitim kadrom ponudi tržištu što veći asortiman proizvoda i usluga iz oblasti mašinske obrade i konstruisanja različitih varijantnih riješenja.

Eden Garden

Eden Garden je 2001. godine registriran u BiH kao Joint Venture kompanija sa istoimenim italijanskim partnerima, da bi od 2007. godine Vranešević otkupio italijanski dio i postao 100% vlasnik. Firma se bavi proizvodnjom baštenskih suncobrana i danas zapošljava 30 radnika. Izvozno su orjentirani, a zemlje EU, Amerika i Azija su im glavni tržišni kupci s tim što u posljednje vrijeme Katar i Saudijska Arabija pokazuju sve više interesa za visokokvalitetne suncobrane.
S obzirom na sve veću potražnju i zahtjeve inostranog tržišta, planovi rukovodstva su širenje proizvodnje, reinvesticije i zapošljavanje novih radnika.



Fabrika za pocinčavanje je osnovana 1968.godine, a koja je radila u sklopu velikog giganta "Energoinvesta". Iz rata je izašla oštećena granatiranjem i malo toga je ukazivalo na uspjeh.
Ipak, s poslom su krenuli 2003. godine i to sa 27 zaposlenih, koji mjesečno uspijevaju da pocinčaju oko 150 tona elemenata. O koliko skromnim počecima je riječ, najbolje govori podatak da su trenutni kapaciteti fabrike oko 1.200 tona pocinčanih elemenata na mjesečnom nivou. Obim proizvodnje u 2016. godini uvećan je za čak **45 odsto** u odnosu na prethodnu, a što se odrazilo i na prihode. Osnovna djelatnost je antikorozivna zaštita toplim cinkom, ali je preduzeće ušlo i u priču u vezi s proizvodnjom putne ograde i zaštite na putevima, a bavi se i trgovinom cijevi i profila svih vrsta.Orijentisani su i na domaće i na strano tržište. Izvoze oko 35 odsto kako usluga, tako i proizvoda. Imaju velike ugovore u auto-industriji s „Volkswagenom“ i „Audijem“, kao i s velikim građevinskim firmama. U pitanju su sigurni poslovi sklopljeni uglavnom na period od pet godina.



Alpro je danas jedna od vodećih kompanija u proizvodnji arhitektonskih profila na prostorima bivše Jugoslavije. Visoko stručan kadar, iz svih oblasti, i inovativna i moderna rješenja sadržana u njihovim proizvodima su garant njihovog uspjeha, kao uspjeha korisnika njihovih proizvoda. Oni svojim ne nude samo profile, već integrisan visoko-tehnološki proizvod koji treba da odgovori zahtjevima najekstremnijih eksplatacionih uslova. Svojim kupcima obezjbeđuju rješenje koje u potpunosti treba da odgovori njihovim potrebama i očekivanjima. Izuzetan kvalitet poslovanja, a na šta su oni naročito ponosni, je dobra komunikacija sa korisnicima njihovih proizvoda, tako da svoje kupce smatraju dijelom jedne velike Alpro porodice, koja je iz dana u dan sve brojnija. Danas Alpro u svom proizvodnom programu ima veliku lepezu različitih profila kao što su: standardni profili, profili za vrata i prozore sa i bez termičkog prekida, profili za ograde, profili za klizna vrata i prozore, profili sa fasade, profili za pregradne zidove, profili za elektro, mašinsku industriju itd. U saradnji sa matičnom kompanijom svakodnevno rade na uvođenju novih sistema profila i na unapređenju postojećih.



Sarajevo-gas je osnovan 1975. godine kao ekološki projekat sa jasno definisanim ciljem kontinuirane isporuke prirodnog gasa. Osnovna djelatnost preduzeća je distribucija prirodnog gasa, upravljanje i održavanje gasnog sistema Kantona Sarajevo. Davno pokrenuta nastojanja za očuvanje kvalitete zraka traju i danas i obavezuju nas da svakodnevno istrajavamo na daljnjem razvoju gasne infrastrukture i zadržavanju gasa kao ekološki najprihvaljivijeg energenta. Implementacijom Menadžmenta tehničke sigurnosti, Sarajevogas je učinio veliki iskorak ka dostizanju evropskih standarda u oblasti sigurne i tehnološki besprijekorne distribucije gasa.



Za 59 godina postojanja i uspješnog rada Kompanija Boksit bila je i ostala nosilac razvoja ne samo Milića, nego i regije Birač.
Boksit je danas je jedna od najznačajnijih Kompanija u RS i BiH. Bilježeći stalni rast i razvoj, od klasičnog preduzeća za istraživanje, proizvodnju i pripremu rude boksita, veoma uspješno valorizujući taj prirodni resurs, Kompanija je razvila i druge djelatnosti, sa kojima je uspješno izašla na tržište. To su prvenstveno: saobraćaj, proizvodnja i prerada nemetala, elektro-mašinstvo, proizvodnja opreme i rezervnih dijelova, gradjevinarstvo, proizvodnja hrane, drvoprerada, ugostiteljstvo, prodaja naftinih derivata, veleprodaja robe iz vlastitog proizvodnog programa i druge robe. Boksit je akcionarsko društvo sa većinskim privatnim kapitalom i koje je u cijelosti privatizovano. U vlasništvu je većeg broja malih akcionara i fondova, a većinski paket ima menadžment Kompanije. Boksit je jedno od najuspješnijih preduzeća i nosilac je velikog broja najznačajnijih priznanja. Kompanija ima pravo da istražuje i eksploatiše rudu boksita i mineralne sirovine za period od 30 godina.



Preduzeće "Grijanjeinvest" osnovano je 1991.godine u Sarajevu, a obnovilo je rad na Palama 1995. godine. Zapošljava oko 30 radnika od kojih su 5 diplomirani inženjeri mašinstva.
Osnovna djelatnost je projektovanje i izvođenje termotehničkih instalacija: klimatizacije, grijanja i hlađenja. Preduzeće ima stalnu saradnju sa Katedrom za termotehniku Mašinskog fakulteta Univerziteta u Beogradu. Zajedno sa stručnjacima Mašinskog fakulteta Beograd i preduzećima "Simon" Valjevo i “MPG KGH” Beograd učestvuje u obnovi termotehničkih instalacija Svetog manastira Hilandara. U proteklih 20 – ak godina predano su radili na poboljšanju životnog standarda građana primjenjujući savremena, energetski efikasna dostignuća iz ove oblasti.



Termoelektro d.o.o. Brčko je privatno i nezavisno preduzeće osnovano 23.07.1997. godine. Preduzeće je nastalo iz Holdinga Termoelektro a.d. Beograd osnovanog davne 1948. godine. Termoelektro je specijalizovano preduzeće za: izgradnju, remont, rekonstrukciju, revitalizaciju i održavanje termoenergetskih, industrijskih i drugih postrojenja, kao i izradu i montažu nestandardne opreme i konstrukcija. Termoelektro pruža kompletnu i kvalitetnu uslugu od inženjeringa i izrade projekata do organizacije na samom gradilištu po principu „ključ u ruke“.

HIDROELEKTRANA „VIŠEGRAD“ je počela sa radom 1989.god. Instalisanu snagu od 3×105 MW ostvaruje sa Kaplan turbinama, uz prosječnu plasiranu godišnju proizvodnju od 1010 GWh, preko 3 monofazna transformatora po 115 MVA, odnosno, 15,75/400 kV postrojenja. Srednji višegodišnji protok je 342 m^3/s, akumulacija ima ukupnu zapreminu od 161 hm^3 i dužinu oko 40 km. Rekord godišnje proizvodnje je ostvaren u 2010.g. sa proizvedenih 1.283,05 GWh električne energije. Ukupni instalisani proticaj od Qi=800 m^3/s raspoređen je na tri agregata koji se sastoje od 3 vertikalne Kaplan turbine jediničnog proticaja od 267 m^3/sek sa betonskim spiralnim kućištem sa pripadajućim turbinskim regulatorima. Prečnik rotora turbine je 6,015 m, konstruktivni pad iznosi 43 m, stepen iskorištenja η=0,94, uz nominalan broj okretaja n=136 o/min snaga pojedinačnog agregata iznosi 105 MW

„Bekto Precisa“ je porodična kompanija sa višedecenijskim poslovnim iskustvom u oblasti proizvodnje visokosofisticiranih industrijskih alata za plastiku i obojene metale, kao i kombinaciju metal-plastika, ali i mnogobrojnih proizvoda koji se brizgaju od plastike a koji imaju široku primjenu u više industrijskih grana i svakodnevnoj životnoj upotrebi. U početku zamišljena kao mala porodična firma, „Bekto Precisa“ je danas izrasla u kompaniju evropskog formata koja se prostire na više od 50.000 kvadratnih metara i u čijim pogonima radi oko 450 ljudi na 300 najmodernijih industrijskih mašina.
Sa potpuno zaokruženim sistemom proizvodnje, od ideje do finalnih proizvoda, postala je jedinstvena u čitavom regionu jugoistočne Evrope.
Naša vizija i strategija je ponuditi kupcima najbolju uslugu i proizvode uspostavljajući individualni pristup sa svakim kupcem te na osnovu prepoznavanja njihovih specifičnih zahtjeva i potreba u prilici smo na najoptimalniji način udovoljiti njihovim zahtjevima i narudžbama. Kvalitet proizvoda i zadovoljstvo kupaca naša je najveća poslovna satisfakcija.

Servitec Balkan d.o.o osnovan je 2012. godine u Istočnom Sarajevu gdje je i sjedište. 2013. godine u saradnji sa Mašinskim fakultetom otvoreno je predstavništvo u Mostaru kao i kancelarija u Goraždu. U periodu od osnivanja do danas ostvarli smo kontakte sa brojnim poslovnim partnerima iz Španije sa kojima imamo veoma uspješnu saradnju. Naše aktivno predstavništo za teritoriju Španije i Evropske unije predstavlja kompanija Metaltren SL, Lleida.

Kompanija je osnovana 1993. godine, a Centrotrans-Eurolines postaje većinski vlasnik ovog društva 2005. godine kada preuzima više od 50% vlasništva dionica. Centrotrans-Eurolines je kupovinom ove firme proširila i integrisala tržište na međunarodnim linijama za Srbiju i Crnu Goru, uvezala lokalne linije u Istočnom Sarajevu, a sve u cilju uvezivanja tržišta BiH u jedinstveni poslovni prostor i ambijent. Nakon ulaska Centrotrans-Eurolinesa u ovu firmu evidentno je povećanje obima poslovanja, unapređivanje načina rada, smanjenje troškova i poboljšanje komunikacije s korisnicima usluga. Tokom 2007. godine uvedeni su ISO standardi 9001:2000, čime je sistem upravljanja društva podignut na veći nivo i poslovanje je u najvećoj mjeri usklađeno sa zahtjevima savremenog poslovanja.Centrotrans Istočno Sarajevo obavlja sedam međunarodnih, četiri republičke i dvanaest gradsko-prigradskih linija, ima preko 70 zaposlenika, a vozni park broji preko 25 kvalitetnih vozila.

Preduzeće „Gross“ društvo sa ograničenom odgovornošću za proizvodnju, promet i usluge iz Gradiške osnovano je 2005. godine i upisano u registarski uložak Osnovnog suda u Banja Luci. Osnovna djelatnost društva je bila spoljnjnotrgovinski promet. 2007. godine preduzeće „Gross“ d.o.o. Gradiška potpisuje Ugovor o koncesiji za istraživanje, eksploataciju i preradu rude olova i cinka sa Vladom Republike Srpske na ležištima „Srebrenica“, „Srebrenica II“, „Kazani“ i „Vitlovac“ opština Srebrenica.

Pokretanje djelatnosti čija je osnovna svrha održavanje koegzistencije industrije i prirode nametnulo je stroga pravila po kojima firma "Eco Trade " radi. Svjesni činjenice da se uspjeh ostvaruje ponajprije primjenom svjetskih normativa struke na tržištu, utemeljili smo naše poslovanje u ulaganju u kadrove, napredne tehnologije i opremu. Poseban se trud ulaže u razvoj međuljudskih odnosa između zaposlenih, što ujedno znači i veću efikasnost. ECO TRADE d.o.o, Gradiška, ekologija i zaštita životne sredine, preduzeće je s ograničenom odgovornošću osnovano 1996. godine. Kvaliteta, brzina i kvalitet našeg djelovanja, primjena sigurnosnih mjera u cilju zaštite ljudi i okoline te, strogo uvažavanje potreba i želja poslovnih partnera već godinama rezultiraju zadovoljstvom svih strana i dugoročnim poslovnim saradnjama. Naši su poslovni partneri naime najbolji pokazatelj poslovnosti "Eco Trade"-a.

Komunalno preduzeće Vodovod i kanalizacija a.d. Istočno Sarajevo osnovalo je Povjereništvo grada Istočno Sarajevo, 1996.godine, s ciljem obezbjeđenja organizovanog snabdijevanja vodom i odvođenja otpadnih voda u dijelu grada Istočno Sarajevo, koji čine tri gradske opštine: Istočno Novo Sarajevo, Istočna Ilidža i Trnovo. KP VIK a.d. Istočno Sarajevo obavlja sljedeće djelatnosti: snabdijevanje potrošača pitkom i higijenski ispravnom vodom, odvođenje otpadnih voda, izgradnja, rekonstrukcija i održavanje Sistema vodosnabdijevanja i odvođenja otpadnih voda, (priključaka, vodovodnih i kanalizacionih objekata, elektromašinskih postrojenja, vodomjera, postrojenja za dezinfekciju vode, hidranata, mjerne i regulacione tehnike vodovodnog sistema, kaptaža rezervoara i pumpnih stanica) vođenje tehničke dokumentacije i katastra podzemnih instalacija vodovoda i kanalizacije, sanitarno tehnički poslovi u funkciji kontrole kvaliteta vode, kao i postavljanje cijevnih instalacija, projektovanje građevinskih i drugih objekata o čemu se brine preko 100 zaposlenih radnika.

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