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28th - 30th November 2012.

Jahorina, B&H, Republic of Srpska



University of East Sarajevo

Faculty of Mechanical Engineering

Conference on Mechanical Engineering Technologies and Applications

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Isto no Sarajevo . Jahorina, BiH, RS
28-30. Novembar 2012.

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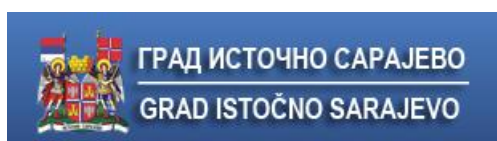
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PREFACE

Production in developed countries is based on the modernization and optimization of the production processes with the application of new technologies that are the result of scientific research. The application of new technology enables companies efficient production and competitiveness in the world market.

Faculty of Mechanical Engineering, University of East Sarajevo, organizes the First international conference "COMETA2012 - Conference on Mechanical Engineering Technologies and Application", which has tasks: to increase economic competitiveness in the region and the create a unique European Research Area.

Globally, the worldwide we are witnessing a rapid development and a host of new technological solutions, which occur primarily in the multidisciplinary development (mechatronics) but also in development of completely new technologies, such as nanotechnology, new energy sources, intelligent machines and processes, micro-technique, etc. All of this puts researchers and engineers in the new challenges and creates opportunities for products and technologies that provide a precondition for economic recovery and creation of new jobs.

COMETA2012 conference program structure is consisted of the following thematic areas: Production technologies and advanced materials, Applied mechanics and mechatronics, Development of products and mechanical systems, Energetics and thermo - technique, Renewable energy and environmental protection, Quality, management and organization, Maintenance and technical diagnostics.

Participation in international conference COMETA2012 was achieved by: 182 authors from 9 countries, with a total of 90 papers, including 4 plenary and 3 of introductory, 4 leading commercial companies and many small and medium enterprises. Bruel & Kjar Workshop: "Measurement of noise and vibration", was also organized at the conference, as well as a round table discussion: "The importance of quality infrastructure of B&H within the European integration".

The presence of a large number of participants from Bosnia and Herzegovina and abroad as well as the problems which are processed at the conference, coincide with the themes promoted by the European Union in its development programs.

On the basis of previous exposure, a gathering of scientists and researchers at the international conference COMETA should be understood not only as an exchange of knowledge and achievements of the narrower set of scientists and researchers, but also as a constant and serious attempt to focus social consciousness and social life on activities that ensures progress and prosperity of any society, and that is productive work, creating new knowledge and economic development.

On behalf of the Organizing Committee of the Conference COMETA2012, thank all authors, reviewers, as well as institutions, companies and individuals who contributed to realization of the Conference.

East Sarajevo, October 28th, 2012.

President of the Organizing Committee

Prof. dr Ranko Antunović



CONTENTS

PLENARY LECTURES

1. **Stefan Wagner**
IMPROVED FAILURE DESCRIPTION IN FORMING OF AUTOMOTIVE SHEET METAL PARTS 1
2. **Gorazd Hlebanja**
CHARACTERISTICS OF NON-INVOLUTE GEARS 9
3. **Aleksandar Veg, Emil Veg**
DEVELOPMENT OF A HAND-HELD VIBRODIAGNOSTIC INSTRUMENT 21
4. **Milosav Ognjanović**
TECHNICAL SYSTEMS DEVELOPMENT TOWARDS TO ACTUAL TRENDS AND METHODOLOGY IN ENGINEERING DESIGN 31

INVITED PAPERS

5. **Ljubodrag Tanovic**
INVESTIGATIONS IN DEVELOPING A NEW GENERATION OF MACHINE TOOLSS 37
6. **Ranko Antunović, Aleksandar Veg**
ANALYSIS OF DYNAMIC BEHAVIOR OF ROTATING MACHINES 43
7. **Vojislav Miltenović, Biljana Marković, Milan Banić, Aleksandar Miltenović**
FUTURE TECHNOLOGY AND EDUCATION OF ENGINEERS 53

Session I

MANUFACTURING TECHNOLOGIES AND ADVANCED MATERIALS

Chair: Milan Zeljković, Ljubodrag Tanović, Obrad Spaić

8. **Milan Zeljkovic, Aleksandar Zivkovic, Slobodan Tabakovic**
COMPUTER AND EXPERIMENTAL AIDED ANALYSIS OF HIGH-SPEED SPINDLE ASSEMBLY DYNAMIC BEHAVIOR 63
9. **Dejan Jeremić, Nebojša Radić**
IMPLEMENTATION OF CARBON FIBER IN THE AUTOMOTIVE INDUSTRY 75
10. **Obrad Spaić, Budimirka Marinović**
INFLUENCE OF WEARING DRILLS ON DRILLING AXIAL FORCE 83
11. **Obrad Spaić, Zdravko Krivokapić, Slavoljub Grče**
MODELING OF AXIAL CUTTING FORCE USING NEURAL NETWORKS 91
12. **Milija Krašnik, Dragiša Vilotić, Lepasava Šiđanin, Žarko Petrović**
EXPERIMENTAL VERIFICATION OF DIFFERENT THEORETICAL APPROACHES FOR DEFINING FLD 99
13. **Aljoša Ivanišević, Igor Kačmarčik, Dejan Movrin, Miroslav Plančak, Sergei Alexandrov, Dragiša Vilotić**
INFLUENCE OF FRICTION AND NUMBER OF DEFORMATION PHASES ON FORMABILITY OF STEEL C45E 109

14.	Aleksandar Košarac, Saša Prodanović, Milan Zeljković POSSIBILITIES FOR INTERACTIVE CONTROL OF MACHINE TOOLS IN THE VIRTUAL REALITY ENVIRONMENT	117
15.	Saša Živanović, Zoran Dimić, Nikola Slavković, Dragan Milutinović, Miloš Glavonjić CONFIGURING OF VIRTUAL ROBOT FOR MACHINING AND APPLICATION IN OFF-LINE PROGRAMMING AND EDUCATION	125
16.	Zorica Djordjević, Mirko Blagojević, Saša Jovanović, Vesna Marjanović, Nenad Kostić MATERIAL TYPE INFLUENCE ON STATIC AND DYNAMIC CHARACTERISTICS OF COMPOSITE SHAFTS	133
17.	Slobodan Stojadinović, Jasmina Pekez, Nikola Bajić, Eleonora Desnica HARDENING OF AlMgSiCu ALLOYS AS A FUNCTION OF THE THERMO-MECHANICAL TREATMENT	141
18.	Zdravko Božičković, Dragoslav Dobraš, Milorad Poljašević THE INFLUENCE OF THE DEFORMATION IN THE PROCESS EXTRACTION ON QUALITY OF WIRES FOR REINFORCEMENT MESH	145
19.	Svetislav Marković, Dragoljub Veličković, Marijana Marković, Marija Popović, Jelena Milić, Ljubiša Milovanović THE ABILITIES AND PRACTICAL APPLICATIONS OF LASER CONTOURING CUTTING OF MATERIALS IN THE MAINTENANCE OF MECHANICAL SYSTEMS	153

Session II

APPLIED MECHANICS AND MECHATRONICS

Chair: Aleksandar Veg, Ranko Antunović, Nebojša Radić

20.	Nebojša Radić, Dejan Jeremić BUCKLING ANALYSIS OF DOUBLE-ORTHOTROPIC NANOPATE USING NONLOCAL ELASTICITY THEORY	161
21.	Ljupco Trajcevski, Tale Geramitchioski DYNAMIC RESPONSE SIMULATION OF PLANETARY GEAR BY NEWMARK METHOD	171
22.	Tale Geramitchioski, Ljupco Trajcevski, Vangelce Mitrevski COMPUTER SIMULATION A VIBRATION SIGNAL FOR THE GEAR FAULT DIAGNOSTICS	179
23.	Rusmir Bajrić, Ninoslav Zuber, Denijal Sprečić REVIEW OF VIBRODIAGNOSTIC METHODS FOR PLANETARY GEARBOX GEARS CONDITION MONITORING	187
24.	Ninoslav Zuber, Rusmir Bajrić REVIEW OF VIBRODIAGNOSTIC METHODS FOR ROLLER ELEMENTS BEARING CONDITION MONITORING	195
25.	Saša Nikolić MOTOR CURRENT SIGNATURE ANALYSIS TO DETECT FAULT OF INDUCTION MOTOR	205
26.	Nenad Marjanović, Biserka Isailović, Vesna Marjanović, Nenad Kostić INTEGRATED APPROACH TO STRUCTURAL OPTIMIZATION IN CAD SOFTWARE	213

27. **Vladimir Milovanović, Dragan Rakić, Miroslav Živković, Snežana Vulović, Miroslav Milutinović**
THERMO-MECHANIC ANALYSIS OF CEMENT TRANSPORT WAGON
- IDENTIFICATION OF THE CAUSE OF CRACKS 221
28. **Nedeljko Vukojević, Fuad Hadžikadunić**
EXPERIENCES OF APPLICATION OF VIBRATORY RESIDUAL
STRESS RELIEVING METHODOLOGY ON LARGE WELDED
CONSTRUCTIONS 229
29. **Boris Rakić, Nikola Beloica, Danica Josifović, Lozica Ivanović, Andreja Ilić**
STRESS - STRAIN ANALYSIS OF HYDRAULIC CYLINDER AT
EXCAVATOR BUCKET MECHANISM 235
30. **Lozica Ivanović, Danica Josifović, Mirko Blagojević, Blaža Stojanović, Andreja Ilić**
DETERMINATION OF GEROTOR PUMP THEORETICAL FLOW 243
31. **Aleksandar Nikolić, Milan Blagojević, Vladimir Milovanović, Miroslav Živković, Miroslav Milutinović**
ANALYSIS OF HEAT TRANSFER THROUGH THE BEAM SUPPORT
OF THE WAGON STRUCTURE CALCULATED BY SOFTWARE PAK
MULTYPHISICS 251
32. **Marko Topalović, Miroslav Živković, Nenad Busarac, Snežana Vulović**
IMPROVEMENT AND INTEGRATION OF FEM SOLUTION USED FOR
R&D INTO FEMAP 255

Session III

DEVELOPMENT OF PRODUCTS AND MECHANICAL SYSTEMS

Session III-1: DESIGN OF POWER TRANSMISSIONS

Chair: Miloslav Ognjanović, Siniša Kuzmanović, Dragan Milčić

33. **Miloš Ristić, Milosav Ognjanović**
RELIABILITY-BASED DESIGN OF BUCKET WHEEL EXCAVATOR
GEAR DRIVE UNITS 263
34. **Milan Rackov, Siniša Kuzmanović, Željko Kanović, Miroslav Vereš**
SOME IRREGULARITIES WHICH MAY OCCUR DURING
IMPLEMENTATION HCR GEARING 269
35. **Dragan Milčić, Miroslav Mijajlović, Dragoljub Živković, Slobodan Miladinović**
CALCULATION OF LOAD CAPACITY OF AXLES AND SHAFTS
ACCORDING TO DIN 743 277
36. **Predrag Živković**
EXPERIMENTAL IDENTIFICATION OF FAILURE AND RELIABILITY
CALCULATION OF ELEMENTARY PLANETARY GEARS POWER
TRANSMISSIONS 285
37. **Radoslav Tomović**
NEW APPROACH TO THE MODELING OF ROLLING BEARINGS 293
38. **Dragan Milčić, Miroslav Mijajlović, Boban Anđelković, Miodrag Milčić**
SOFTWARE SYSTEM FOR CALCULATIONS OF MACHINE PARTS –
PROGRAM MODULE FOR FRICTION TRANSMISSION
CALCULATIONS 303

39. **Dragoslav Janošević, Nikola Petrović, Vesna Nikolić, Jovan Pavlović**
ANALYSIS OF HYDRAULIC CRAWLER TRACTORS TRANSMISSION 309
40. **Marko Miletić, Mirko Blagojević, Snežana Vulović, Ivan Miletić**
CONTACT SURFACE ANALYSIS ON CYCLOID DRIVES WITH SINGLE, DOUBLE AND TRIPLE MESHING 315
41. **Miroslav Milutinović, Milosav Ognjanović, Spasoje Trifković**
DESIGN PARAMETERS IDENTIFICATION OF AUTOMOTIVE GEARBOX BASED ON DESIRED RELIABILITY 323

Session III-2

ENGINEERING EDUCATION AND INNOVATION IN DESIGN

Chair: **Vojislav Miltenović, Gorazd Hlebanja, Biljana Marković**

42. **Tihomir Mačkić, Mirko Blagojević, Živko Babić**
ANALYSIS OF PARAMETERS THAT HAVE AN IMPACT ON CYCLO DRIVE EFFICIENCY 331
43. **Nenad Kostić, Mirko Blagojević, Vesna Marjanović, Zorica Đorđević, Nenad Marjanović**
INFLUENCE OF CYCLOIDAL GEAR PROFILE CORRECTION TO THE NUMBER OF CONTACTS BETWEEN THE ELEMENTS OF A CYCLOIDAL SPEED REDUCER 339
44. **Nada Bojić, Dragan Milčić**
EFFECTS OF VARIOUS PARAMETERS TO SLIDING BEARINGS 347
45. **Miroslav Živković, Miloš Janošević, Snežana Vulović, Nenad Busarac, Marko Topalović**
THERMAL ANALYSIS OF HIGH POWER REDUCTION GEARBOX 355
46. **Biljana Marković, Milan Banić**
REQUIREMENTS FOR DEVELOPING ENGINEERS EDUCATION – HOW TO PARTICIPATE IN INTERNATIONAL PROJECTS? 359
47. **Mirko Blagojević, Zorica Đorđević, Vesna Marjanović, Nenad Marjanović, Blaža Stojanović, Rodoljub Vujanac**
STRESS AND STRAIN STATE OF CYCLOID DISC 367
48. **Dejan Krstić**
IMPACT OF EURO NCAP TESTS ON BODY MODIFICATION IN AUTOMOTIVE INDUSTRY 375

Session IV

ENERGETICS AND THERMO - TECHNIQUE

Chair: **Dušan Golubović, Mirko Dobrnjac, Buzatu Gabriel Cosmin**

49. **Milan Plavšić, Zdravko Božičković, Dušan Golubović**
MATERIALS-RELATED ISSUES IN CATALYTIC AND BOILER-TURBINE PLANTS 383
50. **Miljan Savić, Biljana Marković**
ESTABLISHING ENERGY EFFICIENCY SYSTEM IN ACCORDANCE WITH THE REQUIREMENTS OF EN ISO 50001 391
51. **Vangelce Mitrevski, Tale Geramitcioski, Vladimir Mijakovski, Monika Lutovska**
RISK ASSESSMENT IN NATURAL GAS TRANSMISSION SYSTEM 399
52. **Saša Jovanović, Zorica Đorđević, Milorad Bojić, Slobodan Savić, Biljana Stepanović**
WEATHER CONDITIONS IMPACT ON ELECTRICITY CONSUMPTION 409

53.	Buzatu Gabriel Cosmin, Mircea Paul Mihai, Dinu Radu Cristian ENERGY EFFICIENCY OF A COGENERATION SYSTEM	415
54.	Šefik Bajmak ANALYSIS OF ENERGY EFFICIENCY AND ECONOMIC SEPARATED SYSTEMS WITHIN THE SUPPLY CENTRALIZED HEAT AND COOLING ENERGY	423
55.	Jela Burazer, Dragana Kalabić, Mirko Dobrnjac CALCULATION CHOICE AT THE VERTICAL PNEUMATIC TRANSPORT OF THE DUST MATERIAL	431
56.	Slobodan Stefanovic, Zivoslav Adamovic, Radoje Cvejic, Imre Kiss MATHEMATICAL MODEL OF THE SYSTEM FOR REGULATION OF ROLLING THICKNESS ON FIVE STRANDS TWIN TRAIN	435
57.	Velibor Karanović, Mitar Jocanović, Darko Knežević, Milija Kraišnik DEVELOPMENT OF ELECTROHYDRAULIC ACTUATOR FOR ROBOTS	447
58.	Dragoljub Živković, Marko Mančić, Dragan Milčić SYMULATION OF A HYBRID TRIGENERATION SYSTEM DESIGNED FOR DEMANDS OF A RESIDENTIAL BUILDING	457

Session V

RENEWABLE ENERGIES AND ENVIRONMENTAL PROTECTION

Chair: Petar Gvero, Stojan Simić, Mircea Paul Mihai

59.	Srđan Vasković, Petar Gvero, Vlado Medaković, Davor Milić THE IMPORTANCE OF ANALYSIS ENERGY CHAINS BASED ON BIOMASS FOR ENERGY PRODUCTION	465
60.	Stojan Simić RECYCLABILITY-SIGNIFICANT REQUEST FOR DESIGN AND CONSTRUCTION IN THE METAL INDUSTRY	471
61.	Stojan Simić, Snježana Vujić, Omer Kovač ADEQUATE WASTEWATER MANAGEMENT SIGNIFICANT SEGMENT OF CONSERVING OF ENERGY IN REFINERIES	479
62.	Mircea Paul Mihai, Sanda Diana (Firincă) Enache, Cătălin Mihai, Sorin Abagiu, Ivan Felicia Elena Stan SMART GRIDS CONCEPT USED IN RURAL AREAS	487
63.	Dejan Krstić MANAGEMENT OF THE INNOVATIVE PROJECTS FOR CONQUEST OF MANUFACTURING SOLAR PHOTOVOLTAIC MODULE	495
64.	Roganović D., Đurović D. DETERMINATION OF HEAVY METALS IN THE BARK OF CYPRESS (CUPRESSUS SEMPERVIRENS L.) IN THE VICINITY ALUMINIUM PLANT PODGORICA (KAP) - MONTENEGRO	503
65.	Panaiteescu F.V., Panaiteescu M., Stan, L.C. ANTHROPIC IMPACT WATER QUALITY IN THE PORT MARINE MANGALIA	511
66.	Panaiteescu M., Panaiteescu F.V., Panaiteescu I.I., Panaiteescu V.A. A NEW TECHNOLOGY FOR SHIP HEAVY FUEL OIL SYSTEM	517
67.	Mina Radić, Jovana Arsić, Marija Džaleta, Svetlana Stevović IMPROVEMENT OF ENVIRONMENTAL QUALITY BY SETTING UP THE EXTERNAL VERTICAL GARDEN ON THE EXISTING BUILDING	525

Session VI
QUALITY, MANAGEMENT AND ORGANIZATION
Chair: Rade Ivanković, Slavko Arsovski, Slaviša Moljević

68. **Slavko Arsovski, Zora Arsovski, Miladin Stefanović**
INFLUENCE OF SIZE OF ORGANIZATION AND NUMBER OF
INTEGRATED MANAGEMENT SYSTEMS (IMS) ON ORGANIZATION
OF IMS PROCESSES 533
69. **Rade Ivanković, Zdravko Krivokapić, Đurđica Kučinar**
IMPACT OF PRODUCT QUALITY ON COMPANY PROFITABILITY
BY MEANS OF EXPERT SYSTEMS 541
70. **Biljana Marković**
APPLICATION OF REQUIREMENTS OF INTERNATIONAL
STANDARD EN 9100:2009 IN AIRSPACE INDUSTRY 549
71. **Slaviša Moljević, Dragan Rajković, Bogdan Marić,
Vlado Medaković, Slavoljub Đurđević**
INTEGRATED SYSTEMS MANAGEMENT IN SMALL AND MEDIUM
ENTERPRISES 557
72. **Ljubica Duđak**
PERSONAL MANAGEMENT AND HUMAN RESOURCE
MANAGEMENT – DIFFERENCES 567
73. **Nina Đurica, Maja Đurica, Miha Marić**
THE ROLE AND USE OF INFORMATION-COMMUNICATION
TECHNOLOGY IN HIGHER EDUCATION 577
74. **Vlado Medaković, Bogdan Marić, Slaviša Moljević, Srđan Vasković**
ORGANIZATIONAL MODELS AND DEVELOPMENT GENERIC
TECHNOLOGIES FOR THE MANUFACTURING INDUSTRY 587

Session VII
MAINTENANCE AND TECHNICAL DIAGNOSIS
Chair: Milan Blagojević, Radoslav Tomović, Ranko Antunović

75. **Andreja Ilić, Lozica Ivanović, Danica Josifović, Vukić Lazić**
THE METHODOLOGY ASPECTS FOR MONITORING THE MACHINE
ELEMENTS, COMPONENTS AND SYSTEMS 593
76. **Milan Blagojević, Miroslav Živković, Aleksandar Nikolić**
THE INFLUENCE OF THE DSLR CAMERA SHUTTER COUNT ON
THE ACCURACY OF THE PHOTOGRAMMETRIC MEASUREMENTS 601
77. **Željko Batinić, Zoran Radović, Petar Nikšić, Ranko Antunović**
NEW TECHNOLOGIES AS A FUNCTION OF CONTROL OF
MECHANICAL SYSTEMS 607
78. **Mihajlo Vujičić, Radoslav Tomović**
APPLICATION OF TECHNICAL DIAGNOSTIC IN MAINTENANCE OF
GEOTECHNICAL MACHINES 615
79. **Vojin Vukotić, Dragan Čabrilo**
REENGINEERING OF MECHANICAL EQUIPMENT ON
THE BUCKET WHEEL EXCAVATOR 623
80. **Mitar Jocanović, Velibor Karanović, Đorđe Vukelić,
Darko Knežević, Milija Krašnik**
DIAGNOSTIC EQUIPMENT FOR EXAMINATION PHYSICAL AND
CHEMICAL CHARACTERISTICS OF UTTO, STOU TRACTOR OILS 631
81. **Marko Šolaja, Vladimir Gluhović**
SENSOR SYSTEM ON CHAIRLIFT „OGORJELICA 1“ 641

82. Goran Orašanin, Dalibor Vlaški	PRESSURE MANAGEMENT IN THE WATER SUPPLY SYSTEMS	647
83. Rajko Tanasijević	IMPORTANCE OF MAINTENANCE BY MEANS OF INFORMATION SYSTEM PRODUCTION SYSTEM	655

**Session VIII
STUDENT SECTION**

Chair: Milija Krašnik, Srđan Vasković, Ranko Antunović

84. Zoran Radović, Željko Batinić, Nemanja Prorok, Srđan Vasković	APPLICATION OF VIRTUAL INSTRUMENTATION IN MONITORING OF MECHANICAL SYSTEMS	663
85. Nikola Vučetić	CONSTRUCTIONAL SOLUTION FOR INSTALLATION OF GAS (LPG) ON MOTORCYCLE	673
86. Nikola Vučetić	END OF LIFE MOTOR VEHICLES RECYCLING	683
87. Vladimir Gojković, Ranka Gojković	DEVELOPMENT AND PROSPECT OF NEW HYDROPOWER SYSTEM IN THE REPUBLIC OF SRPSKA	693
88. Vladimir Gluhović, Marko Šolaja	SNOWMAKING SYSTEM ON MOUNTAIN JAHORINA	701
89. Ranka Gojković, Vladimir Gojković	IMPLEMENTATION SOLAR AND WIND ENERGY FOR IRRIGATION OF AGRICULTURAL LAND	707
90. Marina Kondić	APPLICATION OF INDUSTRIAL ROBOT „LIMAT RT 280-6“ IN THE PROCESS OF WELDING	715

INDEX OF AUTORS 723

PRESENTATIONS OF PARTICIPANTS

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PLENARY LECTURES



IMPROVED FAILURE DESCRIPTION IN FORMING OF AUTOMOTIVE SHEET METAL PARTS

Stefan Wagner¹

Summary: During the conventional process reliability assurance of sheet-metal forming processes for the manufacture of car body parts, both in numerical metal-forming simulation and in quality assurance of current series processes, besides the characteristic values of the single-axis tensile test, the Forming Limit Curve (FLC) is used as a failure criterion. Very often, this criterion is an insufficient assessment which can be explained by the fact that with the FLC the failure mechanism of the membrane instability, i.e. the material failure, is only characterized based on the local constriction assuming linear deformation paths (strain paths). In reality, however, for drawing processes with nonlinear forming paths as well as drawing processes with overlaid bending components, the failure mechanisms must take account of the corresponding higher order and exact failure criteria from the preceding feasibility studies. For this reason it is necessary to develop new methods for characterising the formability of sheet metal materials, capable of representing the failure mechanisms and types of technological loading of all process steps.

Key words: Sheet metal forming, bending, cutting, failure criteria

1. INTRODUCTION

The evaluation of sheet metal parts manufactured by metal forming with regard to the influence of the manufacturing process on the material properties is currently mostly limited to a survey of the deep-drawing process. For conventional safeguarding of process reliability, forming processes are characterised according to the established standard based on forming limit diagrams (abbr.: FLD). However, it has been shown that this failure criterion is not used for all metal-forming manufacturing processes used in the fabrication of sheet metal parts, because the only failure mechanism described here is membrane instability (material failure arising from local necking). Next to the drawing process itself, the process chain for manufacturing vehicle sheet metal body parts is composed of forming operations such as shearing, adjusting flanges to 90° or 120°, or calibration operations. Every single one of these production steps has an influence on the condition and formability of the material. The manufacturing influences of these process steps on the material behaviour must therefore also be included in the

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analysis and evaluated holistically. An example of this is material failure of high-strength steel grades, originating from shear-cut edges. A bending failure mechanism also occurs when seaming, folding or bending high-strength steels or aluminium alloys. This failure does not comply to any homogenous, even material stress and cannot be described by conventional methods.

To illustrate this connection, the evaluation methods for component design along the "fabrication of vehicle body parts" process chain (compare Fig. 1) is presented.

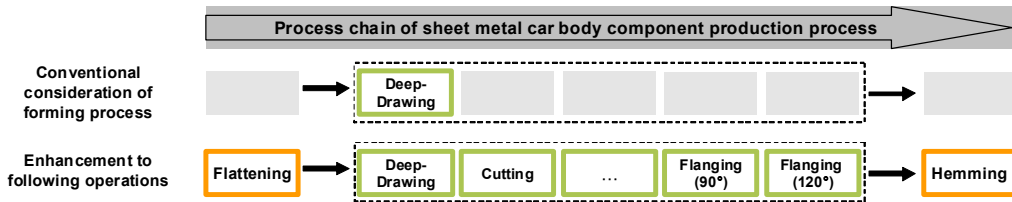


Fig. 1 Metal forming production processes along the process chain

2. CONSIDERATION OF NONLINEAR STRAIN PATHS

2.1 Nonlinear strain paths

As the FEM process simulation of the production of body parts shows, the Forming Limit Curves (abbr.: FLC) failure criterion often leads to an inadequate conclusion regarding the process reliability achieved. Cases exist where the FLC based simulation would have led to an OK assessment, whereas the real part by contrast would have failed e.g. due to cracking (Fig. 2). On the other hand real components are produced without objections, although the results of the FEM simulation based on the FLC would have led to a NOK assessment.

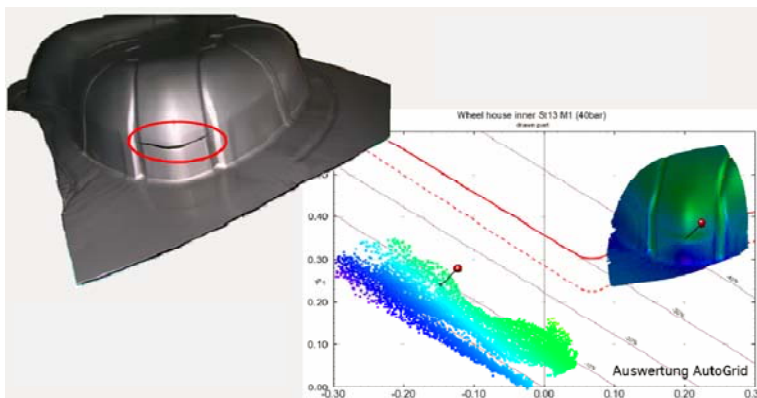


Fig. 2 Difference between FEM calculation and production, part geometry wheel house inner, sheet material St13 (Source: ThyssenKrupp Steel Europe)

The results of single finite elements during the forming simulation (as well as real, measured points within deformation analysis on components) can hereby be mapped and process reliability can be evaluated using their distance to the material-specific FLC. Due to the specific characteristics of the sheet material, the formability depends on the strain of the material or on the applied state of stress and the resulting

state of elongation. The Forming Limit Curve hereby takes into consideration all stress and elongation states that arise during deep-drawing, from uniaxial tensile stress to plane-strain stress and right up to pure stretch-drawing stress.

A linear elongation path, i.e. $\varphi_1/\varphi_2 = \text{constant}$ up to point of failure is assumed in classical FLC. But the true conditions in real sheet metal parts φ_1/φ_2 do not remain constant during forming. Classical FLC can therefore only be used with reservations as the failure line.

2.2 Influence of nonlinear strain paths on the FLC

For nonlinear load paths as they occur in deep drawing or restriking of components made of sheet metal, further consideration is needed regarding material failure. With nonlinear load paths, the position of the FLC shifts depending on the deformation path. As Fig. 3 shows, in addition the shape of the limit curve also changes. A point in the strain space deemed to be permissible under linear conditions may due to a nonlinear load path lead to material failure here on the real component. Thus it is necessary for a holistic process evaluation from a metal forming point of view to recognize nonlinear load paths in the FE-simulation and take these into account accordingly [1].

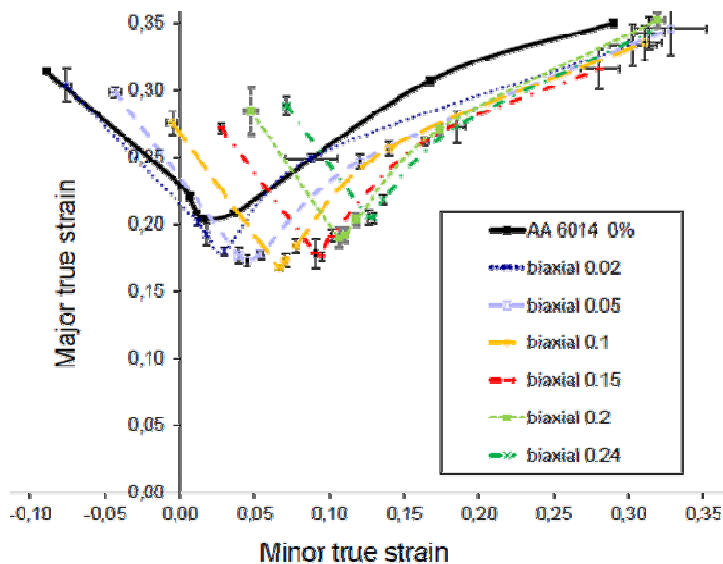


Fig. 3 Shift of the FLC for different biaxial preloadings (Source: IFU/Werber)

2.3 Experimental detection

For this new test pieces have been developed for the multi-axis tension frame set up at the IFU for the optimization and validation of material models, which can be subjected during an experiment to different loading scenarios (Fig. 4).

With the multi-axis tension frame set up it is possible to record the FLC of sheet-metal materials, i.e. in contrast to the Nakajima experiment with a spherical punch, with an almost "infinite radius". The design of the test piece geometry for uniaxial, plane strain and biaxial loading by contrast is simulated. This test piece geometry is currently being developed further at IFU so that the "plane FLC" can subsequently be compared with the conventional standard FLC determined by the Nakajima experiment.

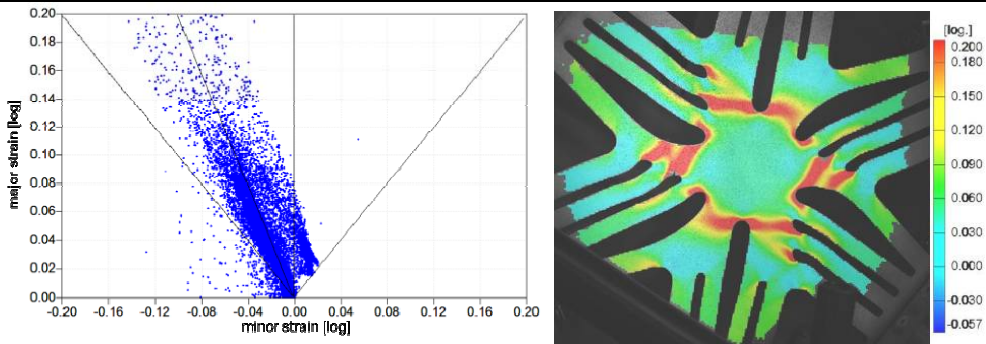


Fig. 4 Forming Limit Diagram and optically evaluated deformation distribution of a hexagonal tensile specimen (Source: IFU/Hönle)

3. CHARACTERIZATION OF THE REMAINING FORMABILITY OF SHEARED COMPONENT EDGES

3.1 Behaviour of sheared edges

As a rule, the raw material for a component to be made by deep drawing is usually a sheared blank. Particularly with high and highest strength sheet-metal materials a higher probability of cracking in the area near these sheared edges can be observed (Fig. 5).



Fig. 5 Cracking of sheared edges (Source: Audi AG)

This behaviour is due to deformation-induced hardening at the sheared edges. Investigations at the IFU were able to show that the zone affected by the hardening may extend up to approx. 2 mm normal to the cut plane (Fig. 6).

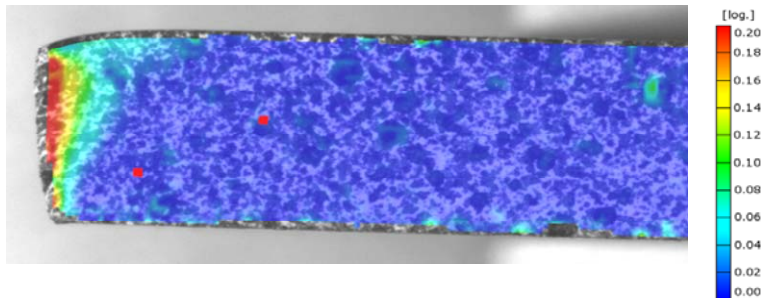


Fig. 6 Affected zone by shearing (Source: IFU/Held)

3.2 New developed test geometry

In this area a reduced formability is to be expected. The sensitivity of the edge cracking behaviour described above can be determined by a specially developed "Diabolo-Test" procedure and in-plane bending test (Fig. 7). To take metal forming operations close to reality into account, nonlinear load paths must also be considered. These findings supply the necessary background for a valid damage model and thus improve the chance of predicting edge cracks.



Fig. 7 New developed »Diabolo-Test« (Source: IFU/Held)

3.3 Forming Limit Curve - Edge

The formability which can be supported by the cut edge is described by the "Forming Limit Curve - Edge" (in short FLC-E) in Fig. 8.

The FLC-E gives an indication of remaining formability at the cut edge which can be measured after the shearing process. Here the maximum attainable deformation for cut edges are calculated from the shift in the conventional FLC, based on the hardening due to the shearing process [2].

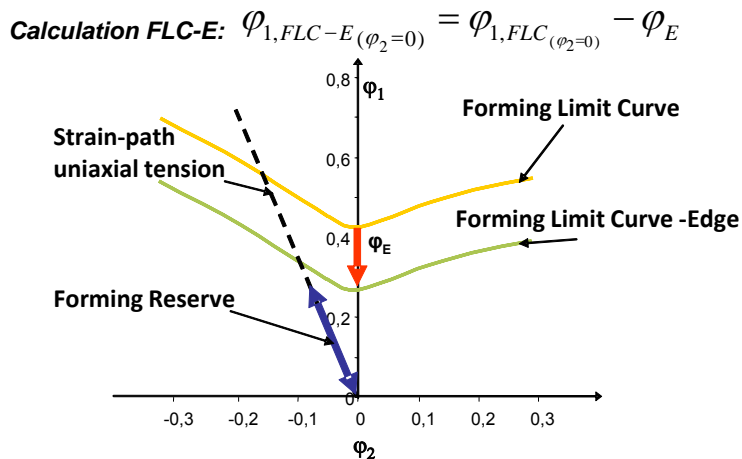


Fig. 8 Calculation of the Forming Limit Curve "Edge" (FLC-E) (Source: IFU/Held)

4. ASSESSING BENDING DOMINATED PROCESSES

4.1 Process chain

The classical material properties for the assessment of deep-drawing processes are only partly suitable for describing the material failure of bending-dominated metal forming processes. The reason for this lies in the different failure mechanisms of bending and deep drawing. The often used Bending Limit Curve (BLC) is based on the assessment of deformation changes at the bending edge. As with the Forming Limit Curve, the Bending Limit Curve describes a critical amount of deformation above which cracking can be expected at the bending edge. Depending on the preceding loading from deep-drawing and stretch-forming operations and the accompanying material hardening, different deformation distributions occur at the bending edge. It can be proved experimentally that the deformation at the bending edge is located with increasing pre-stressing at the bending edge. This is reflected again both in the rise in the maximum attainable deformation as well as in a reduction of the deformation zone during the bending process. In the bending gradient assessment approach, the evaluation of the local increase in deformation change during bending serves as input for the calculation of process reliability.

Besides the need to ensure metal forming reliability over the entire manufacture process, i.e. from deep drawing to joining the outer and inner parts through hemming (Fig. 9), at the same time the demands on the outer appearance of bending and hemming edges are also rising.

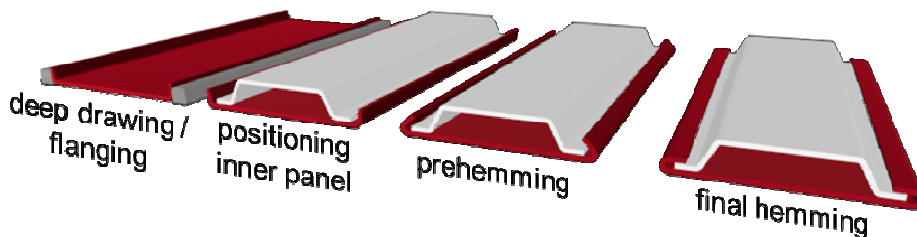


Fig. 9 Schematic illustration of the process chain for producing a hemmed joining
(Source: IFU/Hönle)

4.2 Process analysis of car body parts due to folding operations

First of all, deep-drawing operations as they occur in the production of car body parts will be observed in detail. Therefore it is necessary to focus on the regions (Fig. 10a) that will be hemmed in the following operations. With the use of optical metrology the occurring strains as well as the strain-paths of the deep drawing operation can be visualized and analysed. In the following example, the forming process of a car door will be discussed.

There are various load conditions along the green and red edges shown in Fig. 10. The type of load condition in the deep drawing operation is described by the α -ratio, which is defined as the ratio of minor and major strain values. Corresponding to the measurements shown in Fig. 10b load conditions vary from uniaxial tension ($\alpha = -0.5$), plane-strain ($\alpha = 0$) to biaxial tension strain ($\alpha = 1$).

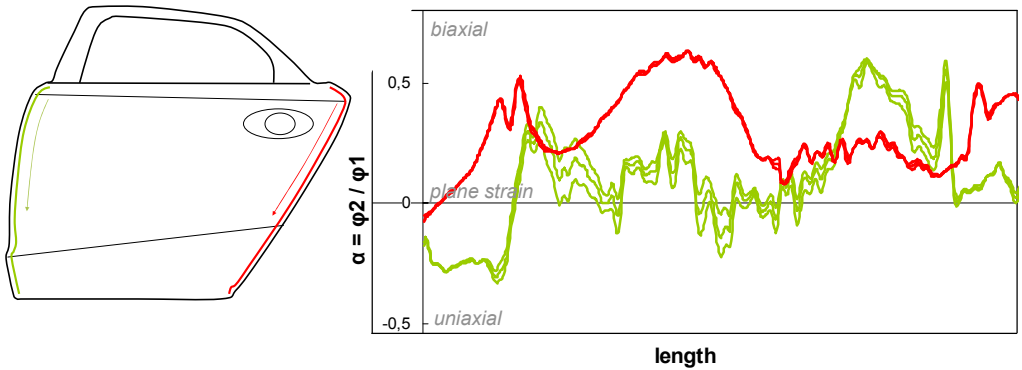


Fig. 10 Typical car door geometry with hemmed edges (left, green and red), Analysis of loading conditions (α -ratio) on hemming edges during deep drawing operation (right) (Source: IFU/Denninger)

The most predominant load during deep drawing seems to be in this case, the plane strain condition and biaxial strain condition. Generally, in bending and hemming operations the dominating load condition is plane-strain. Nevertheless, in bending operations of convex or concave part geometries little uniaxial or biaxial strain can also occur [3].

4.3 Bending Limit Curve

A Bending Limit Curve, (abbr.: BLC), is used to characterize bendability, in the same manner as the FLC is used to describe formability under pure or combined stresses from deep-drawing and stretch drawing. Consideration of the bendability of sheet metal materials caused by tolerable deformations allows the maximum tolerable bending deformations to be applied in the FLD.

Using the bending limit diagram, the process reliability of seaming and bending processes, which occur when adjusting, can be evaluated. This failure criterion can be used both for predominantly bend-forming processes, such as seaming and bending processes, as well as for adjustment processes.

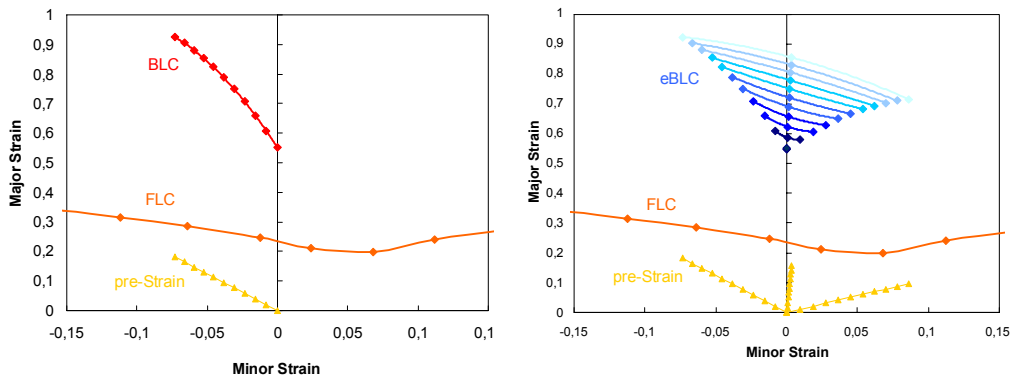


Fig 11 Bending Limit Curve (left) and enhanced Bending Limit Curve (right) for 6016 - Al-alloys, 1.14mm, bending radii 0.4mm (Source: IFU/Denninger)

4.4 Enhancement of the Bending Limit Curve

The original Bending Limit Curve shown in Fig. 11a includes solely uniaxial pre-loads. It is also based on the assumption, that there is homogeneous fracture for all strain paths and that therefore the BLC can theoretical be used for any type of deep drawing load by transforming the pre-strain path. Furthermore, the limits for deep drawing operations, known as Forming Limit Curve (FLC) is included in the diagram for comparison. The enhancement of the existing BLC due to load paths occurring in deep drawn car body parts is shown in Fig. 11b [3].

5. CONCLUSION

The further development of the FLC, FLC-E and BLC evaluation procedures previously presented here is in the combination of both failure criteria into a unified, "combined Forming Limit Curve" (cFLC). This can be used in the manufacturing process of i.e. vehicle body parts, in which the cutting and bending processes are superimposed on the drawing operations, thereby resulting in deformations which exceed the classical limit forming curve (e.g. in the lower dead centre of the press). Depending on the prevailing level of bending, increased formability - in the form of an increased Forming Limit Curve - results by considering combined processes with superimposed shearing and bending stresses (Fig. 12).

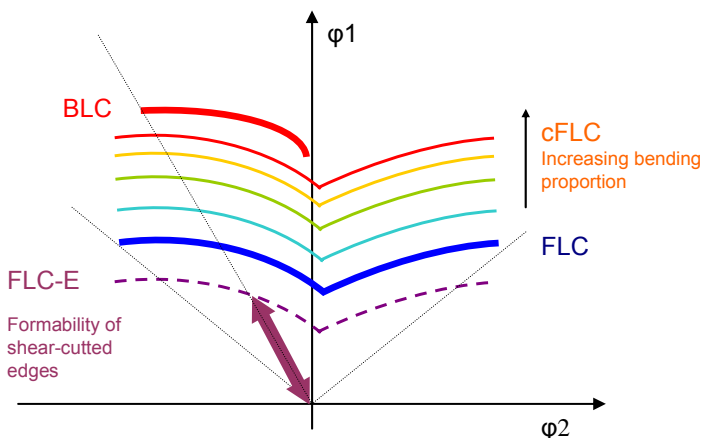


Fig. 12 Forming limit diagram (FLD) with Forming Limit Curve (FLC), bending limit diagram (BLC), shearing edge limit curve and remaining formability (schematic)
(Source: IFU/Held, Denninger)

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CHARACTERISTICS OF NON-INVOLUTE GEARS

Gorazd Hlebanja¹

Summary: The paper deals with a gradual development of S-gears, which can be classified as a non-involute gear type. The primary aim in this context is to develop gears which would be characterized by the convex-concave contact. Such a contact type implies certain features, like lower flank pressure, higher oil film thickness, better sliding circumstances, and lower contact temperatures which are also discussed in the paper. The conducted experiments confirmed these assumptions. The S-shape was used not only for spur and helical gears but for the other gear types as well. And this gradual development led to the alternatively defined gear tooth flank, based on the mathematically defined rack profile. Some alternative gear tooth shape designs are represented in the paper as well.

Key words: non-involute gears, S-gears, convex-concave contact

1. INTRODUCTION

Gears are basic machine elements necessary in accurate power and rotation transmission from a power supply unit to an arbitrary work machine. Uncountable work machines govern numerous processes with a variety of rotational speeds. The pairs consisting of a power and a work machine imply more sophisticated geared transmissions each new generation. Basic development and economic trends lead to:

- an increasing working power of energy supplying machines and demands for working machines;
- a higher rotational speed and variety of speeds of such machine pairs;
- a higher capacity of working machines and automation production;
- an increased power flow;
- higher loads and more demanding working circumstances of such gears;
- gears endurance for the entire life cycle is becoming a law;
- lower vibrations and less noise and uniform running;
- plenitude of production capacities and competition;
- lower prices of gear transmissions.

All above directs to the search of new ways to improve competitive abilities of gear manufacturers, that is improved production methods, automation, and materials. In particular, gears are produced with better tolerances, surface finish and hardness.

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However, the majority of gears is of the involute type, which implies a convex-convex contact with some weak points. So gear tooth shape improvements implying convex-concave contact appear to be a reasonable solution.

2. CURVED PATH OF CONTACT

Charles-Étienne Louis Camus (1699–1768) discovered the basic principles of contemporary gearings [1] in 1733 and independently Leonhard Euler in 1752. Therefore, the condition that has to be fulfilled for a pair of gears to operate is defined by the following: *if, in uniform rotation, power is to be transmitted via a pair of teeth, then the normal to the teeth flanks at the contact point P on the path of contact must pass through the pitch point C* [4], which is exactly the law of gearing known today.

Leonhard Euler (1707 Basel–1783 St. Petersburg) sought the most advantageous shape of gear teeth flanks [2]. He was the first to publish a treatise on the usefulness of the involute for the shape of gear teeth flanks [3], which is in common use today. He also showed how to graphically determine the radii of curvature. Cycloids, involutes and rolling curves can be used to form gear teeth according to the law of gearing.

Gradual development evolved in the perfect, optimal shape of the involute gears which transmit power by the convex-convex contact. However, the intrinsic property of the involute gear is their curvature radius function in the dedendum part when approaching the base circle. Values in general are small and limit to zero at the base circle and therefore imply high contact loads in this area, Fig. 1. Additionally, for gears with low number of teeth the dedendum flank is comparatively short thus invoking excessive sliding and friction losses. Yet another problem is undercutting of the dedendum area. This was why many researchers and engineers sought new solutions and the concave-convex pair appears to be an obvious solution. This is an intrinsic feature of the S-gear shape, which are discussed in this paper.

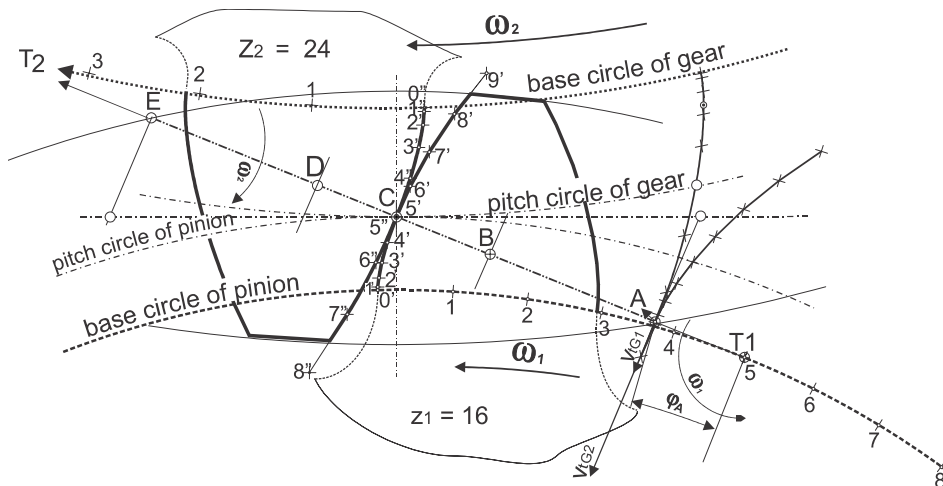


Fig. 1 Circumstances at the meshing start in involute gears

Therefore, the goal was to define tooth flanks of adequate characteristics. This was achieved by the curved path of contact which implied a concave-convex fit of the meshing gear teeth flanks. The path of contact is defined as a set of contact points of the meshing gear pair transmitting rotation, where the above set complies with the law of gearing. The path of contact should warrant sufficiently high contact ratio. The

contact load in the kinematic pole C depends on the pressure angle α_C . The highest limit of the starting pressure angle α_A should be also limited. The sector defined by points A, C, 1, Fig. 2, represents the zone of possible paths of contact. The condition for manufacturing gears of the same module with arbitrary number of teeth by the same tool profile is the half-symmetrical path of contact.

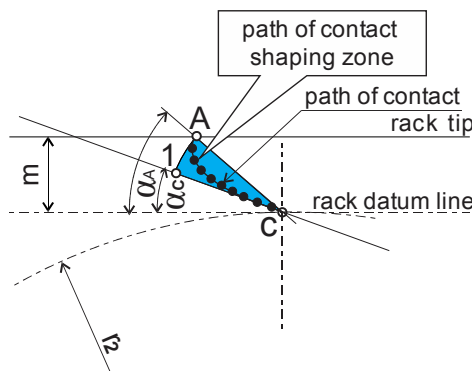


Fig. 2 Path of contact shaping zone [5]

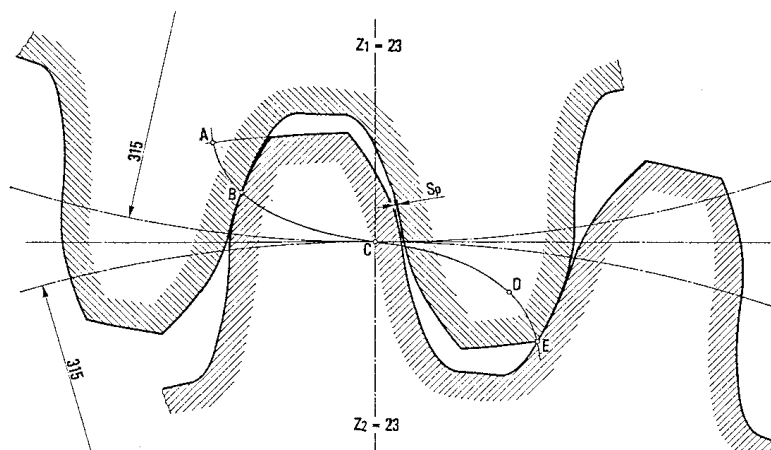


Fig. 3 Industrial implementation [5]

Gears are designed according to their root strength and flank durability. The path of contact shape and the root fillet influence the root thickness. However, the flank shape essentially influences its durability. The most important factors influencing flank durability are the reduced radius of curvature and sliding. The higher radii imply lower Hertzian pressure. The sliding circumstances are essentially improved in the case of convex-concave contact. The research showed that areas of the path of contact with a higher curvature imply lower sliding and higher reduced radii of curvature. Due to necessity of the stronger oil film in the meshing start zone the path of contact curvature in that area should be higher and the path of contact gets a distinctive S-form.

This tooth flank form was used in grooved roller gear for rolling mills. It was installed in Sisak rolling mill. It transmitted 1500 kW at 80 up to 160 RPM. Material was alloy steel 30CrMoV9. The tooth profile is illustrated in Fig. 3. Initially the involute gearing was installed, which suffered severe scuffing in the gear teeth dedendum and addendum areas. S-formed gearing was an essential improvement. This gear form

was also reported in Niemann and Winter's *Machinenelemente* [6].

Successful implementation of such non-involute gears led to additional research which was oriented towards the definition of the S-gear path of contact in such a way to ensure smaller flank pressure, better lubrication and less sliding and which would be linear or almost linear in the vicinity of the kinematic pole C. Fig. 4 represents such a path of contact, with the basic characteristic of gradual increase of curvature towards the meshing start and end and corresponding gear and pinion flanks.

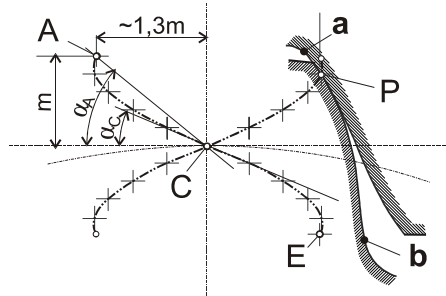


Fig. 4 S-shaped path of contact

In order to make any evaluation of the S-gears they need to be compared to the involute gears. Therefore, typical characteristics have been calculated for both gear types. Since these comparisons should be experimentally verified on the FZG-machine several gear characteristics are adapted accordingly. Both gear pairs and their corresponding data are illustrated in Fig. 5.

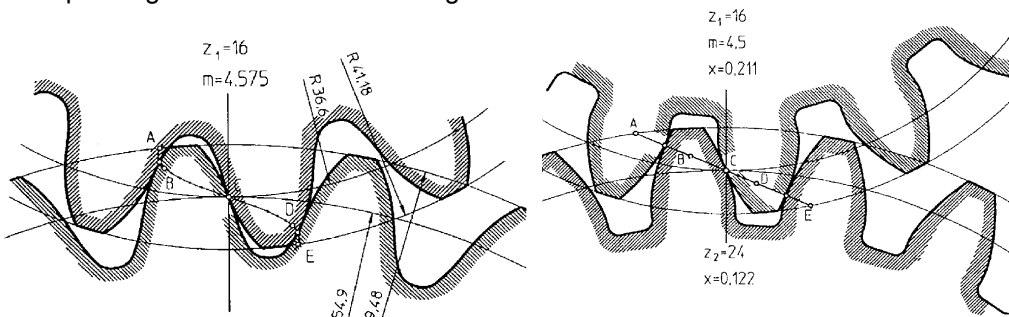


Fig. 5 S- and E-gears for FZG testing

Therefore, S- and E- gears should be compared regarding damages, which might appear during operation:

- fracture due to overloading;
- damages of tooth flanks due to pitting;
- cold and hot scuffing; and
- wear of tooth flanks.

The measure of endurance against tooth fracture is the tooth root stress, which further depends on the tooth root thickness and fillet radius. It was demonstrated in this particular case that the S-gear teeth are stronger in the root, as well as their fillet radius is larger, which also imply that S-type teeth are stronger for approximately 20%.

The contact load of tooth flanks is evaluated by Hertzian pressure σ_H . For cylindrical surfaces we have:

$$\sigma_H = \sqrt{\frac{F \cdot E}{2\pi(1-\nu^2)l}} \cdot \frac{1}{\rho_{red}} = 0,418 \sqrt{w \cdot E'} \cdot \sqrt{\frac{1}{\rho_{red}}} \quad (1)$$

However, Hertzian pressure may not exceed maximal allowable limit σ_{Hdop} . The contact force F , the tooth width l and the reduced radius of curvature ρ_{red} are those design parameters which decisively influence gear durability. The calculated values for Hertzian stress σ_H are represented for both gear types on Fig. 6. It should be pointed out that the Hertzian pressure and the pressure angle α_C in the kinematic pole C are equal for both gear types.

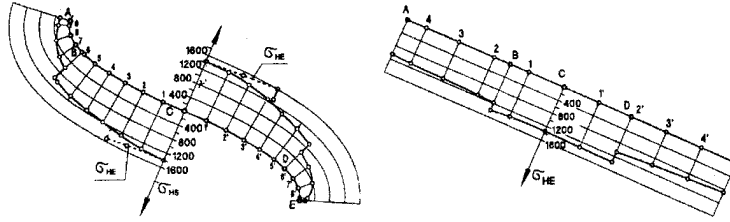


Fig. 6 Hertzian pressure for S- and E-gears

The measure of endurance against damages of tooth flanks is oil film thickness h_o , which is defined by the Dowson-Higginson's equation [7]:

$$h_o = 1,6 \cdot \alpha^{0,6} \cdot \eta_0^{0,7} \cdot E^{0,03} \cdot w^{-0,13} \cdot \rho_{red}^{0,43} \cdot u^{0,7} \quad (2)$$

Factors in this equation are α – pressure coefficient of oil; η_0 – dynamic viscosity; E – module of elasticity; w – line load of teeth, i.e. F/l ; ρ_{red} – reduced radius of curvature; and u – sum of relative velocities. Having equal loads of S- and E-gears, equal lubrication means, the same rotational speeds and equal gear materials, the only remaining parameters influencing the oil film thickness are the reduced radius of curvature ρ_{red} and the sum of relative velocities u . Both parameters have better characteristics for the S-gears (i.e. higher relative velocities, higher reduced radii of curvature) and therefore imply better lubrication and thicker oil film. Fig. 7 represents velocity circumstances in the vicinity of the meshing start and meshing end points.

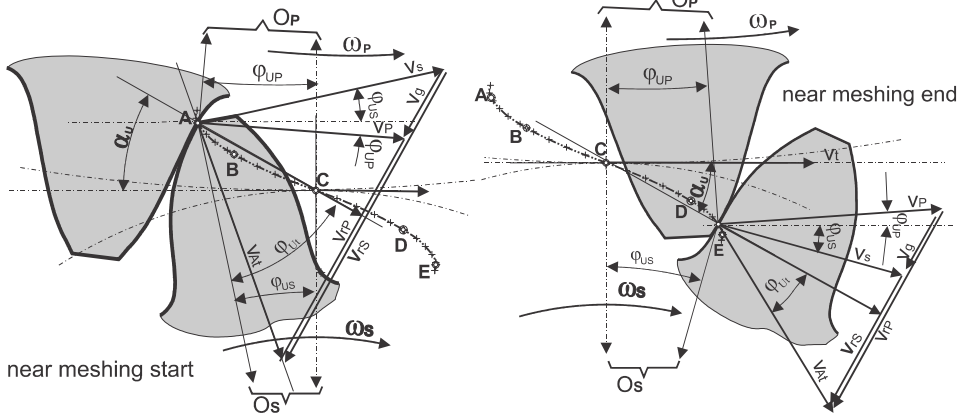


Fig. 7 Velocities in meshing start and end areas for S-gears

Yet another important issue is a temperature characteristic of a meshing gear pair. Blok's temperature concept [8], represented in Eq. 3 is adopted here.

$$\vartheta_{fl} = 0,62 \mu w^{0,75} \left(\frac{E'}{\rho_{red}} \right)^{0,25} \frac{|v_{rS} - v_{rP}|}{\sqrt{B_{MS} v_{rS}} + \sqrt{B_{MP} v_{rP}}} \quad (3)$$

Symbols in the equation are: ϑ_{fl} – “flash” temperature; μ – friction coefficient; w – contact load (line load); ρ_{red} – reduced radii of curvature; v_{rS} , v_{rP} – relative velocities of

the flanks in contact; B_{MS} , B_{MP} – property of material; $B_M = \lambda \rho c$, where λ stands for thermal conductivity, ρ for material density and c for specific heat. The friction coefficient is given by [6]

$$\mu = 0,12 \cdot \left(\frac{w \cdot R_a}{\eta \cdot u \cdot \rho_{red}} \right)^{0,25} \quad (4)$$

where additional factors are u – sum of the relative velocities and R_a – average surface roughness. Fig. 8 illustrates behaviour of the flash temperature along the path of contact. It can be observed that the flash temperatures tend to be comparatively smaller in the meshing start and end areas for the S-gears.

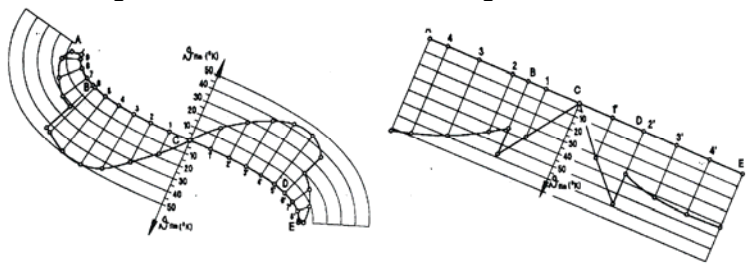


Fig. 8 Flash temperatures along the path of contact for S- and E-gears

3. EXPERIMENTAL WORK

Theoretical assumptions have been verified by experiments, which have been conducted in order to examine endurance against:

- pitting of tooth flanks
- scuffing of tooth flanks
- surface heating, wear and efficiency

Table 1 Data of the gears used in experiments

	Designation	S-gears		E-gears	
Module	m_n [mm]	4,575		4,5	
Number of teeth	z	16	24	16	24
Coefficient of the profile shift	x	-	-	+0,233	+0,12
Kinematic circle diameter	d_w [mm]	73,2	109,8	73,2	109,8
Pressure angle in C	α_c [°]	22		22,438	
Face width	b [mm]	20		20	
Centre distance	a [mm]	91,5		91,5	
Rotational speed	n [min ⁻¹]	2100	1400	2100	1400

Experimental work has been carried out on a FZG testing machine, so values for the module and the centre distance were adapted accordingly. The selected material was alloy steel 42CrMo4, which was heat treated to 28-30 HRC prior to toothing. Experimental lots comprised (a) hardened and tempered gears “V” and (b) hardened, tempered and plasma nitrated gears “NV”. Technical data of gears are

collected in Table 1.

Experimental results with regard to pitting are summarised in Woehler digagrams, Fig. 9. Results indicated that the load capacity for hardened and tempered S-gears was slightly increased, whereas for hardened, tempered and nitrided S-gears the load capacity was bigger as that for E-gears. However, more experiments would have been necessary.

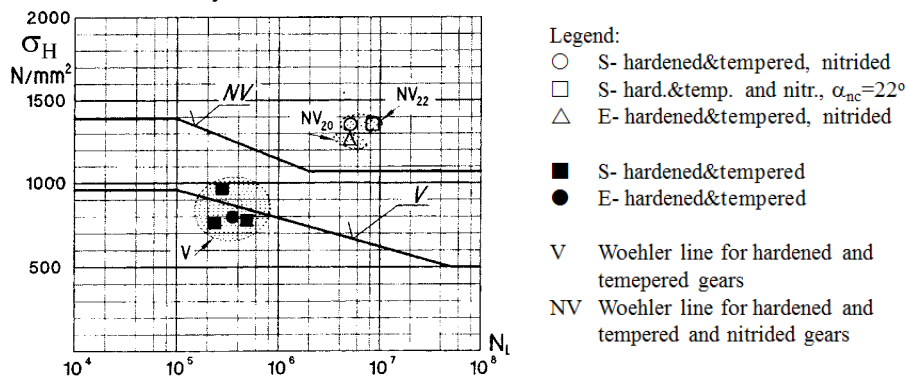


Fig. 9 Wöhler diagrams of the pitting experiments

Hardened, tempered and nitrided S- and E-gears have been tested with regard to scuffing. Experiments were conducted according to the load levels prescribed by DIN ISO 14635-1 [9]. E-gears exhibited scuffing damages of the addendum part of the flanks already at the load level 11, whereas S-gears did not have damages even at the level 12. Oil ISO VG 100 without additives was used in both cases. Gears have been lubricated with gears dipped into the oil. The oil temperature in the casing was 90°C in both cases. Each loading level lasted for 15 minutes. The oil temperature in the casing during this time increased due to friction losses of the operating gears. Measurement of temperatures clearly indicated that oil in the casing was less heated in the case of S-gears, which implies that losses in this case were lower. The difference in the temperature increase between S- and E-gear type was approximately 10%.

Wear of gear tooth flanks was determined during the pitting tests by weighting gear pairs on a precision balance. Weighting was conducted before and after experiments for both gear types. The experiment on the FZG loading level 9 lasted 4x10⁶ rotations of the pinion. Results are summarised in Table 2. It can be concluded that the wear of S-gears is approximately half of that in E-gears, which can be attributed to the thicker oil film. More information can be found in [10].

Table 2 Wear of S- and E-gear flanks

Gear type	Load level according to DIN 51354 (DIN ISO 14635-1)	Wear [mg]		
		Pinion	Gear	Sum
S-	9	17	16	33
S-	9	15	8	23
E-	9	41	21	62

4. PROTOTYPES AND MODELS

Design work with the S-type path of contact, which was first used for spur gears, continued in the direction of other gear types in order to explore their usability

[11]. Such gear types are:

- helical gears
- crossed helical gears
- ZS worm drives
- internal S-gears for planetary gear trains

Working prototypes or models were produced for the each type, as revealed from Fig. 10.

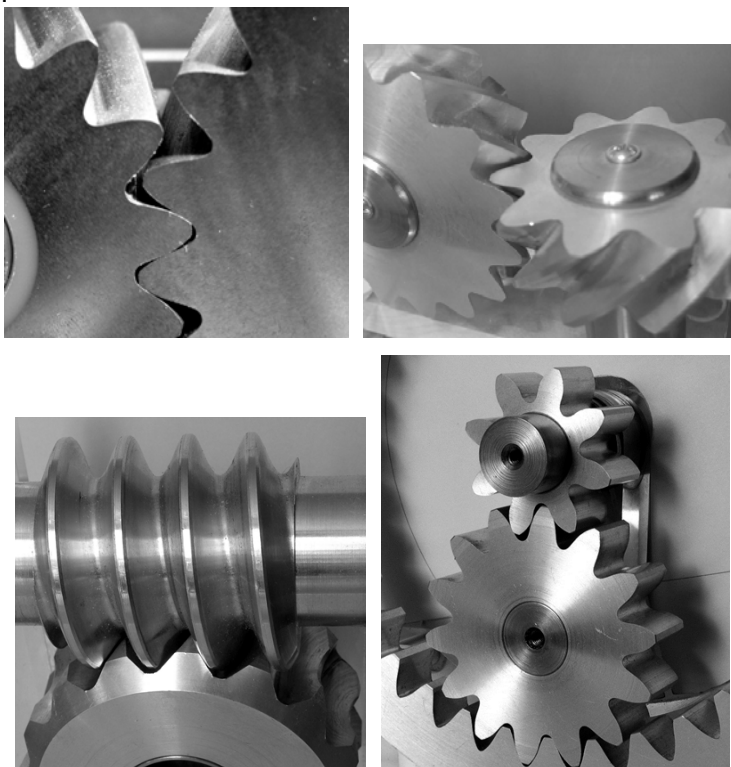


Fig. 10 Working models for various S-type gearings
(a) helical; (b) crossed helical; (c) ZS worm drive; (d) planetary arrangement

5. RECENT DEVELOPMENT

ZS- worm drives have been designed and produced to adapt an industrial housing and then run with and without load to discover possible damages on the worm gear. Positive feedback led to another proposal, that is cylindrical worm-gearings with a progressively curved shape of teeth flanks, the so called parabolic worm gear drives [12], Fig. 11. The proposed approach in cylindrical worm gearings design is based on the mathematically defined worm tooth profile in the worm axial plane, wherefrom the worm gear tooth profile derives and profiles in any parallel plane can be calculated and in this way teeth flanks are defined. The primary feature of the proposed teeth flanks is their progressive curvature and continual concave-convex contact. Worm and worm gear meshing of such an arrangement generates better lubricating oil film, resulting in better EHD lubrication conditions, therefore reduced energy losses and lower wear damages are anticipated. An experimental worm-gearing loaded under working conditions verified theoretical considerations. Computer simulation also confirmed contact theory of the proposed gearing.

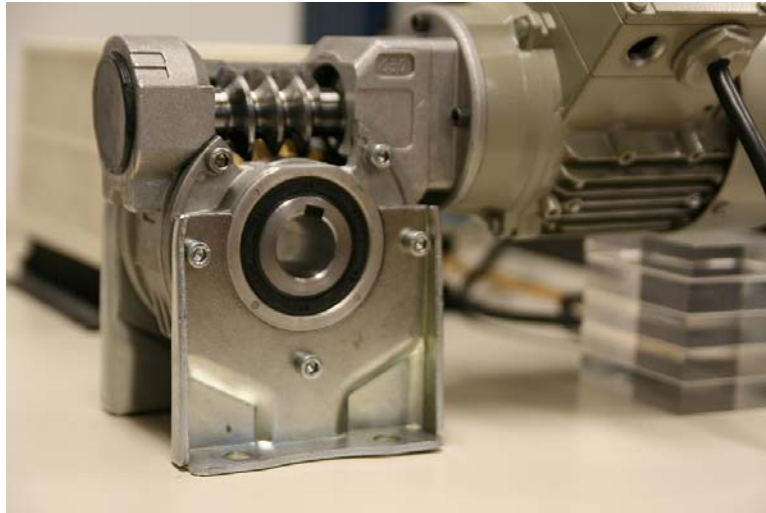


Fig. 11 *Parabolic worm-gearing – industrial housing after an observation window had been cut off*

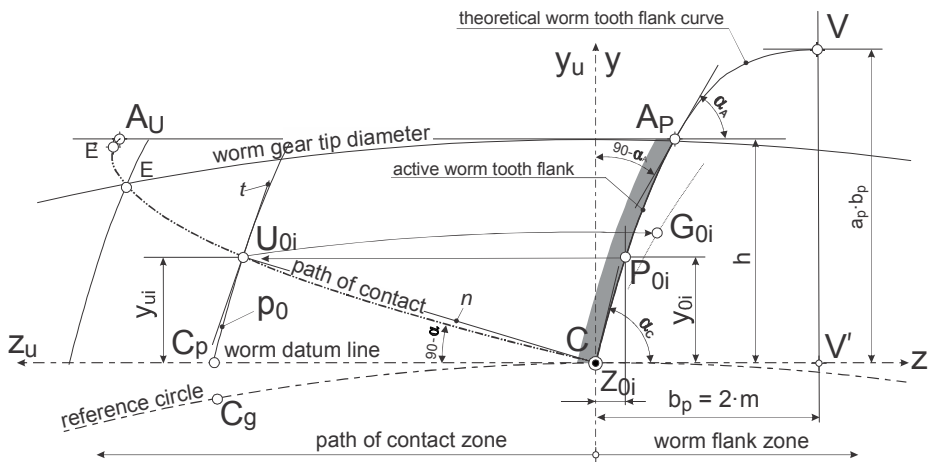


Fig. 12 *Worm tooth basic profile and the corresponding path of contact in the axial section*

An another interesting approach is a new version of WN gears [13] which are illustrated in Fig. 13. According to this proposal, the tooth flank profile is comprised of three circular arcs, with the first arc forming the addendum; the second one forming the dedendum; and the third arc forming the intermediate section, which prevents the flanks from touching as they rotate around the kinematic pole C. The advantage of this solution is a simple flank geometry, which is easier in terms of tools, while the relative rotation of one gear vis-à-vis its pair is similar to the movement of the shaft in the bearing. The essential element of the UPT gears is the absence of the pitch line and the gear-teeth contact in the transverse plane. In addition, there is no sliding between the teeth flanks in the transverse plane. Power is mainly transmitted by the rolling of the teeth flanks at both

contact points, with the simultaneous sliding of the teeth flanks around the pitch point C. The contact load is divided into two contact points. Better lubrication conditions can be expected as a result of the thicker oil-film thickness and lower heat generation. And the most important features of the UPT gears are non-intermittent sliding and power transmission. These features indicate that UPT gears can be used with heavy loads in non-stop operating condition, for example, in the power transmission of wind turbines, gear units for refinery services, and similar applications.

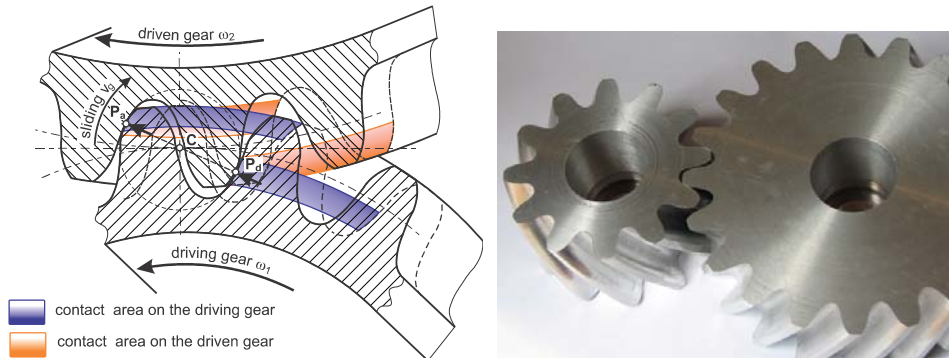


Fig. 13 Illustration of the contact areas
UPT gear pair with $m_n=5$ mm; $z_1=12$, $z_2=20$



Fig. 14 S-gears defined from the rack profile
material: alloy steel, $z_1=10$, $z_2=30$, $m=1$ mm

The necessity to define a cutting tool contributed to the development of the S-gears where gears are based on the definition of the basic rack tooth profile. The latter is defined by a mathematical function. According to the fundamental law of gearing for each point P_i of the base rack profile a single point U_i on the path of contact is assigned and based on that a unique point G_i on the gear tooth flank is defined. Such a gear pair made of alloy steel is photographed on Fig. 14. The basic rack profile is defined as an analytic curve, Eq. (5):

$$y_{P_i} = a_p \left(1 - (1 - x_{P_i})^n \right) \quad (5)$$

In this way we have a clearly defined cutting tool and arbitrary gears defined through this rack profile by proper coordinate transformations. The size factor a_p and the power factor n can also be optimised in order to achieve required results, e.g. ticker

root, or the size of convex-concave area, as it can be seen from Fig. 15. The diagram shows how the change of vital parameters influences the path of contact, gear and pinion tooth flank shape and the rack profile.

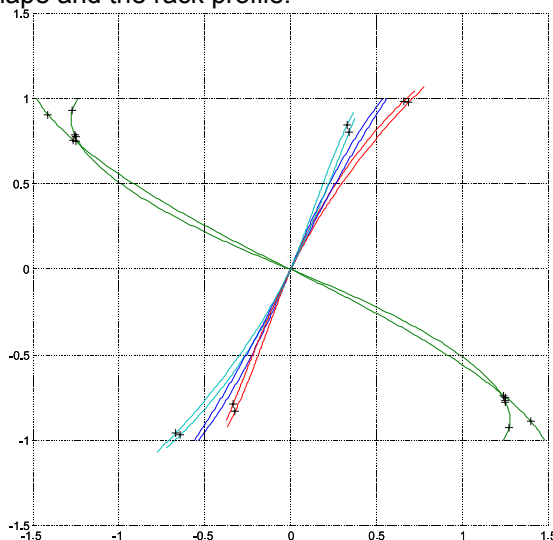


Fig. 15 *Influences of parameter changes on gear and path of contact shapes*

The crucial characteristics of the S-gears can be summarised by the following statements. The mating gears exhibit convex-concave contact in the vicinity of the contact start and contact end. The minimal teeth number of S-gears can be as low as four. The S-gear tooth flank profile assures higher comparative curvature radii, and thus lower contact load and higher relative velocities of the contact surfaces which imply better lubrication. Due to their S-shape, the velocity characteristics of mating gears are improved, especially in both external areas with high relative velocities and low sliding velocity. The meshing start zone in involute gears represents potential danger of micro-pitting, whereas S-gears exhibit advantage in this context due to the thicker oil film in this area, which diminishes possibility of damage. Another important feature of the S-gears is more evenly distributed contact point density, which causes lower sliding and less power losses. The dedendum flank of pinion is not substantially smaller as that of gear addendum even for low number of teeth.

6. CONCLUSION

Let us conclude this paper with some advantages of the S-gears and their differences from the E-gears.

The S-gears have higher root strength, which is due to thicker teeth in the root and bigger fillet radius. A higher strength of flanks can be also attributed to the S gears due to their convex-concave contact, implying lower Hertzian stress. Due to convex-concave contact and high relative velocities in the meshing start area the thicker oil film forms there, preventing scuffing and makes tip relief in S-gears unnecessary. Thicker oil film implies less wear, lower losses and better efficiency. For many common applications nitriding may be sufficient procedure, which makes special heat treatment and subsequent grinding unnecessary. S-gear gaps are thinner, which implies less cut off material. The contact point density of the S-gears is more evenly distributed, which causes lower sliding and less power losses.

However, the acting force varies in accordance with pressure angle deviations

along the curved path of contact, which is dissimilar to the involute case. The centre distance depends on the number of teeth and the module. The profile corrections are limited in comparison to the E-gears. And due to the curved path of contact there is some sensitivity to centre distance deviations. However, quite many industrial applications incorporating gears with the curved path of contact ran successfully for many years. An attempt has been made to construct the path of contact with a small linear part in the vicinity of the kinematic pole C. And even for the path of contact without such a linear segment it can be observed, that its mid-part near C is almost linear.

We can also state that the S-gears are new, without routine production experience and standards and with little practical experience. However, already mentioned advantages make author believe that this gear type can be a successful substitute for involute gears for diverse applications, like gear-boxes for wind power-plants [16] on the large scale and miniature plastic gears for domestic appliances.

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DEVELOPMENT OF A HAND-HELD VIBRODIAGNOSTIC INSTRUMENT

Aleksandar Veg¹, Emil Veg²

Abstract: A portable hand-held vibro-diagnostic device (Roto-Balance®) is the target instrument to be developed. Market search shows a lack of such devices in the range of powerful yet affordable devices. This paper describes a true engineering approach in developing a novel vibro-diagnostic instrument. Target configuration consists of conventional hardware and software, composed in a synergistic manner to meet both simple and also demanding technical requirements. Outcome of such an approach is appearance of a completely new class design in vibro-diagnostic family. Substantially, it is a user friendly, compact and well equipped device for a wide range of applications in a low budget category.

Key words: vibrodiagnostic, hand-held instruments

1. INTRODUCTION

A brief survey of the market niche in vibro-diagnostics reveals a wide range of competitive devices. Some of them are highly sophisticated, some are rather simple but each one is applicable for appropriate purpose.

SKF offers their Microlog, as shown in Fig. 1.

Model: AX

Processor speed: 400 MHz

Storing capacity: 32 MB (optional SD Card)

Operating autonomy: Six hours

Sampling rate: 40 kHz

Lines density (FFT): 12 800 lines

External communication: USB communication

Screen: LCD 320 x 240 pixels (54 x 72 mm)

List of functions: conformance testing, frequency analysis, speed tracking, temperature measurement, Bump test, Multi plane balancing, Route measurement, Orbit determination



Fig.1. Microlog

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SPM offers their Leonova, as shown in Fig. 2.

Model: Diamond

Processor speed: 400 MHz

Storing capacity: 32 MB (optional SD Card)

Operating autonomy: Eight hours continuous operation

Sampling rate: 20 kHz

Lines density (FFT): 12 800 lines

External communication: USB communication

Screen: LCD 320 × 240 pixels (54 × 72 mm)

List of functions: HD Order tracking, Time signal, Post trigger, Run up Coast down, Bump test



Fig. 2. Leonova

Minibalancer by Hofmann, as shown in Fig. 3.

Model: MC1100

Processor speed: 40 MHz

Storing capacity: 12 MB (optional SD Card)

Operating autonomy: Four hours continuous operation

Sampling rate: 20 kHz

Lines density (FFT): none

External port: RS232

Screen: -

List of functions: Overall vibrations, Rolling bearings condition, rotational speed detection, Early detection of failures, Temperature mea.(Optional), Adjustment and check of belt tension (Option)



Fig.3. Minibalancer by Hofmann

2. TARGET FEATURES OF THE DEVICE TO BE DEVELOPED

Distinctive name

The name of the device must be common, meaningful and familiar to all. Among vast of symbolic names a combination of “Rotational” technique and “Balancing”, is composed into acronym Roto-Balance®. Moreover the font of the Roto-Balance® logo is selected to be remarkable and specific.

Prominent visibility

Modern technology of handy screens made a revolution in clearness, brightness and contrast of displaying, either at day or night. Therefore true graphical dual PLED (128x64), sharp imaging display is used in Roto-Balance®, to provide an outstanding visibility of graphs and alpha-numerics, regardless the ambient illumination.

Indicative keypad

Keypad symbols are selected and organized in such a manner to support smooth and intuitive cruising through different functions in either simple or expert mode. Ergonomic key disposition enables single hand operating, while the swift software allows rapid typing and mode shifting.

Plain speed tracking

Among different kinds of speed and phase tracking options, an enhanced strobe methodology is selected. Main cause for the use of strobe tracking is that rotor marking is unnecessary. Unlike any other speed tracking methodology (photo cell, proximity switch, etc), one just need to approach running rotor, spot the strobe light on it, adjust flashing rate and read the speed. An innovative ultra efficient LED and hyperbolic lenses are used to improve light source brightness. On the other hand ultra short electric spikes at extremely high current rate, economize power consumption. Accuracy of the speed reading is as high as 0.1 RPM within the range 150 – 120.000 RPM.

Understandable balancing procedure

Main goal in developing Roto-Balance® was to design a powerful device for the widest range of possible users, particularly regarding their schooling background. Feeling of comfort and confidence in utilizing Roto-Balance® is extremely important. Therefore the new convergent methodology of corrective angle and mass finding is developed and patented. It consists of trial weight placement and then one to three clearly defined consecutive corrections and placements until the final state of balance is achieved.

High autonomy of operation

One of the most important properties of a portable measuring device is operating autonomy. Combination of strong, capacitive batteries and low power consumption promote Roto-Balance® into a supreme class of reliable instruments.

Demonstrative human interface

Roto-Balance® core advantage over similar instruments would be simplicity in operation. Novice operators become familiar with Roto-Balance® operating without boring study of hundred pages large Operating Manual. Concept of intuitive cell phone like manipulation is taken as imperative in Roto-Balance® human interface programming.

Cluster of expert functions

In order to develop a device of dual level operation (Simple and Expert), its Digital Signal Processing board is capacitive enough to fulfill appropriate technical demands. Furthermore, the extended functions, like XL FFT measurement, Start up/Coast down Log and routed data collect are the specific functions which require higher processing speed and more storing space. Therefore the performance of the DSP board is optimized both by its capacity and price.

Routed machine train measurement

To ease a mnemonic selection of predefined routes, typical machinery trains are configured in a graphical form. Thus the access to the machine train is significantly accelerated both for a new measurement and also for measurement recall. Operator simply chooses the appropriate machinery configuration and then within a second can start measurement or review measured data. Each machine train, at all prominent points inherently offers measurement of: vibration RMS value over three principal axis (horizontal, vertical, axial), dominant spectrum tones, bearing status and surface temperature.

Data transferability (Bluetooth module)

Site measurement is usually concluded with a final reporting either in a paperback form or electronic archiving. To facilitate that usually boring operation a Bluetooth connection to PC is incorporated into Roto-Balance®. Herewith a true communication with a desk top PC is established, enabling data import-export to a predefined reporting templates, data bases and trend reviews.

Remote operation (PC + Bluetooth)

To protect the operator of risky measurements in harsh area (high temperature, noisy space, strong air stream, etc.), a useful mode of remote operation is developed. Bluetooth communication with the adjacent PC enables distant steering of the Roto-Balance® from the safe place.

Perceivable information of vibration severity

In the sense of rapid recognition of machinery status Roto-Balance® performs a true conversion of vibration severity into a traffic light indication in accordance with ISO 10816-1. Recommended operating limits for different quality grades are translated into three color (level) graduation (green, yellow, red) which explicitly indicated how smooth machine runs.

Intuitive handling

A serious study on the convenience of device handling marked the general principles of the Roto-Balance® commanding. According to these guidelines the steering software is created.

Handy size and slim line

Regularly robust and large instruments are difficult to use. Therefore Roto-Balance® is developed in a handy size with an ergonomic shape.

3. Roto-Balance® DESCRIPTION

Roto-Balance® is a utilizable, handy, site balancer having prominent features in signal analysis and data collection. However, Roto-Balance® comprises both SIMPLE and EXPERT operating mode allowing either novice or mastery expert to benefit from its vibro-diagnostic abilities. Extensive information on the vibration severity is available solely in a single key press. Roto-Balance® identifies the machine health, detecting (ISO proposed) vibration velocity in a comprehensive form of RMS or a set of dominant spectral tones.

In the blink of an eye the complete picture of the machine health is accessible. Furthermore one can review a signal vs. time graph (oscilloscope arrangement) as well as a table of dominant spectral harmonics.

Strobe light tachometer simply catches RPM in the range of 150 to 120.000 RPM.

Site balancing is performed implementing an original methodology, based on a transition from an initial, gradually to a final, ISO acceptable, unbalance vector.

In EXPERT operating mode a routed data Log is available. Set of typical machine configurations (Drive unit – Gear box –Coupling – End device) is preprogrammed as a core frame for data collection. A train of successive steps rolls out as a guided route through the prominent machine points and their principal axes (Horizontal, Vertical, and Axial). Once the route is completed, data package is stored at

one of 50 available memory locations, ready to be transferred to a PC and reported. Data set can also be used for the post event analysis.

Main features:

- True graphical dual PLED (128x64)
- Intuitive SIMPLE or EXPERT operating mode
- Full compliance with ISO 10816-1
- Vibration severity prompt identification G /Y/ R - LED bar
- Rolling Bearing - instant health detection
- Protection Rating IP65
- pre-routed Data Log
- Data transfer via Bluetooth protocol
- Strobe light tachometer
- Rapid, easy and accurate site balancing

Simple operating modes:

- Strobe speed detection
- Vibration severity measurement
- Bearing noise detection
- Site balancing
- Contactless temperature measurement



Fig. 4 Roto-Balance®

3.1 Strobe speed detection

A stroboscope, also known as a strobe, is an instrument used to image a cyclically moving object to appear as stationary or slow-moving.

First step in strobe speed measurement is placement of a bright marker on the rotational part while it stays at rest. The alternative is to recognize a prominent spot on accessible, rotating surface. For the precise measurement machine must run steadily at the rated speed. Strobe light should be pointed towards the rotor. Two different buttons are available for flashing speed adjustment. They are used to trim the picture image stationary. Another application of these buttons is to slide the phase of “the frozen picture”. Hereby, index marker might appear at 12 o'clock, or any other prominent position. Certain problem arises when the strobe frequency is a half of the rotor running frequency. In that case rotor appears also stationary, with a single marker, but detected speed is inappropriate. Therefore a special button is deployed to double the strobe frequency instantly. By that, the confusion, whether the frequency is right or not is efficiently solved. If the image, at doubled frequency stays single marked, then the doubled frequency is actually the right one. If the image appears with two opposed markers (180° angle between them), then the adjusted strobe frequency was right.

When the operator freezes the image by the trimmed, proper strobe frequency, actual speed can be easily read on the display of the Roto-Balance®.



Fig. 5. *Improper strobe frequency*



Fig. 6. *Proper strobe frequency*

3.2 Vibration severity measurement

After having the accelerometer connected and placed on appropriate spot, Roto-Balance® offers following measurements.

Internal band-pass filters are instantly set with properly detected rotating speed. Thus the device promptly acquires vibration severity as an RMS value. In accordance with ISO 10816-1, vibration severity is indicated by the color LED column. Green bar indicates A domain (for the selected quality grade), yellow bar indicates B/C domain, and the red bar indicates D domain. This LED bar is useful for the novice operators in vibro diagnostics and corresponding ISO standards. [1]

The lower display simultaneously shows signal versus time or frequency spectrum. When set into frequency mode, Roto-Balance® performs the FFT (Fast Fourier Transformation) analysis and presents seven dominant spectrum tones.

3.3 Bearing noise detection

Bearing failure is one of the foremost causes of breakdowns in rotating machinery. Such failure may have a catastrophic outcome, resulting in costly downtime. One of the key issues in bearing prognostics is defect detection at its incipient stage and alert warning before it develops into a serious failure.

For the assessment of the rolling bearing, the same source of the signal, accelerometer, is used as for the vibration severity. [3][2] After selecting mode of bearing noise detection, Roto-Balance®, overtakes acceleration signal and calculates its envelope (1st and 2nd tone extracted) Also the acceleration power factor [dB] is calculated, referred to the nominal noise level. Separate LED bar is available for bearing health indication. Green bar shows the noise level below 20dB, yellow bar shows the range 20 – 35 dB and red bar turns on when noise exceeds 35dB.



Fig. 7. *Bearing noise detection*

3.4 Site balancing

Rotor unbalance appears when its axis of rotation and axis of inertia do not coincide. Axis of rotation is determined throughout the process of manufacturing, while the axis of inertia is defined by the symmetry of all body particles. Process of balancing consists of two stages: first - unbalance vector detection and second unbalance vector correction either by mass remove or mass deposit at the appropriate position.

Roto-Balance® provides unbalance vector measurement in order to reduce it below the ISO recommended value for the appropriate quality grade. Throughout a few iterations the device leads operator to the right size of the correction mass and corresponding angle of placement.

Set of data needed for the successful balancing involves: rotor speed, revolving direction, vibration severity, and phase angle.

For the proper angle calculation, Roto-Balance® must “know” the sense of rotation. This info supplies operator via keypad. The operator also marks the prominent index point on the shaft or rotor body prior to balancing.

Running speed is measured at the machine steady operation (procedure explained in the former section).

After having speed determined, and the signal from the accelerometer, Roto-Balance® performs an initial unbalance vector measurement. Result of that measurement is shown in the figure 8.

Next step is a trial mass placing, followed by a new unbalance vector measurement.

When STROBE beam is on the running rotor index image appears at an arbitrary angle. It is advisable to slide it into a prominent position (for example 12 o'clock) and keep that reference all the time of site balancing.

The size of the correction weight is trimmed throughout the balancing. Sometimes increases (> 100%), sometimes decreases (< 100%), compared to the size of the trial weight. The correction angle is displayed numerically and graphically.

New angle is referred against the current position of the weight. (NOT INDEX POSITION OR STARTING POSITION). [4]



Fig. 8. *Initial unbalance vector*



Fig. 9 Trial weight placement on the rotor



Fig. 10. New measurement in process ("frozen rotor", index, correction mass)



Fig. 11. "frozen" picture in the 12 o'clock position



Fig.12. New unbalance vector measurement

3.5. Contactless temperature measurement

Besides a pure detection of vibration severity, it is also important to know whether the machine works within the proposed temperature range or not. Usually the increased temperature indicates a strange behavior, more often an upcoming failure. Therefore the list of Roto-Balance® functions is appended with contactless IR temperature measurement. IR module provides information of surface temperature up to 200°C.

Distinction between IR emissions of different surfaces is made by a simple selection of the most appropriate material from the list. Thus the surface temperature.



Fig. 13. Temperature measurement

List of EXPERT MODE FUNCTIONS

- **Extended data log (FFT)**
- **Start up / Coast down record**
- **Machine train record**
- **Remote operation from PC (Bluetooth communication)**
- **Data transfer and reporting (Bluetooth communication)**

3.6 Technical specification

Roto-Balance® is basically featured on a dual processor concept. DSP board operates as a slave unit, while the user interface is at a master level. Thus the DSP operates in the background, regardless the current communication towards user. It is equipped with the 16 bit ADC, providing adaptable sampling rate (14KSps – 140KSps) and digital anti-aliasing filter. Operating speed is 20 MHz, with a 16kb Cache memory.

Master unit operates at 7.37MHz (4kb Cache, 512kb Flash). Two ultra-bright PLED displays (128x64), Black/amber at 16 level grayscale, deliver distinctive graphic and alpha-numeric information to the user. Blue Tooth communication enables wireless data transfer and reporting.

Four NiMH rechargeable batteries provide energy supply to the instrument. [5]

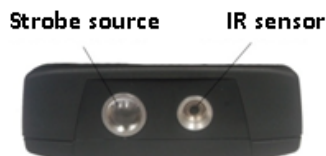


Fig. 14 Top view

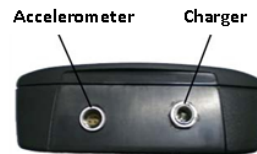


Fig. 15 Bottom view

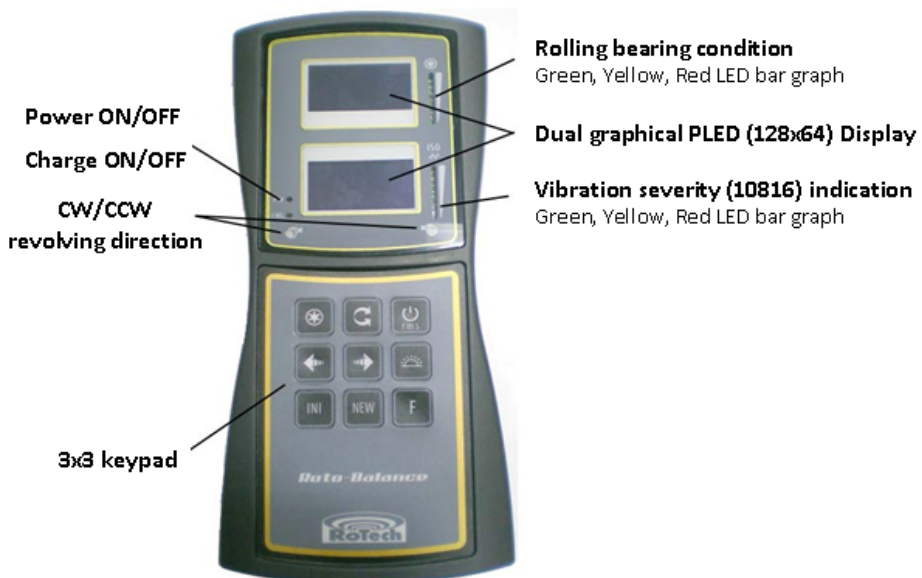


Fig. 16. Front view

4. CONCLUSION

Prior to engineering and design work in developing a portable hand-held vibro-diagnostic device the target scope of modes, functions and the instrument outlook are very carefully outlined. This analytical approach in specifying desired features facilitated the subsequent efforts in searching for the best possible performance. Experimental phase in developing prototype significantly expanded product to market time, but the technical demands and appropriate standards are strictly defined for this class of product. Operational evaluation of the product went much easier, however Roto-Balance® showed an outstanding attractiveness for novice users, while experienced ones appreciated simplicity and effectiveness of the invented device. Finally market verification came with the first lot of purchased instruments. Briefly, the complete project of research, development, design, engineering and marketing of the new vibro-diagnostic device turned into extremely successful arrangement. Due to courtesy of RoTech company, which financed the research project, this market niche is enriched with the new class instrument.

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TECHNICAL SYSTEMS DEVELOPMENT TOWARDS TO ACTUAL TRENDS AND METHODOLOGY IN ENGINEERING DESIGN

Milosav Ognjanović¹

Summary: The actual situation of product development is in the great contradiction. Methods and tools for product development are at the high level but exist the lack of the new products at the global level. One of the main reasons for latent and permanent economic crises is the lack of the new products. The article trays to explain this lack by discussion of fulfillment of the three postulates responsible for product development.

Key words: Product development, Engineering design, Technical systems

1. INTRODUCTION

The actual trend in product development is characterized by products with high quality of action with the same principle of action which existing in the course of long time. Existing various very productive and high level methodology and tools for product development, but also existing the lack of number of developed new products. It is obvious that methodology is not enough for this purpose. The objective of the article is to identify this contradiction and try to predict the future product development.

Product development methodology and prediction of the future trends supporting the TRIZ approach [1]. The TRIZ initiate effective solutions of problems and supporting breach of cognitive barriers. This approach contains various tools and methods for this purpose. Prediction of product development methodology and product development itself are analysed in references [2] and [3]. The first analysis is based on the state in the science and technology analyse, including past and the future. Analysis in reference [3] is based on at the articles published in the Journal of Engineering Design. This analysis shows the picture of the trends in products development and in methodology for product development. References [4] to [8] shove approaches in design methodology development. Article [4] discusses possibility, structure and organization of integrated approaches in design, vertical and horizontal. The strong source of ideas, principles and solutions is biological systems. Biomimetrics [5] or bionics is approach with the objective to transform biological solutions into technical. Articles [6-8] discusses various aspects of product development such as ethnography, emotion and sustainability. The special methodology, property based design is

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suggested in reference [9]. The last three references [10-12] contains the author contributions to identification of the trends in the past and future product development [10], actual methodology for gear transmission units design [11], and the postulates identification and their responsibility analysis for product development [12].

2. ACTUAL SITUATION AND TRENDS

The global actual situation is characterised by economic crises which in latent form prolongs in the course of long time. It is very known that economic prosperity is result of production and of market activity. It is also known that the global industry is in stagnation and at the market is noticeable lack of the new products. The wheel of the global economy, slowing down, permanently. Investments can't find opportunity in production which can guaranty the profit and better employment. The world economy is based on the automotive industry which also slowing down because the market is saturated by this products. The real question is why the lack of the new products exists in the period with expansion of methods and tools for product development. The answer is complex and contains some of the facts which it is necessary to recognise. These are the meaning of the new product and what it is necessary to be fulfilled for product development, except methods and tools.

In order to identify what does it mining the new product, in Fig.1a is explained the term innovation. The lowest level of innovation is variant solution based on existing principles and technology. The higher level contains the new principles for existing functions of products or technologies. The highest level is invention which implies the new function, the new structure and product behaviour. This discussion in the term of "new product" implies this level of innovation. In Fig.1b are presented five levels of innovations, more precisely comparing to Fig.1a. The first two levels corresponds to innovations in the form of variant solutions, the thread to the new principle and forth and fifth to invention.

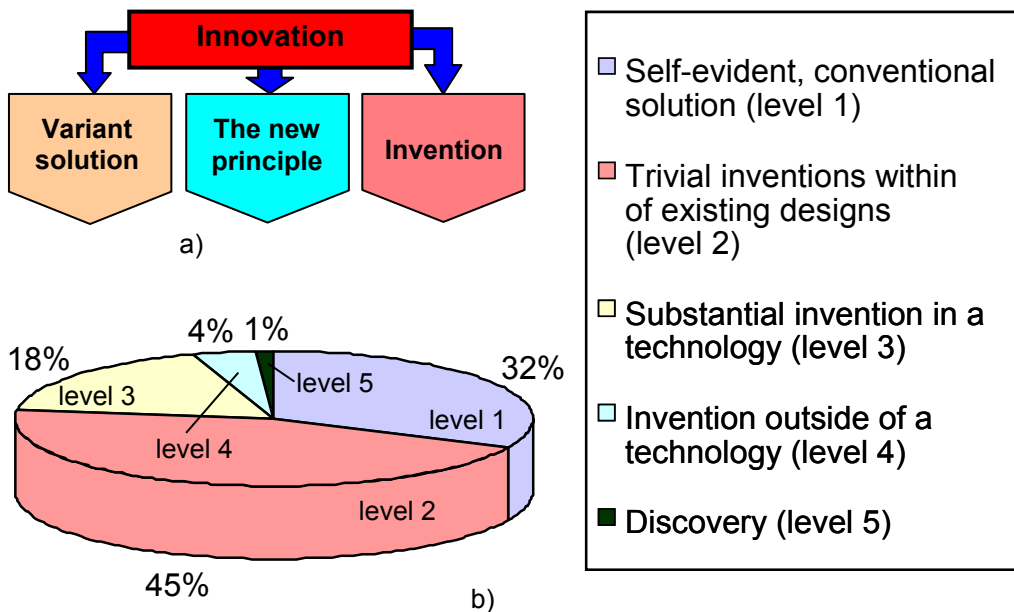


Fig. 1 Types (a) and levels (b) of innovations

Statistics presented in Fig.1b shows that in the actual situation products have the same principles and from generation to generation increase quality. Existing technical (mechanical) systems acting in the form of mecatronic systems and integrated with software systems. Typical example is structure and principle of action of modern cars. These are mecatronic systems supported by software systems, but the basic principle of action wasn't changed but the quality of action is significantly increased. This is actual trend in product development. It is no innovations of fourth and fifth level. Increase of existing products quality are innovations inside of existing principles. This are not result of the science level increase, this is result of technology level increase. Some of the new technical systems, for example mobile telephone or digital computer are based on scientific discoveries old more than one century. Thanks to technological progress.

3. METHODOLOGY AND TOOLS

Search for product development methodology was start in the second part of 20th century. Market competition and industrial companies' survival couldn't depend on personal skills and creativity. At the beginning it was search for methods for idea generation for the new products. In 1970 – ties the procedure for engineering design of mechanical systems is standardized and then started period of expansion of the new methods and tools. Computer development very strongly supported this activity. All efforts are spent to increase quality level of existing products. For this purpose it was necessary to integrate the knowledge from various scientific and technological areas. Existing products got multidisciplinary and methodology for the purpose of those products development had to be integrated. This is horizontal integration which include development of mechanical sub-systems, electronic sub-systems, software sub-systems, etc. (Fig. 2a). Teams for these products development are connected in the nets (Fig. 2b) and can be distributed all over the world, thanks to World Wide Web net.

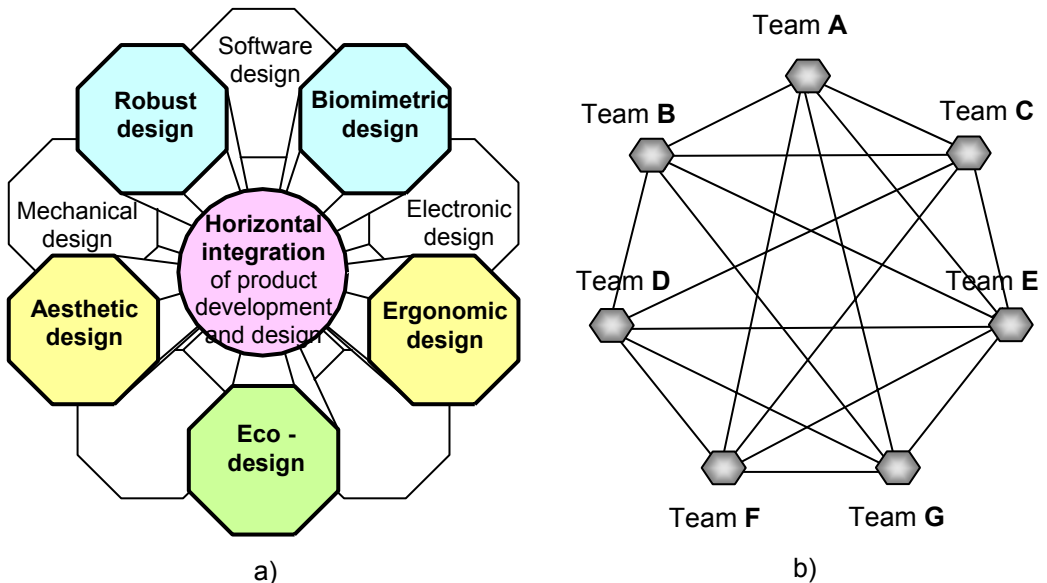


Fig. 2 a) *Horizontal integration of design process*
b) *Global network in horizontal integration*

In the meantime of methodology and tools development, various methodologies are raised in order to increase design efficiency. These are based on vertical integrations of activities, personality and the flow of information. The most known approach in this sense was Concurrent (simultaneous) engineering. Virtual approaches also supported these objectives.

Some of the design methods which have dominant position are method of robust design and method of axiomatic design (Fig.3). These are the groups of various approaches with the same objective. Robust design methodology have objective to provide unsensitive values of design parameters (Y in Fig.3b) with variation of parameters of service conditions X. In Fig.3a that design constraints important for design parameters DP definition, can be arranged according to expected service conditions. Also functional requirements FR have to adapted to service conditions. Axiomatic design presents the group of methods for analitic transformation of Functional requirements FR into Design parameters DP or reverse. Members of transformation matrix [A] can be defined by Design constraints which are in relation with service conditions and ther variation or randomness. Presented corelation provides robustness of design parameters of mechanical system components.

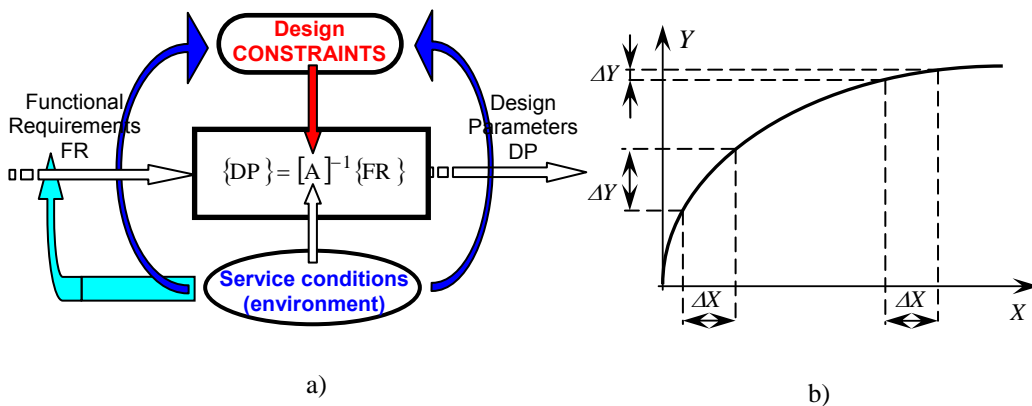


Fig. 3 Robust and axiomatic design a) Design constraints identification
b) Design parameters robustness

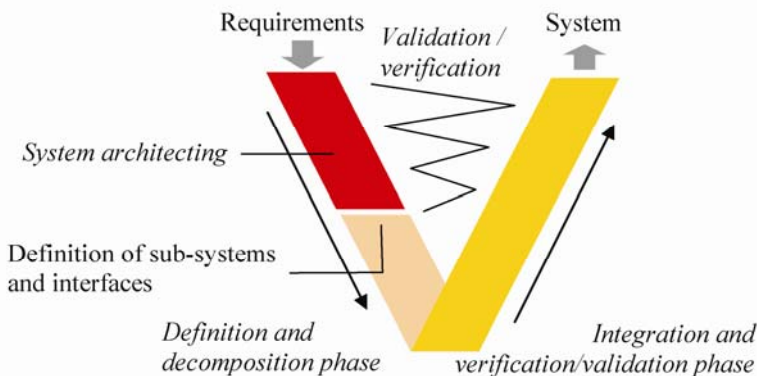


Fig. 4 V-model of technical systems development according to VDI-2206

For the purpose of the technical system development, the new model of this process is standardised by VDI-2206 (Fig.4). The model contains the system architecture deduction in order to identify structure components and component properties. Then follows design parameters definition according to necessary properties and constraints (Fig.3a). The system integration (Fig.4) contains composition of the system components and properties in order to provide expected (desired) system behaviour and indicators of system quality. Property based design method is very compatible to this model [9].

It is important to mention the TRIZ methodology which trays to lead product development and design process, methodology and tools development and other connected activities. Product (technical systems) functions, structures and behaviour research and innovation are actual activities. The TRIZ methodology is in this course with the objective to design the future situation in technology and society.

4. SCIENCE AND TECHNOLOGY

According to previous analysis it is obvious that high level of methods and tools is not enough for expansion of product development. It is necessary to be fulfilled all three postulates for it. These are, except high level of creative methodology and tools, to have scientific discoveries and inventions, and as the third one, the new power sources. **Nanotechnologies** are in harmony with expected new scientific discoveries which can support new technical systems development. Technical systems will be more and more similar to biological systems, and nanotechnologies will provide identification of biological principles and their transformation into technical principles. Apart from development, nanotechnologies will support significantly the increase of the level of knowledge for this purpose, i.e. increase of the level for scientific postulate fulfillment. **Fusion energy sources** are one of the main potentials and challenges for expansion of new product development in the future. Present energy sources based on mechanical power have numerous disadvantages (low quantity, ecological disturbances, high cost, etc.). Expected new energy sources as well as sources based on fusion principles can change the situation. Energy in unlimited quantity with necessary properties can change the existing principles of technical systems (principles of transportation, material processing, etc.) and avoid transformation of all of them into mechanical in order to be applied. In this way, postulate of the new power sources will be fulfilled in the quantitative and also in qualitative sense.

Fulfillment of postulate of scientific discoveries or inventions and postulate of the new energy sources, will not come true in the next short time. The next period will have a very slow trend of product development, economic stagnation and latent global economic crises. In the meantime we can expect increase of social tensions and wait for changes. After a long time of expectation for postulate fulfillment, resource potentials for product development will significantly increase. These are new energy sources, new areas of technology, and new and successful approaches in technological and scientific creativeness. Significantly increased potentials can produce expansion of the new products. This means to brush away the existing products with the new ones and to produce industrial and technology revolution. The wave of the new products can be basically with different principles. Mechanical era of technical products can be replaced by biological or similar. Every sudden change and replacement of technical systems disturbs economic and social and natural environment. This needs to be a special area of global human interest, i.e. it needs to be ready when the wave of the progressive potentials rises. Social progress without great disturbances will be provided by spurring of this wave and subsequently by skilful navigation and control in order to escape inconveniences.

5. CONCLUSION

Actual situation shows the lack of the new products at the global level. In the local area existing confusion in the mining of the term the new product and absence of product development in the past. The term of the new product is explained using the six levels of innovation. Furthermore development of the methods and tools for product development is presented. Actual methodology for product development is also presented. The reason for the lack of the new product, regardless to high level of design methodology and tools, is explained. The lack of the new scientific discoveries and inventions, and the lack of the new power sources. Fulfilment of all three mentioned postulates can provide expansion of the new products. Actual product development and high level of existing product quality is result of high level of technology.

6. ACKNOWLEDGEMENT

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INVITED PAPERS



INVESTIGATIONS IN DEVELOPING A NEW GENERATION OF MACHINE TOOLSS

Ljubodrag Tanovic ¹

Abstract: *The paper presents an overview of investigations in the area of developing a new generation of machine tools intended for machining the components of up to a few mm size, of high precision and of a variety of materials. The first part outlines some of the novel and recently developed micro-manufacturing machines in the world, while the second part gives the results achieved in the micro-cutting of stone- and ceramic-based brittle materials. Also, a part of the results realized within the current projects at the Faculty of Mechanical Engineering, Chair of Production Engineering, is presented.*

Keywords: *miniaturization, micro-cutting, machine tools, processes, tools*

1. INTRODUCTION

Micro-manufacturing encompasses the creation of very high dimensional and form precision products made of various materials with feature sizes ranging from a few microns to a few millimeters [1]. It all started in the late 1980's by the development of Micro-Electro-Mechanical Systems (MEMS). An exponential growth in the demand for miniaturized components that are characterized by small dimensional and form features, function, reduced energy consumption, design flexibility, high accuracy and superior performance in sectors such as defense, medical, biotechnology, telecommunications and energy has fuelled a widespread interest in micro-manufacturing in both R&D institutions and industry worldwide [2]. Hence, micro-manufacturing is rapidly evolving in response to a growing demand for miniaturized products frequently manufactured in low volumes and characterized by complex geometry and high surface finish. Some industrial micro-manufacturing systems are presented in Fig. 1.

Miniaturization has all the prerequisites to become a leading technology of the 21st Century, which is supported by the facts:

- a) Annual R&D expenditures for this area by industrialized countries has been in billions of dollars in recent years and the trend for more investments continues to exponentially grow in the foreseeable future, with engagement of the major R&D institutes and faculties.
- b) Manufacturing of miniature engineering systems and devices in micro and nano scales will be a dominating economic factor of the development of

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- society in the period to come.
- c) There will be imminent paradigm shifts in the transformation of the traditional manufacturing technology to physical-, chemical-, biological-oriented processes. Industry and educational institutions need to be prepared for such shifts.
 - d) Countries that do not transform their process industry and educational system from traditional to miniaturization oriented processes and products will not be able to valorize economic benefits of such industrial revolution in our history.

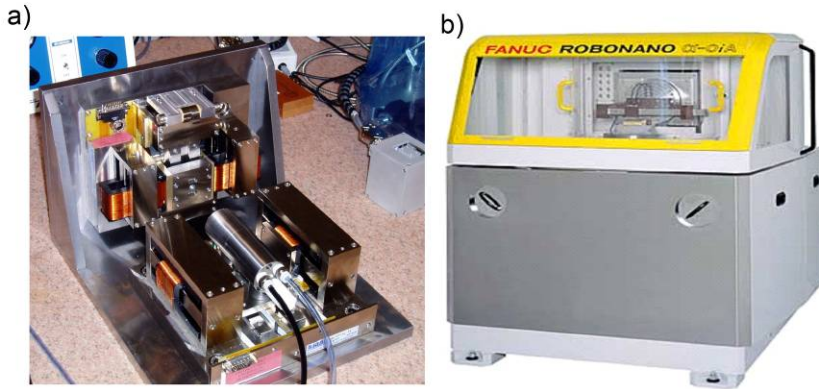


Fig.1 . a)2nd Generation 3-Axis mMT; b) 5-axis Robo-Nano (FANUC)

There is an ever increasing demand by industrial sectors for the production of miniaturized components that are characterized by minimizing energy and materials used for the manufacturing process, integration with electronics, simplifying systems, cost/performance advantages, faster operation, increased selectivity and sensitivity, exploitation of new effects etc.

2. MICRO – MACHINING SYSTEMS

Micro-machining systems can be broadly classified into four main categories: subtractive, additive, near-net-shape and hybrid systems [3,4].

- a) Subtractive systems encompass micro-mechanical machining (turning, drilling, milling and grinding), micro-electro discharge machining (EDM), micro-electro-chemical machining (ECM), micro-focused ion beam machining (FIB).
- b) Additive systems include selective laser sintering (SLS), stereo lithography (SLA), I 3D printing processes.
- c) Near net shape systems comprise micro-rolling, micro-casting, micro-injection, micro-extrusion and the other.
- d) Hybrid systems combine two or more conventional micro-manufacturing processes. The objective is to enable the machining of hard materials, or to improve machinability and higher process accuracy.

It is possible to define the micro-machining process from two viewpoints:

First viewpoint

- Micro-machining is the collection of all cutting operations that are performed on micro/meso- scale components and products that fall into the 100µm to 10mm size range.
- Micro-machining is characterized by the requirement of producing high accuracy complex geometric features in a wide variety of materials in the above-defined size range.
- Micro-machining requires the use of downsized tooling (micro-tools in the 50 to 500 µm diameter range), small chip thickness (submicron to a few microns) and speed settings (50000-200000 min⁻¹).

Consequently, the main difference between macro and micro-scale cutting is the dominance of slipping and ploughing over shearing and the need to necessarily consider micro-structural effects.

Second viewpoint

Definition of micro-machining from the standpoint of the chip thickness value is possible to categorize as follows:

- Macro-scale machining. Operations are performed at conventional regimes at thickness values that are larger by an order of magnitude than the cutting edge radius, hence dominated by shearing, and for which micro-structural effects can be neglected. The values of chip thickness are larger than 10µm.
- Micro/meso scale machining. These operations are characterized by the dominance of ploughing, rubbing, plastic and elastic deformation effects due to the fact that the tool's cutting edge is approximately on the same order as the chip thickness value. The values of chip thickness fall into the submicron to a few microns range.
- Nano-scale machining. This term is commonly associated with ultra-precision machining by single point diamond tools that have the possibility of sharpness without tool edge radius or with very low radius, so that the chip thickness value can fall in the nanometer size range.

3. MICRO-MACHINING PROCESSES

A large number of researchers dealing with developing a model of deformation and fracturing regarded the interaction between the cutting tool and the workpiece as being identical in a number of ways: the indentation effects caused by a diamond indenter during hardness measurements, through the cutting process itself, the analysis of cracks development and through the real machining process.

The first group of researchers performed indentation with a diamond indenter as in hardness measurements and considered the material behavior through cracks occurrence. These researches go into two directions: by how the force acts during the indentation (dynamic and static) and by the effects of the indenter's shape.

Lawn and Wilshaw [5] think that fracture patterns in brittle materials, under blunt indenters, usually develop due to the presence of cracks immediately outside the contact zone. By increasing the normal load, these surface cracks evolve into the so-called Hertzian cone cracks (Fig. 2).

Anton and Subhash [6], unlike the traditional static indentation models, which

cannot capture the strain rate effects, consider that the current dynamic indentation provides a more realistic representation of the influence of loading rate on the material removal mechanisms during a dynamic process.

Lawn and Swain [7] performed indentation with a sharp indenter (cone and pyramid) and found that an embedded penny-shaped crack is increased so that its propagation reaches the surface and assumes the radial configuration.

The second group of researchers, though to a lesser extent, performed the cutting process in a variety of materials by a single diamond grain.

Mishnaevsky [8] performed the real cutting process in brittle materials and observed the mechanisms involved in material destruction (deformation, crushing, cracking and spalling). He considers that neither Hertzian cone cracks nor circumferential cracks are formed. Instead, penny-shaped cracks in the cutting force vector direction are formed.

Chiaia [9] provides a system analysis for the current approaches to the issues of micro-cutting processes in brittle and quasi-brittle materials. It was shown that various interaction mechanisms beneath the tools during the penetration process are essentially reduced to plastic deformation and brittle fracturing.

The third group of researchers analyzed the crack formation and development in brittle materials.

Labuz et al. [10] studied crack formation in granite and concluded that micro-cracking develops around the crack tip covering the fracture process zone and together with the fracture free length defines the effective crack length (Fig. 3).

Abe et al. [11] investigated the formation and proliferation of cracks in granite and their effects on the fracture process zone.

The fourth group of researchers performed the real cutting and grinding processes and analyzed the crack formation and chip brittle fracturing mechanisms. They measured the cutting forces, the cutting strength and tool wear in ceramics and granite with the aim to recommend the efficient abrasive machining [12,13].

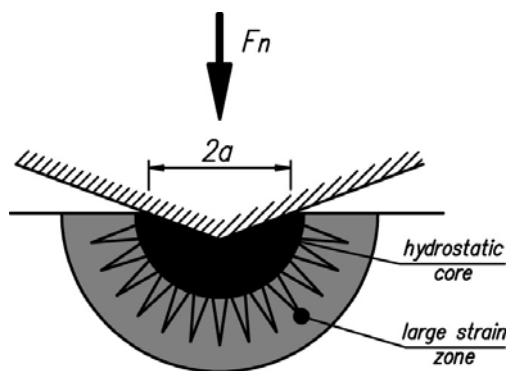


Fig. 2 Indentation of brittle materials: formation of the large-strain zone



Fig. 3 Schematic illustration of crack system produced by Vickers indentation

3.1 Chip formation mechanism

The micro-cutting experiments performed on brittle materials and the observations of the generated traces show the presence of median/radial and lateral cracks, ductile flow, chipping along the groove, and crushing beneath the diamond grain (Fig. 4). The appearance of individual traces can be associated with ductile flow followed by crack formation. Median cracks are the result of the diamond grain penetration, while lateral cracks are initiated during unloading in the vicinity of the plastic zone. The tangential force increases tensile stresses perpendicular to the direction of the grain's penetration, leading to the proliferation of some lateral cracks and their evolution into radial cracks that occur on the ceramic's surface itself. The formation of thin-dispersive chips can be explained by the ceramic grains crushing phenomenon that occurs ahead and beneath the diamond grain [14,15].

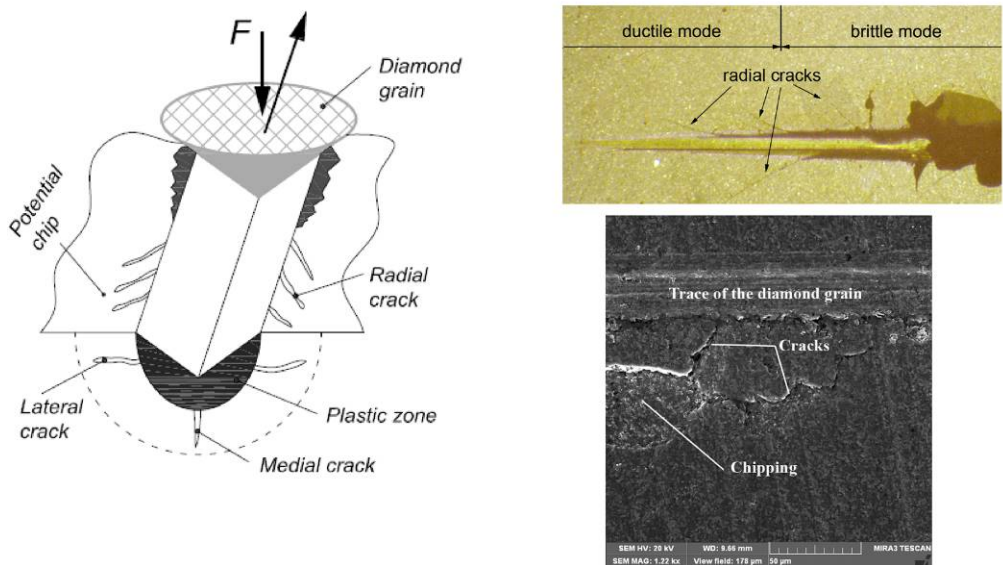


Fig. 4 Illustration of the chip formation process at indenter's motion

In the brittle material micro-cutting two regions are evident. They can be defined by the grain penetration depth (critical depth) that restricts the region of plastic deformation followed by crack formation from the region of fracture-induced detachment of the machined material. The critical depth can be used as one of the criteria for the grinding process optimization.

4. CONCLUSION

The paper shows some trends in the development of novel micro-manufacturing machines used for machining a broad spectrum of products from metals, polymers, ceramics etc. Machining systems of a new generation are a basis for the manufacturing technologies development in all branches of industry. Currently, the industrial production of such machining systems requires the solution to a large number of issues related to stacked axes, large moving masses, limited acceleration, need for ultra-high-speed spindles, inaccurate micro-tools and low inaccuracy. In addition, there is not yet a well defined theoretical framework for the cutting process

mechanism in micro scales, which is different from views of the macro-cutting theory. This refers to both brittle and non-brittle materials. At the Faculty of Mechanical Engineering the project 'Development of a new generation of domestic machining systems' is under way. It encompasses the above considered issues and a larger number of papers published in the leading indexed journals confirm that we are on the right track.

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ANALYSIS OF DYNAMIC BEHAVIOR OF ROTATING MACHINES

Ranko Antunović¹, Aleksandar Veg²

Summary: Operating supervision and the condition monitoring of the rotating machines, deploying exact diagnostic methods, can be considered as a good insight into the current state of a technical system and exact assessment of maintenance necessity. In this way, one can survey a large scale of machines and processes, without loss of reliability, as well reducing the costs of maintenance and increasing system profitability. This is the paramount demand of the modern production philosophy. The paper, considers importance of data selection and implementation of appropriate diagnostic techniques with particular emphasis on the analysis of the dynamic behavior of rotating machinery.

Shown are some of the results of diagnostic analysis that have been conducted on the machines in a real operation, applying advanced methods of technical diagnostics.

Key words: rotating machines, monitoring, diagnostics

1. INTRODUCTION

The progress of computer and measurement techniques and the appearance of powerful software associated with the constant price reduction, provided a significant step forward in monitoring and protection of rotating machines. Regularly, such configurations became very affordable and available. Achieving the goal of inexpensive and efficient device for monitoring, all the rotating systems of major importance will be equipped with it, in less than 40 years. Thus would be age of error free operation in the long term. Machinery set up would be automatically conducted for different operating modes, aimed on identifying the causes of malfunction and archiving the specific events, important for machine record. Such devices are already deployed to monitor large number of industrial plants around the world, and will remain indispensable equipment for both new and rebuilt plants [1].

The most common deficiencies of rotating machines that can be promptly identified by the use of control-diagnostic system are: unbalance (asymmetry of rotor mass and inertia), misalignment, damaged roll/sleeve bearing, faulty inclination, resonant behaviour, disturbances of electrical and magnetic origin, aerodynamic and hydrodynamic influences, malfunction in gearing/belt drive, loose parts, mechanical impacts, rotor to stator scrub, mechanical rotor anisotropy.

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2. PARAMETERS AND METHODS OF ROTATING MACHINES SURVEY

Monitoring parameters of the rotating machines are usually related to the structural parameters (frame and machine vibration, process and casing temperature, clearance in the bearing, oil pressure, etc..). All the parameters can be divided into several groups:

- The parameters of the dynamic machine motion : absolute and relative vibration.
 - The parameters of the position: the position of the rotor in the bearing sleeve, the relative motion of the shaft (axial displacement), relative elongation of the shaft, absolute elongation of the housing.
 - Other diagnostic parameters: rotational speed, temperature, shaft eccentricity, electrical parameters, the acoustic parameters and the technological parameters.
- In general, approximately 90% of all deficiencies that appeared at the rotating machines, affected the vibration response.

Occurrence of certain faults on the machine produce a stable excitation which generates a specific oscillatory motion. The outcome of the vibration response analysis reveals the character of the excitation force and determine the cause of machine malfunction Fig. 1. [2]

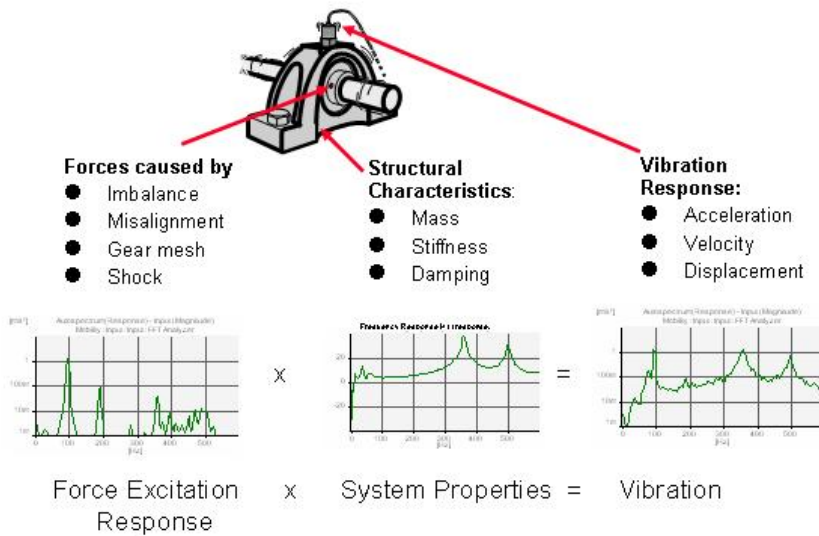


Fig. 1 *Dependence of system response to the excitation force*

Commonly used Vibrodiagnostic methods are: simple vibration severity detection, spectral analysis, phase analysis, real-time vector analysis, orbits, DC analysis, record trends, SPM analysis, energy analysis, Zoom FFT analysis, CPB analysis, cepstral analysis, SED detection, HFD, LFD, SEE technology, modal analysis. It is possible to extract major causes of dynamical disorder by early detection. [5]

There are some other methods which contribute to a proper identifying of real causes of malfunction. They are: Monitoring and analysis of air gap, analysis of the magnetic flux, analysis of partial discharge, monitoring of parts wear, detection of combustion products, monitoring of system fluids (oil and lubricants, gases, coolants...), corrosion monitoring (visual methods, gravimetric and electrochemical methods)

3. DYNAMIC PROBLEMS CLASSIFICATION AND OPTIMAL DIAGNOSTIC MODEL

Dynamic problems are usually typical for certain group of machines, depending on their power, speed, size, foundation, etc. Standard ISO 10816 classifies all the machines into 4 categories. Each category is determined by the permitted level of vibration severity, disposition of measuring points, measuring axis and the recommended measuring parameters (Fig. 2).

Machine		Class I Small Machines	Class II Medium Machines	Class II Large Rigid Foundation	Class III Large Soft Foundation
In/s	mm/s				
0.01	0.28				
0.02	0.45				
0.03	0.71		GOOD		
0.04	1.12				
0.07	1.80				
0.11	2.80		SATISFACTORY		
0.18	4.50				
0.28	7.10		UNSATISFACTORY		
0.44	11.20				
0.70	18.00				
1.10	28.00		UNACCEPTABLE		
1.77	45.90				

Fig. 2 Vibration Severity Per ISO 10816-1

Some causes are typical for some machines. Therefore the two families of machines are recognized:

- GROUP 1, running with rolling-element bearings
 - Machines classes I – in accordance with ISO 10816
 - Machines classes II - in accordance with ISO 10816
- GROUP 2, running with journal bearings
 - Machines classes III - in according ISO 10816
 - Machines classes IV - in according ISO 10816

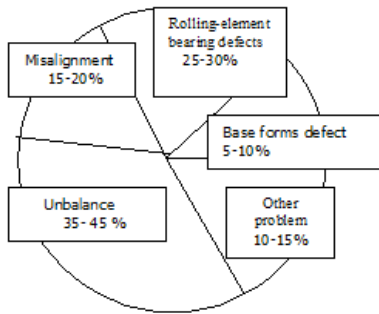


Fig. 2 Probability of certain defect appearance in machines Group 1

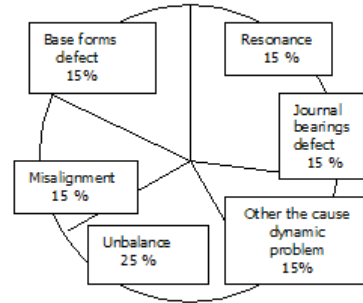


Fig. 3 Probability of certain defect appearance in machines Group 2

A true study of possible causes of disturbed machine operation, brought us to conclusion that the optimal model of fault detection must be based on [7]:

1. Identifying the cause of dynamic problem
2. Simplicity for use and performance
3. Early detection
4. Economy aspect

The optimal set of methods, which satisfy the criteria, involves: vibration severity detection, spectrum analysis, polar trend of the signal. Additionally the machines belonging GROUP 1, should be observed by HFD method, while the machines from the GROUP 2 need Bode chart and orbit analysis.

4. CONFIGURATION OF THE MONITORING-DIAGNOSTIC SYSTEM

In order to provide the appropriate data record, necessary for the evaluation and analysis, the monitoring system must be configured to collect all the relevant data. As well the device should arrange the data in a relevant form (format), appropriate for instant decisions of possible machine trip, and maintain recommendations. System must be restrictively conveyed, allowing only authorized persons to access data record, and alarm settings.

Regularly, monitoring system consists of: 1) Transducers (sensors), 2) Data collect unit and 3) Diagnostic system for data record, analysis, alarm raise and data transfer.

Signal from the sensor undergoes amplification and raw filtering in order to present properly vibration level, all spectral components, phase lag, etc.

Some modern instruments use a computer facility for data record, data presentation and data transfer. Moreover, the computer is capable of detailed spectral analysis and data archiving in different forms, Fig.4.

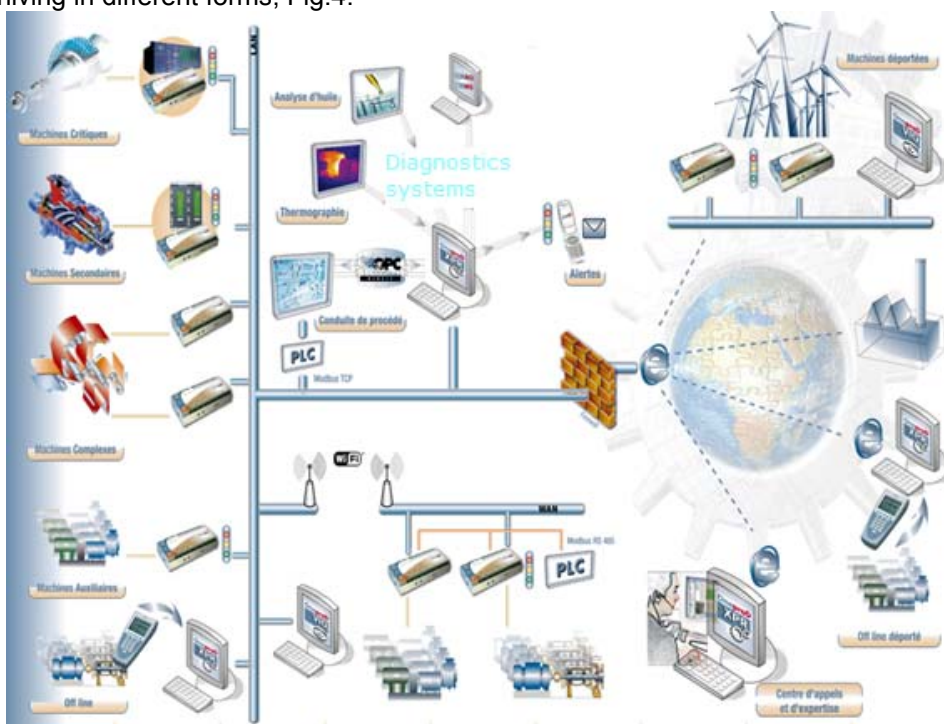


Fig. 4 Data collect, data transfer and archiving with modern diagnostic systems

Besides the ability of signal conditioning and analysis, PC can communicate with the expert systems, transferring the to them both data and responsibility for the proper decision. This is applicable either in the long term operation or in transition stages like start up and machine coast down .

Most of the built-in diagnostic systems are equipped with the adaptable knowledge base. That is the memory space where the user knowledge is stored, in order to expande system experize. When set, the whole diagnostic process develops automatically, securing an optimal diagnosis always at hand [8].

The development of communication allows remote monitoring of the machines regardless their location against the location of control staff. Also, the machine producer can be involved in the monitoring process, contributing by its expertize to the

competent reaction on any alert/alarm event. As well by such producer oriented monitoring the data base of systematic equipment faults is promptly updated.

5. DIAGNOSTICS ON SITE

Here follows some examples of site diagnostics, conducted at the Thermal Power Plant Gacko, implementing COMPASS, Bruel & Kjaer diagnostic system.

5.1. Electric feed pump (machinery GROUP 1)

Location: Thermal Power Plant Gacko, Plant: Feed Pump

Technical data: electric three-phase AC motor, rated power P = 630 kW, 750 RPM. Multistage pump, 6 impellers. Rolling bearing tyupes: L1-6326, N326-L2, L3 and L4-6318

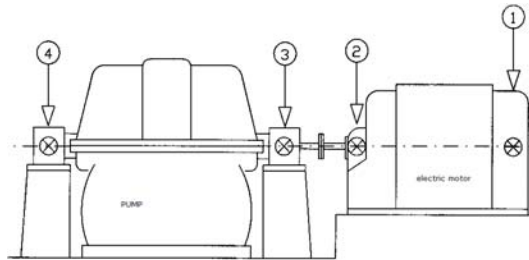


Fig. 5 Feed Pump

Process parameters: water pressure at the pump inlet 1.7 [bar],
water pressure at the pump discharge 6.2 [bar].
motor current 62 [A].

Inspection Methodology:

- 1) measurement of vibration severity of all bearings in either of three main axis
- 2) spectral analysis at each point
- 3) HFD bearing detection.

The results

- vibration severity

Table 1. Overall vibration levels

Bearings	Horizontal	Vertical	Axial
	$\sum v_{RMS}$ [mm/s]	$\sum v_{RMS}$ [mm/s]	$\sum v_{RMS}$ [mm/s]
1	1,6	1,2	1,8
2	1,2	1,1	1,3
3	1,9	2,1	1,5
4	3,2	3,1	1,2

MACHINE assessment

In accordance with ISO 10816 standard: *permissible*.

- Spectral analysis

Beneath is the spectral plot of the horizontal vibration at the outer, 4-th bearing. In order to identify the main causes of faulty behaviour, the characteristic frequencies are needed.

Fundamental tone of rotation is $1X = 12.5$ Hz.

Frequency signature for SKF6318 is: BPFO= 38,6 Hz, BPFI=61,2 Hz; BSF=26,1 Hz; FTF=4,75 Hz,

Vane pass frequency of impeller is $12.5 \times 6 = 75$ Hz (BPF)

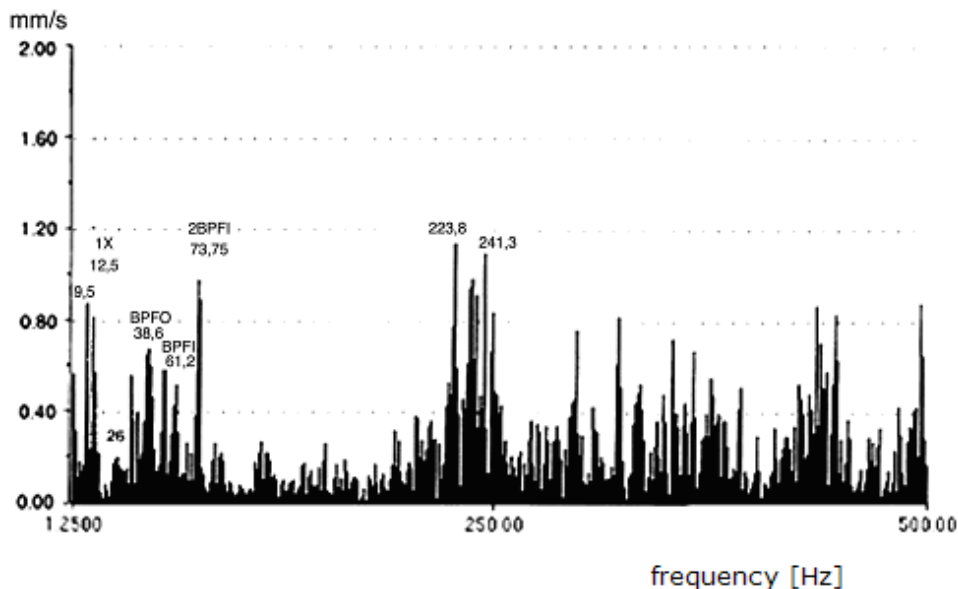


Fig. 6 Spectrum plot horizontal vibration at outer 4th bearing

Spectrum plot indicates damaged rolling-element in outer 4-th bearing, Fig. 6.

- HFD overall value

HFD equals 9,2 g. This is a high value.

5.2. Turbine (machinery GROUP 2)

Location: Thermal Power Plant Gacko,
Plant: Steam Turbine

Operating mode:

Active power $P = 262$ MW, reactive power $P_{\text{reah}} = 40$ MVA.

Steam parameters inlet: $t = 520$ °C, $p = 235$ bar, primary steam flow $Q = 750$ t / h.

Secondary steam parameters: $T = 525$ °C, $p = 34$ bar.

Level of condensate 120 cm,

Vacuum level in condenser $p = 0.86$ bar.

Oil temperature at turbine bearings discharge (°C):

$t_1 = 68$, $t_2 = 60$, $t_3 = 60$, $t_4 = 56$, $t_5 = 56$, $t_6 = 64$, $t_7 = 71$, $t_8 = 58$,

oil pressure at bearing discharge $p = 1.55$ bar.

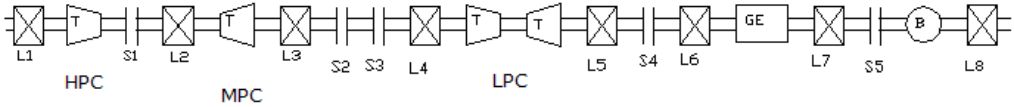


Fig. 7 Steam turbine Power train

Other parameters:

- Speed $n = 3000$ RPM,
 - axial displacement 0.30 [mm],
 - absolute spread HPC 30.7 [mm],
 - absolute spread of MPC 20 [mm],
 - relative elongation HPC 1.96 [mm],
 - relative elongation MPC -1.65 [mm],
 - relative elongation of LPC 3.26 [mm].
- Temperature in bearing body: $t_1 = 54, 55$ (two measurement points),
 $t_2 = 53, 53$,
 $t_3 = 68, t_4 = 61, t_5 = 62, t_6 = 67, t_7 = 68$

Test methodology:

- vibration severity on all turbine bearings.
- spectral analysis at each measuring point of increased vibration where needed, polar trend graph 1X and 2X fundamental.

The results

- Bode plot

1X fundamental at start-up, 1-st bearings.

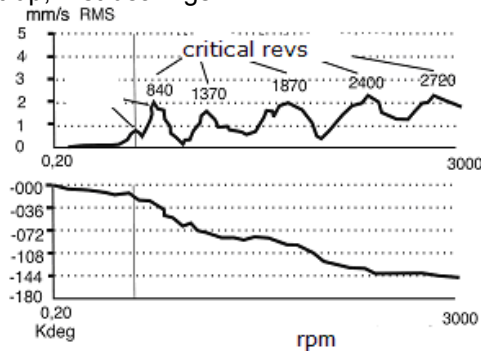


Fig. 8 Bode plot

Turbine critical are at (RPM): 1- 840; 2- 1370; 3- 1670; 4- 2400; 5- 2720, Fig. 8.

- vibration severity

Table 2. Overall vibration levels

Bearings	HOR	VER	AX
	$\sum v_{RMS}$ [mm/s]	$\sum v_{RMS}$ [mm/s]	$\sum v_{RMS}$ [mm/s]
1	3,4	1,8	1,8
2	2,1	1,8	2,1
3	1,4	3,6	2,2
4	2,0	1,9	2,3
5	3,2	2,7	2,1
6	3,3	4,6	6,5
7	3,8	5,8	9,3
8	6,4	5,2	4,1

- Spectral analysis

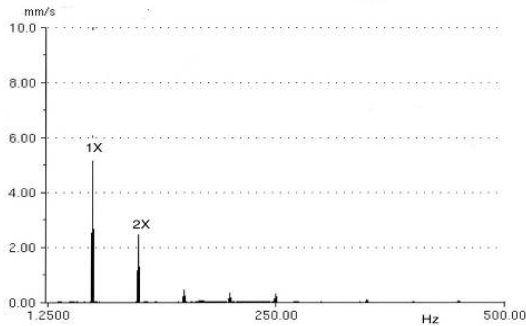


Fig. 9 Spectral plot at 6th bearing (V)

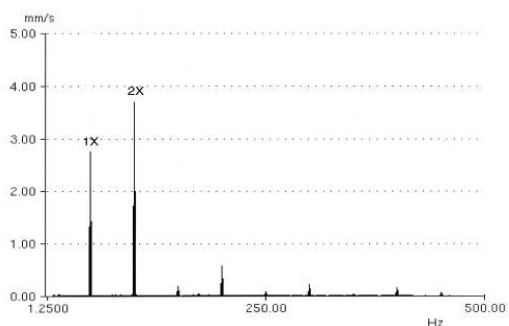


Fig. 10 Spectral plot at 7th bearing (V)

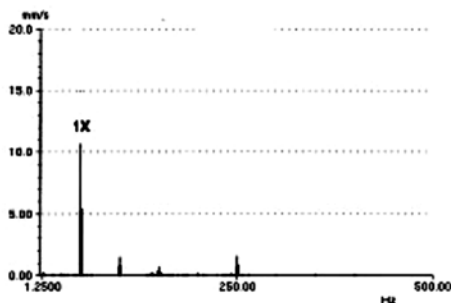


Fig. 11 Spectral plot at 7th bearing (A)

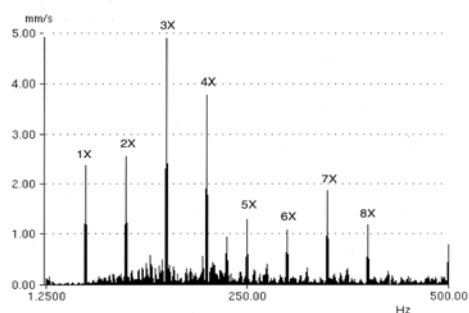


Fig. 12 Spectral plot at 8th bearing (V)

Spectral plot clearly verifies that the unbalance and misalignment of the generator are the main causes of increased vibrations. Additionally, spectral plot at the 8th bearing indicates slack, while the 7th bearing suffers of reduced stiffness in the axial direction.

Note: More illustrative picture of deficiency origin is delivered with polar trend plot of 1X and 2X fundamental in radial and axial bearing of the generator, Fig. 9,10,11,12.

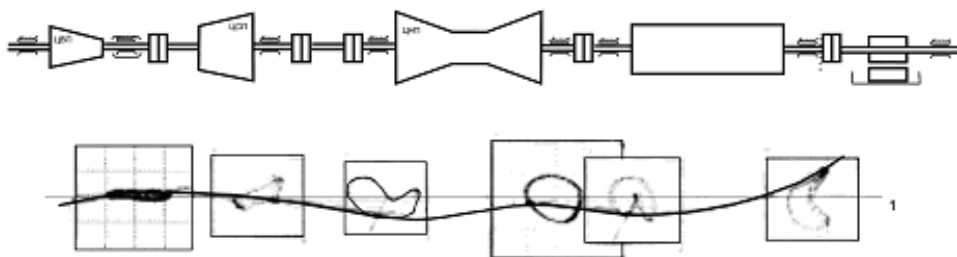


Fig. 13 Orbit analysis for the turbine bearings

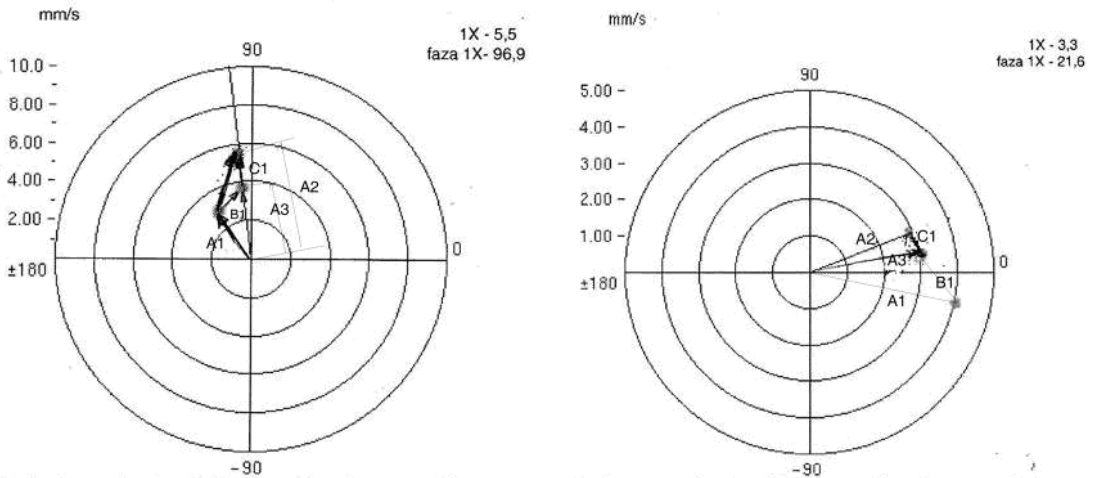
In order to identify the real cause of the problem it is necessary to correlate the diagnostic parameters with the parameters of the process.

- **Polar trend plot**

Polar trend plot 1X and 2X fundamental is made for bearings 6 and 7.

Polar trend 1X fundamental (V) at the 6th and 7th bearing is collected while:

- Operating at rated speed (3000 RPM), without excitation on generator
- Machine at rated power
- Machine coasts down after power cut of the generator excitation..



Picture. 14 Polar trend plot at 6th and 7th bearing

Polar trend plot clearly shows that there is a change in amplitude and phase of 1X Fundamental with power increase. This fact indicates the mass asymmetry of the rotor mass, possibly change in rotor geometry, which may be due to thermal distortion or impact of asymmetric magnetic field. Further analysis of the polar trend 1X Fundamental indicate also some other effects, such as:

- Vector at A1- 1X intensive component, while cold
- Vector at A2- 1X intensive component, on full a full power
- Vector at A3 - 1X intensive component after power cut.

It is obvious that the vector B1 (Fig. 14) indicates thermal unbalance, also has a minor influence on the overall dynamic state (vibration severity slightly changes). On the other hand vector C1 indicates asymmetric magnetic field vector, which significantly affects the dynamic state of the machine, because its phase coincides with the residual unbalance at the seventh bearing.

6. CONCLUSION

Recent development of the microprocessor technology and digital signal processing, allows outstanding progress in conceiving on-line monitoring systems. Nowadays bundles of signals are processed practically in real time. Therefore modern methods in technical diagnostics provide a deep insight into the following issues:

- When and where the damage occurred (technical diagnostics)
- How the damage progresses over time,
- How soon comes the final failure (technical prognostics)
- What is the cause of failure (technical genetics)

Substantial goal of the condition based maintenance is to recognize timely the possible threats for smooth and restless operation. The set of properly configured measurements, composed with the monitoring concept and signal analysis lead to a reliable technique of early fault detection. Dynamic behaviour of the machine is thus constantly observed with the high degree of proactive protection and deep understanding what occurs under the machine cover.

In this way, machines are managed properly, resulting with increased availability and improved utilization. Maintenance costs are reduced to the minimum while the profitability of the machinery increases to an almost theoretical level.

A humble contribution of this paper is addressed to those who still compromise between full capacity of modern monitoring systems on a valuable machinery and usually traditional low cost diagnostic techniques with a poor performance.

NOTATION

<i>FFT</i> - Fast Fourier Transform	BPFO – Outer Race Frequency
<i>SEE</i> - Spectral Emitted Energy	BPFI – Inner Race Frequency
<i>CPB</i> - Constant Percentage Bandwidth	BSF – Ball Spin Frequency
<i>SPM</i> - Spectrum Pulse Method	FTF – Fundacion Train Frequency
<i>HFD</i> - High Frequency Domain	<i>SED</i> - Selective Envelope Detection
BPF – Blade Pass Frequency	<i>LFD</i> - Low Frequency Domain
CVP - High Pressure Cylinder	<i>CDS</i> - Computer Diagnostic System
MPC - Medium Pressure Cylinder	<i>RPM</i> - Revolution Per Minute
LPC – Low Pressure Cylinder	

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FUTURE TECHNOLOGY AND EDUCATION OF ENGINEERS

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Summary: Companies are today forced, due to growing market competition, to put on the market quality products with numerous innovations. Consequently, they have to implement new ideas and to solve complex problems and tasks in a short period of time. In order to realize this, it is essential to have quality staff. Engineers with university education must be prepared to use new opportunities and future technologies and applications that are responsible for products and manufacturing processes. Innovative thinking and work are crucial for education of engineers. Engineers are those who develop, compute and experiment, plan and manage the flow of the economy. Topic of this paper are future working areas of engineers, that are largely determined by the future technologies.

Key words: engineer, education, technology, future

1. INTRODUCTION

It is considered that the organization is successful if it offers something that solves the problem to the others. It can be a product or service. The success of the organization is based on the fact that such a solution "has" and it is offered to the market. It does not matter whether this solution exists for thousands of years or is the result of spontaneous inventions or ingenious ideas to achieve the success of the organization through the development process that must meet the requirements of the customer.

The key to the success of an organization is the development of products that could meet as much as possible the demands of the customer. Marketing and realization of products are equally important and must be mutually agreed upon.

The development is a decisive factor for the transformation of research potential and experience in the company's success. In this way, existing potential and knowledge through the product development are transformed into competitive products and profits.

The development is a creative task which is systematically creating a new product. Product development allows companies to offer customers attractive products. Knowing new technologies and the constant use of innovations provides a base for the

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conquest of new markets. Companies that do not develop and improve their products quickly lose their position in the market. In order to realized such a responsible position it is essential that companies have university educated staff with appropriate job competencies.

2. CHANGES AND CHALLENGES THAT ARE SHAPING FUTURE SOCIETY

Our civilization owes its present appearance to advances in technology and engineering capabilities to allow the application of technical achievements in different spheres of social life. Relying on scientific knowledge and recognizing the needs of society, Engineers have shaped the world we live in and enable the continued progress of science and society, relying on scientific knowledge and recognizing the needs of society.

Today's society is increasingly taking on the characteristics of the knowledge society, where all processes in human activities depend on the knowledge and skills based on knowledge. In this context, it is very likely that the three most important tasks in the knowledge society are: problem identification, problem solving and exchange of ideas.

One of the important tasks of engineers in the future will be to help society by adapting new advanced technology to their needs. In this sense is necessary to identify the trends that dominantly shape the future society, politic, economy, environment, technology and market.

Fundamental changes and megatrends in future society:

1. Globalization - the creation of a single economic, political and cultural space on the planet where people, ideas, goods and capital are free to circulate. Globalization as a process is not new and it takes place for centuries, but its full expansion experienced the advent of the Internet. Information and communication technologies have led to a shortening of the duration of the cycle in commerce, banking and manufacturing. Increase of frequency of this cycles creates the impression that the world is decreasing and accelerating.
2. Networking. Internet makes it easy to reach out to like-minded people around the world. People are less familiar, and more and more connected through social networks like Facebook, Twitter, Linked-in or YouTube. In this moment (September 2012) Facebook has a little bit less than 1 billion active users.
3. Human population growth. Predictions are that from the current 6.9 billion people in 40 years, world population will grow to over 9 billion people. Changes that occur by growth of world population is very difficult to track because they lead to very rapid change and great challenges.
4. Preservation of harmony between humans and the environment. A series of major natural disasters in the last 10 years (global warming, climate change, wildfires, earthquakes, rapid extinction of plant and animal species) caused that the need for sustainable development to become one of the dominant forces that shape the future.

The influence of the above mentioned megatrends are reflected in:

- Dramatically increased dependency of "all against all";
- Increasing mobility and migration of the population;
- Individualization of lifestyles;
- Easier access to knowledge;
- Reducing barriers to entry into new businesses;
- Increased competition;

- Search for talent all over the world.
Negative trends of development of society:
- Irrational consumption as model of lifestyle in "developed countries". If all the people in the world live on this model, the Earth should be increased by 40-60 times.
- Waste and inability to recycling. The percentage of products that can not be recycled is growing. Around the cities in the world are growing mountains of waste. Our civilization has become a "civilization of garbage".
- Unlimited right to remuneration. The total value of all shares on the planet is limited. At the same time money is limited. This causes the illusion of unlimited growth of money, regardless of the value on the planet. Consequence is the global financial crisis.
- Continuous growth. Stable state of nature is a state of equilibrium, and unstable is uncontrolled growth. Between these two states must be established correlation to regain equilibrium.
- In 2020 the society will be dominated by knowledge, exceptional mobility and competitiveness. Knowledge is the key and only resource that is increasing by its using and sharing. It is difficult to preserve and protect knowledge because its rapidly losing value in the market and is not subject to known procedures and methods of management. Every 7 to 10 years of knowledge doubles. Modern communications and information technologies contribute to a very rapid expansion of knowledge. But on the other side knowledge very fast becomes obsolete. The diagram in Figure 1 shows that the level of knowledge obsolescence in the last 100 years has accelerated 10 times. At the beginning of the 20th century, it was necessary to pass 40 years that the level of knowledge falls by 50%. Today (2012) the period is 4 years. This is especially important for product development.

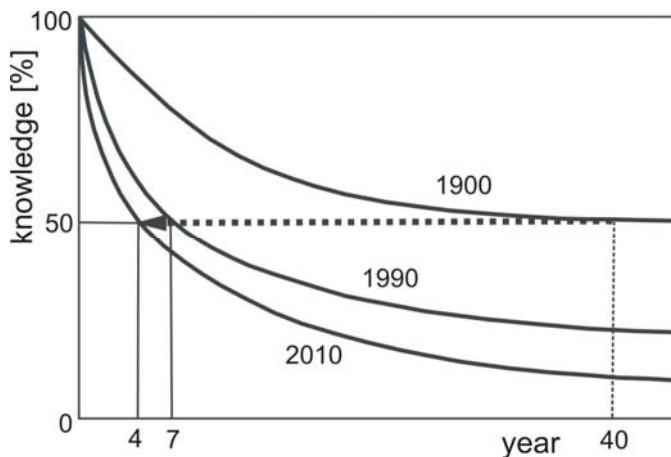


Fig. 1. The speed of obsolescence of engineering knowledge

3. FUTURE TECHNOLOGIES

The word technology comes from Greek τεχνολογία (technología); from τέχνη (téchnē), meaning "art, skill, craft", and -λογία (-logía), meaning "study of-". The technology involves the skills, knowledge and ability of humans to create, develop, produce, and put to use the products to meet the diverse needs - both material and

nonmaterial. So technology is a set of activities that result in creating a value, regardless of whether they are products or services.

The technologies of future are considered technologies that are going to play an important role in future. Approximate future list is as follows:

- Biotechnology and genetic engineering
- Artificial intelligence
- Laser technology
- Aerospace technology
- Nanotechnology
- Optical technology
- The use of renewable energy sources.

3.1. Biotechnology

Biotechnology is the common application of a biology, biochemistry, microbiology and process technologies for their industrial use. Biotechnology deals with the application of biological processes, organisms and systems for industrial production (food, pharmaceuticals, agriculture, energy, mining, chemical industry, service industry).

The discovery that a hereditary trait can replant in the structure of genes (DNA) of other species has led to the development of genetic engineering. Genetic engineering is of great importance in human health, agriculture, forestry and food production. These are opportunities to increase production of raw materials, energy and food while preserving the natural environment as well as production of new and better drugs.

3.2. Artificial intelligence

Artificial intelligence, as part of computer science, is focused on developing a program (software) that will allow computers to behave in a way that could be characterized as intelligent. Therefore, the artificial intelligence is a scientific field which explores how to create a device that could successfully do the jobs that are currently better done by the humans.

About intelligent machines can be talked with the advent of the first computer "Electronic Numerical Integrator And Computer" (ENIAC), that was invented in year 1945 by Mauchly and J. Presper Eckert. In the beginning, computers were primarily used to perform mathematical operations, but it was soon recognized that they have a much greater capabilities. Already the first results in the application of computers pointed to the possibility of a computer with the exercise of certain intellectual abilities.

Today the operational systems that can autonomously perform complex tasks, such as only humans were capable of doing. Very often these systems perform such tasks even more successful than humans. Mechanical systems with computational and mechatronic subsystems can work independently, to govern themselves and to produce other products, freeing the humans and monotonous physical labor, leaving him to work on the more complex and creative tasks.

The main directions of artificial intelligence are:

- The study of natural intelligence (knowing brain function, brain function modeling, simulation of human behavior, reactions and reasoning).
- Achieving intelligent behavior using different approaches, which can not be found in natural systems.

According to the method of problem solving using artificial intelligence can identify three main approaches:

- neural networks

- modeling of evolution and
- heuristic programming.

According to the type of problem solving artificial intelligence can be divided into the following systems:

- systems for solving human common tasks:
- systems for solving formal tasks:
- systems for solving expert tasks.

From the standpoint of education and areas of future engineers are most expert systems for solving tasks, they are present in the following activities:

- Product development, designing,
- fault finding, production planning,
- scientific analysis and diagnostics,
- recognition of shapes and images,
- industrial process control,
- Monitoring of medical devices,
- autonomously moving vehicles (land and water),
- autopilots,
- Management satellites,
- Monitoring installation,
- detection of oil wells.

3.3. Laser technologies

Laser technologies are mainly based on the use of devices - the laser. The term "laser" originated as an acronym for *Light Amplification by Stimulated Emission of Radiation*. A laser is an optical device that emits a coherent beam of photons. In contrast to the light emitted from common sources such as light bulbs, laser light is usually monochromatic, ie. only one wavelength (color) and is focused in a narrow beam. The beam is coherent, which means that the electromagnetic waves are in the same phase and they extend in the same direction. It is composed of excitation systems, resonator and active environment that fills it. It was discovered in the U.S. in the 1960.

Considering the nature of the medium that is used to produce laser light, lasers are divided into:

- solid state lasers,
- gas lasers,
- semiconductor lasers,
- liquid lasers,
- chemical lasers,
- dye lasers and
- free electron lasers.

Laser technology is used in:

- medicine (ophthalmology, laser surgery, break up kidney stones, treatment of tumors),
- measurement techniques (measurement geometry, surface testing, spectroscopy, holography)
- Industrial Production (cutting, drilling, welding, soldering, hardening, control procedures),
- traffic (exhaust gas control, radars, traffic control, safety sensors)
- Trade / Industry (coding, laser printers, laser scanners, microanalysis)

- communications (fiber optics, telecommunication systems, integrated optics, computer systems),
- energy / environment (environmental controls, combustion control, meteorology, the study of fusion)
- Education / Entertainment (CD, laser displays, video equipment).

3.4. Aerospace technology

Aviation and space technology is part of the engineering research and traffic technologies, which includes aircrafts, spaceships and satellites. Development of these systems includes technical, scientific and environmental aspects. Successful realization of this task requires the optimal integration of subsystems and components in the whole system. This integration includes:

- Development of lightweight aircraft structures
- Development of an optimal aerodynamic shapes,
- Development of new constructions of propulsion systems (engines),
- Development of systems for energy supply, control, data transfer and communication,
- Development of subsystems of basic equipment, which should provide function and stability,
- Development of new systems that have to fulfil the requirements of space technology,
- Development of a navigation system.

3.5. Nanotechnology

This term comes from the Greek word nanos (νᾶνος) which means "dwarf" or something tiny, invisible. Nanometre as derived unit of measurement of length is $1 \text{ nm} = 10^{-9} \text{ m}$, that is a nanometre is one billionth of a meter.

Nanotechnology is an interdisciplinary science that includes physics, chemistry, biology, materials sciences, as well as a wide set of engineering disciplines. The term nanotechnology is a synonym for science and technology. As a science, nanotechnology studies physical, chemical and biological properties of molecules and atomic particles. As the technology it is applied to the researches of these sciences including various engineering disciplines for material production and functional systems with particular and unique characteristics.

As an engineering discipline, nanotechnology refers to the techniques and products that include structures of nanometre dimensions in the range of 1 to 100 nanometres, especially those that transform matter, energy and information using nanometre components with precisely defined molecular features.

3.6. Optical technologies

Optical technologies encompass physical, chemical and biological axioms and technologies for acquisition, enhancement, creation, transmission, measurement and use of light. It is considered that optical technologies are foundation and prerequisite for the development of other technologies and their application in the future. They are also a prerequisite for the realization of many innovations in the 21st century.

Optical technologies are primarily applied in information and communication technologies. But they are also used in biosciences and medicine, energy and lighting, in the industrial development of macro and micro structure of industrial sensors, etc...

It is anticipated that with the optical technology the new products such as ultra-powerful microscopes, light computers, advanced solar cells, multi-sensors, etc. will be developed.

4. DEVELOPMENT TRENDS AND ENGINEERING EDUCATION

In the future, the work of engineers will be multidisciplinary and interdisciplinary. It will include the complete product life cycle, from the product idea, through its concretization through development of specific innovative products, manufacturing, distribution, exploitation and finally recycling. The engineers must be able to create a new or improve existing products, through creativity, innovation and fascinating technologies and place it on the market. For the realization of these tasks engineers must have the knowledge of available technologies for successful creation and development of products, taking into account the available material and energy resources and environmental protection.

Table 1 Field of work of future engineers in terms of future technologies

Future technologies	Goals	Challenges (problems)
Biotechnology and genetic engineering	<ul style="list-style-type: none"> - Analysis and modification of genetic material - Analysis and modification of proteins - Analysis and modification of metabolites (small molecules) - Manipulation of cells to a variety of applications - The application of information technologies in the analysis and storage of biological data 	<ul style="list-style-type: none"> - Ethical issues - Synthetic biology - Tissue engineering and therapy treatment at cellular level - Gathering and application of stem cells - Pharmacogenetics - Development of therapeutic vaccines - Nanomedicine (delivery of medicaments and genes, biosensors, biomaterials - implants, in vitro diagnostics) - Manufacturing of industrial crops - Genetically modified animals and crops - Cloning - Nutrigenomics and nutrigenetics - New and improved approaches to industrial biotechnology (biocatalysts and enzymes) - Manufacturing of bioethanol, biodiesel and bio butane
Artificial Intelligence	<ul style="list-style-type: none"> - Biorobotics - Developmental robotics - Ubiquitous computing - Artificial life and multi-agent systems 	<ul style="list-style-type: none"> - Theoretical understanding of behaviour - Achieving higher level intelligence - Automated design methods (artificial evolution and morphogenesis) - Moving into the real world
Laser technology	<ul style="list-style-type: none"> - Development of high energy lasers - Development of weapons and defence systems - Development of new particle accelerators - Development of lased induced nuclear fusion - Vertical-cavity surface-emitting lasers - Centralized clocked lasers 	<ul style="list-style-type: none"> - Consumer safety - Beam coherency - Increase of energy output - diode-pumped solid-state lasers - Fibre lasers - Optical cooling

Because of this, engineers must expand their professional competence in the field of economy, work processes and quality assurance. In the frame of this interdisciplinary and partial work processes the additional qualifications in cooperative social behaviour with management and communication skills are required. This of course requires the development and implementation of relevant plans and programs in the field of education.

Engineers in the development must have the wide knowledge and be oriented towards the products and the processes.

Orientation to the products means comprehensive education of the engineers in the field of sciences and engineering to create new or further development of existing technical products. This primarily applies to activities related to defining the product profile, finding the physical effects for definition of the product concept, design, calculation, sizing, modelling and simulation of mechanical, pneumatic, hydraulic, regulation and control system components, as well as the development and testing of prototypes.

These include activities related to knowledge about other areas of the company, such as purchasing, sales, production, collaboration with customers and manufacturers.

Orientation to the processes means education in the field of methods, systems and management. This is primarily related to the introduction, further development and learning of methods and systems for support of all the above activities, as well as planning and management of development projects, both as a collaborator on the project management and as a project manager.

Special attention in engineering education should be given to education and practical application in the field of modelling and simulation techniques, because of paradigm changes on which the product design process is based. The traditional design process implies that the designer defines the preconditions of loads and boundary conditions corresponding to real conditions of exploitation. Defining these assumptions is a very complicated task because the conditions of exploitation in many situations are stochastic. Definition of boundary conditions is also very complicated task because one product is used in a variety of conditions (geographical, meteorological, et al.). Based on these assumptions stress and strain calculations are done (analytical or numerical), the product design is checked and selection of material from which the product is made is performed. The success of the procedure depends largely on the accuracy of the assumptions and the proper definition of the boundary conditions, and also on the applied calculation methods, which are often empirical.

High integration of multiphysical software tools for modelling and simulation of the behaviour of the product in exploitation, and a substantial increase in processing capabilities of modern computer systems, have enabled that the design process in the product development is based on the simulation of realistic loads and boundary conditions, that is the real physics of the product. Above approach significantly increases the quality and reliability of products.

Special attention in education should be paid to the innovation management and analysis upon which the conclusion about the economic justification of future development projects can be made. Future development projects largely determine which technology development is expected in the future. They will not only largely define the future development projects, but also determine the field of work and operation of the future engineers. Table 1 show an overview of the expected future technologies with the goals and challenges, which can be seen now.

For the realization of those serious tasks it is necessary that the future engineers have an adequate education, focusing on areas that allow the acquisition of adequate working competencies.

Table 1 Field of work of future engineers in terms of future technologies (continued)

Future technologies	Goals	Challenges (problems)
Aerospace technologies	<ul style="list-style-type: none"> - Asteroid mining - Single stage to orbit - Solar power satellite - Non-rocket space launch - Space manufacturing 	<ul style="list-style-type: none"> - Development of efficient propulsion systems - Price - Resilient materials and designs - Design of lightweight aircrafts - Development of systems for energy supply, control, data transfer and communication - Development of navigation systems
Nano-technologies	<ul style="list-style-type: none"> - Development of micro reactors - Development of lab on chip - Surface engineering - Development of flexible displays - Development of polymer LED's - Catalysis materials - Optical and opto-electronic materials - Organic electronics and organic opto-electronics - New magnetic materials - Biomimicry and biomimetic materials - Nanobiotechnology - Superconductivity - Composites and "multimaterials" - Intelligent textiles - Materials for medical applications 	<ul style="list-style-type: none"> - Ethical questions - Development cost - Manufacturing technologies - Toxicity of nanomaterials - Impact of nano technology on humans and environment - Theory of micro flow - Techniques for research on living organisms on nano level
Optical technologies	<ul style="list-style-type: none"> - Miniaturisation, energy efficiency and manufacturing of devices based on optical technologies - Further development of basic photon technologies (lasers, photodetectors, LED, optical fibres, etc.) and their application in medicine, biology, communications, detection, measuring and manufacturing - Evolutionary improvement in optoelectronic devices - Quantum-well modulators - Clocking and Synchronization - Silicon-based optoelectronic devices 	<ul style="list-style-type: none"> - RTD costs - Simplification of design - Scaling of interconnects - Development of interfaces between optical and electronic circuits - Silicon circuits integration technologies - Receiver circuits and low capacitance integration of photodetectors - Absence of appropriate practical optomechanical technology
Fuel cells and alternative energy sources	<ul style="list-style-type: none"> - Replacement of existing batteries and generators - Replacement of combustion principles of fossil fuels - Nuclear fusion 	<ul style="list-style-type: none"> - Price - Durability, reability, stability - Dimensions and weight

5. CONCLUSION

Our world is shaped by engineers using scientific knowledge, technical advances and new advanced technologies in different spheres of social life. Today's society is increasingly taking on the characteristics of the knowledge society, where all

processes and human activities depend on the knowledge and skills based on knowledge.

In the future one of the important tasks of engineers will be helping society to adapt new technologies to its needs. In this sense is necessary to identify the dominant trends that shape the future society, politics, economics, the environment, technology and market.

Education of future engineers must offer a set of knowledge, skills and competencies that will make them capable of strive and adapt to the changing environment. They adapt technology to current needs without breaking the natural balance.

Future development projects largely determine which technology development is expected in the future. They will define the education, field of work and operation of future engineers. The paper gives an overview of the expected future technologies with the objectives and challenges, which can be seen now.

The engineer needs to do more than in the past, acknowledge its responsibility to society. He has to overlook the social, the political, the economic, environmental, and which has the ethical dimensions of his work.

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Session I ***MANUFACTURING TECHNOLOGIES*** ***AND ADVANCED MATERIALS***



COMPUTER AND EXPERIMENTAL AIDED ANALYSIS OF HIGH-SPEED SPINDLE ASSEMBLY DYNAMIC BEHAVIOR

Milan Zeljovic¹, Aleksandar Zivkovic², Slobodan Tabakovic³

Summary: A methodology of experimental identification of machine tool spindle assembly behavior has been developed at the Department for Production Engineering in Novi Sad. The methodology allows analysis of the spindle assembly in terms of dynamic behavior. This methodology is applied to high-speed machine tool spindle assembly analysis. To increase reliability of experimental results, the methodology is combined with computer aided modeling of dynamic behavior, using software packages based on the finite elements method (ANSYS, VRETENO).

Key words: Machine tool, Spindle, CAE

1. INTRODUCTION

From the application aspect, machine tool main spindles are assemblies over which workpiece or tool is supplied by circular (and ultimately linear) motion in order for cutting process to be realized, with very significant and often limited influence on accuracy, productivity and quality of the machine. As the number of revolutions of the machine tool main spindles is increasingly approaching first natural frequency, there is a risk of resonance; which means that by increasing the number of revolutions, vibration amplitude rapidly increases caused by manufacturing error, imbalance and drive and cutting process disruption.

In exploitation, these assemblies are exposed to very complex loads. Cutting forces have variable intensity and direction, especially in the case of vibration cutting. Forces which occur due to motion transfer to the spindle (because of gears, belt-drives, couplings, to name but a few) also have variable direction. These loads are usually not in the same axial plane as the main spindle. Centrifugal forces, due to mass eccentricity (imbalance), cause precession of the main spindle elastic line around geometric axis.

Considering that variable forces, caused by the cutting process, affect the main spindle assembly, it is very important to obtain information related to its dynamic

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behavior for an overall estimation of quality of the assembly. Dynamic behavior was researched by many authors, and in summary, main spindle dynamic models can be classified into two basic groups: a) dynamic models of transverse vibrations and b) dynamic models of torsion vibrations. From the aspect of accuracy and roughness of the surface of the machined workpiece as well as formation self-forced vibrations, transverse vibrations are more interesting. According to research carried out by *Pus* [14] frequency spectrum of the spindle nose vibrations is virtually completely transferred to the workpiece, and its influence on accuracy considering particular frequency intervals can be as follows:

- a) $f=100-200$ Hz - shape deviation (ovality and triangular),
- b) $f=200-320$ Hz – when using grinding methods – triangular and octagonal waves,
- c) $f=320-700$ Hz - surface waviness,
- d) $f>700$ Hz - roughness of the machined surface.

Some research shows that self-forced vibrations appear at frequency which is close to natural frequency of one of the machine elements [10]. Self forced vibrations of high frequency (2000-3000 Hz) are coinciding with natural frequencies of the cutting tool, middle frequent (200-300 Hz) with natural frequencies of main spindle assembly whilst low frequent vibrations (80-150 Hz) with natural frequencies of either slide or workpiece. Middle frequent self-forced vibrations are dominant when using lathe machining.

Study conducted by *Aini et al.* [2] analyzes dynamic behavior of the stiff supported elastic bearing of the main spindle for precise machine tools. Furthermore, authors consider that there is a five-degree-of-freedom motion in each bearing (three translations and two rotations around transverse axes). Based on the analysis, it was concluded that the ratio between outer force and pre-stressing force significantly influences the vibration amplitude and that increase of this ratio leads to decrease of the amplitude.

Using the Maxwell's method of influential coefficients, *Al-Shareef and Brandon* [3] compare two methods for estimation of the bearing dynamic stiffness: method of the consistent mass matrix and method of the concentrated mass. In addition, they consider influence of front bearing stiffness, position of the drive element, damping position and main vibration forms. It was concluded that a small influence of damping in bearings exists, so the position of the outer damping was optimized in order to achieve maximum dynamic stiffness at lowest possible damping value.

Gartnen and Eben [6] developed special software system for analysis of the main spindle assembly dynamic behavior based on the Euler-Bernoulli hypothesis, by introducing the gyroscope effect.

V.R. Reddy and A.M. Sharan [16] use method of reduction of dynamic system matrices, in cases where it is necessary to know only the first several natural frequencies in order to speed up calculation time and economize the usage of processor's memory. Similar considerations can be seen in the research carried out by *Heo and Ehmman* [7] who use method of the construction synthesis based on the sensitivity analysis of the sub construction.

Sadeghipour and Cowley [17] consider effect of the mass distribution on the axial structure dynamic behavior. Authors observe that introduction of damping in between bearings improves dynamic properties and decreases amount of additional mass on back bracket.

Li and Shin [11] developed numeric model for the analysis of influence of bearings configuration on the main spindle dynamic behavior. It was shown that different configuration and different bearing preload mechanisms have great influence on the dynamic reaction of the system like the main spindle.

Above methods are developed using the linear theory, which is based on linear dependence between deformations and displacements, inner and outer forces, stresses and deformations.

According to Portman et al. [13], there are two sources of nonlinearity in ball bearings: a) variable stiffness characteristic and b) variable number of loaded springs (roll elements) in different moments in time. Jiang and Mao [8] analyze influence of the variable bearing pre-stressing on the main spindle dynamic stiffness, whilst taking into consideration variable bearing stiffness properties.

Nataraj and Nelson [12] developed special methodology for calculation of the system with nonlinear bearing support based on trigonometric collocation method.

The latest research efforts focus on the influence of stiffness and damping of the tool holder on the main spindle vibrations, i.e. more precisely the tool vibrations and stability of the cutting process [1], [5], [19].

Analysis of the main spindle behavior led to a large number of mathematical models being developed. Most of these models are based on the finite elements method, where the beam finite elements are commonly used. The nodal points of the beam finite elements have a displacement in the x-direction and rotation about the y-axis. Nodal points displacements in other axes are also taken into consideration, mostly in other spindles (shafts). Influence of damping in the material is ignored in most models, and only damping in bearing supports and outer (additional) dampers is taken into consideration. Regarding the character of the excitation force defining, there are two approaches; first one is deterministic which takes into account the change of the excitation force by sine law, and second one – stochastic, where excitation force has a random character.

A methodology for complex experimental research related to machine tool behaviour analysis and their assemblies has been developed on the Department for Production Engineering at the Faculty of Engineering in Novi Sad. This methodology is based on computer-aided methods and is widely adopted in the field of machine tool spindle assembly analysis. This methodology includes analysis of, dynamic behavior and allows experimental determination of the spindle assembly characteristic performance and, also, the verification of developed constructive solutions and, through this verification, a comparative analysis of CAE systems used in the design process. In this case the analysis was done using system like ANSYS but also a specialized system VRETENO for automated calculation and behavior analysis of the spindle assembly, developed at the Department for Production Engineering.

2. A CONCEPT OF COMPUTER AIDED ANALYSIS AND BASIC THEORETICAL BACKGROUND

The software system VRETENO uses beam finite elements with three degrees of freedom at each nodal point of the axial structure considered. Main spindle is discretized with $(n)=22$ beam finite elements as shown on Fig.1. Finite elements are marked: (1), (2), (3)... (22); whilst nodes are marked: 1, 2, 3... 23. Geometric characteristics of these beam elements are: length, outer and inner diameter, where the inner conic surface of the spindle nose is replaced by cylinders with appropriate middle diameter. Finite elements mesh is dense at the bearings setting places, as the effect of each bearing is replaced by two rows of springs with appropriate radial stiffness.

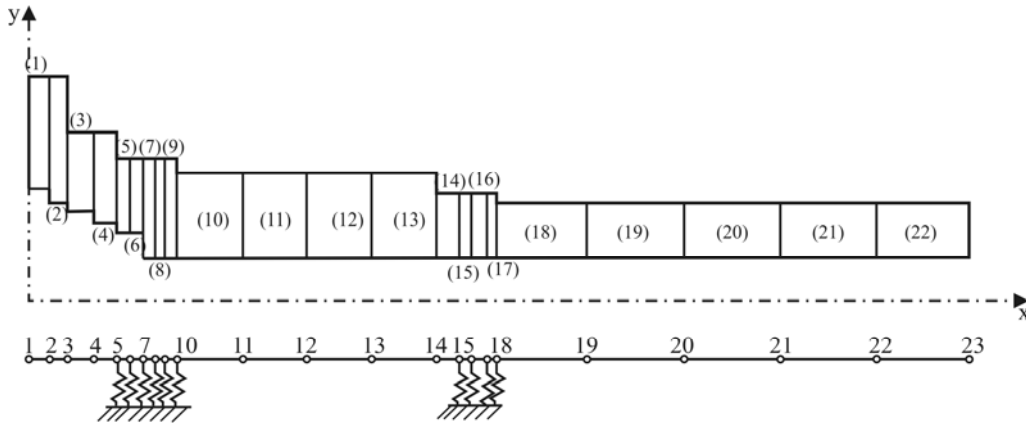


Fig. 1 Spindle discretization by beam finite elements

Previous analysis has shown that number of finite elements has insignificant influence on the results [20], [21].

Also, unlike other software systems based on the technical beam theory, the software system VRETENO uses the Timoshenko beam theory, because this theory considers the influence of the transverse shear deformations. The shear coefficient K , is a purely geometric factor depending on the shape of the cross-sections:

$$K = \frac{A}{I_y(A)} \iint \left(\frac{S_y(x)}{b(x)} \right)^2 dA \quad (1)$$

or

$$\kappa = 4 \left[\frac{2 \cdot r(R^2 + 2r^2) \cdot \sqrt{R^2 - r^2} - 2 \cdot R^2(R^2 - 4 \cdot r^2)}{\arcsin \frac{r}{R} + (5 \cdot R^4 + 13 \cdot R^2 \cdot r^2 + 3r^4) \cdot \frac{\pi}{2}} \right] / [9 \cdot \pi \cdot (R^2 + r^2)^2] \quad (2)$$

where: R and r are the outer and inner radius of the circular-ring cross-section shape. Assuming that the material is homogenous ($p=\text{const}$) the mass matrix $[M]$ is constructed for the axial structure considered. When $r=0$ (circle) then is $K=10/9$, and when $r=R$ (thin-walled round tube) then is $K=3/2$. In the $(r/K, K)$ -plane the curve $K=K(r/R)$ which is defined by expression (2), has two horizontal tangents at the abscises $r/R=0$ and $r/R=1$, and the inflection point at the abscises $r/R=0,456955451\dots$

The system can be used for analysis of free, as well as damped vibrations, based on the hypothesis of small uniform damping. The damping matrix $[B]$ can be calculated as follows:

a) based on hypothesis of modal superposition of damping coefficients

$$[B] \approx [2 \cdot m_i \cdot \omega_i \cdot \xi_i \cdot \delta_{ij}] \quad (3)$$

where: ξ_i - relative damping coefficient for the i -th mode, δ_i - Kronecker's symbol ($\delta_i = 1$ for $i=j$, $\delta_i=0$ for $i \neq j$), m_i - i th mass, ω_i - i th natural frequency.

b) based on hypothesis of Rayleigh proportional damping

$$[B] = \alpha[M] + \beta[K] \quad (4)$$

where: $\alpha = \frac{2 \cdot \omega_i \cdot \omega_j (\xi_i \cdot \omega_j - \xi_j \cdot \omega_i)}{\omega_j^2 - \omega_i^2}$; $\beta = \frac{2(\xi_j \omega_j - \xi_i \omega_i)}{\omega_j^2 - \omega_i^2}$; $[K]$ - stiffness matrix.

c) based on logarithmic damping decrement (δ , as sumed that the damping in the material does not depend on frequency [10]:

$$[B] = \frac{\omega_o}{2\pi} \cdot \delta \cdot [M] \quad (5)$$

The differential equation of small linear forced vibrations of the considered system of $N=(3n+3)-(n_1+n_2+n_3)$ degrees of freedom with internal friction in the matrix form can be written as:

$$[M] \cdot \left\{ \ddot{\delta} \right\} + [B] \cdot \left\{ \dot{\delta} \right\} + [K] \cdot \left\{ \delta \right\} = \left\{ F(t) \right\} \quad (6)$$

where $F(t)=H \cdot \sin(pt)$ is harmonic excitation force which acts in node k of the axial structure, in direction of the generalized coordinate $\delta_k, 1 \leq k \leq N$. The column vector of order N is $\left\{ F(t) \right\} = \left\{ 0 \ 0 \dots F_k \dots 0 \ 0 \ 0 \right\}^T$, $F_k=F(t)$, where H is an amplitude of the excitation force, p is circular frequency of the excitation force and the square matrices of order N are: $[M]$ - mass matrix of the axial structure; $[B]$ – damping matrix of the axial structure; $[K]$ – stiffness matrix of the axial structure.

General solution of the homogeneous part of equation (6) describes free vibrations of the axial structure. Particular solution of the inhomogeneous part of equation (6) describes vibrations of the axial structure caused by the harmonic excitation force. Due to damping in the material, free vibrations quickly disappear, meaning that only particular solution of the equation (6) remains, which describes stationary vibration regime of the axial structure, due to the effect of the harmonic excitation force $F(t)$.

The analytical solution of the problem of steady-state forced vibrations was found with the method of complex amplitude, because of the simple determination of the amplitude-frequency and phase-frequency characteristic.

3. METHODOLOGY OF THE EXPERIMENTAL IDENTIFICATION AND THE EXPERIMENTAL MODEL

The experimental identification of the dynamic behavior is performed by applying the appropriate excitation force in the system. Type of excitation force most frequently used are sine and impulse excitation force and here both excitation forces were used. The principle of absolute excitation was used when applying the sine excitation force and, for the impulse excitation force method, the specialized GenRad 2515 computer and RTA (Real Time Analysis) software package were used. For spindle assembly excitation the B&K equipment was used. The thermal influence on the dynamic behaviour of the assembly considered was determined by applying impulse excitation force. The experimental model is shown on Figure 2, where angular-contact ball-bearings were used with a 45°.

The front-end support consists of three bearings (FAG-B7011C.TPA.P4.K5.UL) in "Tandem-0" arrangement and the rear-end support consists of two bearings (FAG-B7008C.TPA.P4.K5.UL) in "O arrangement". The parameter variation for the experimental, model was done by quantity and arrangement of front-end bearings (Fig. 3).

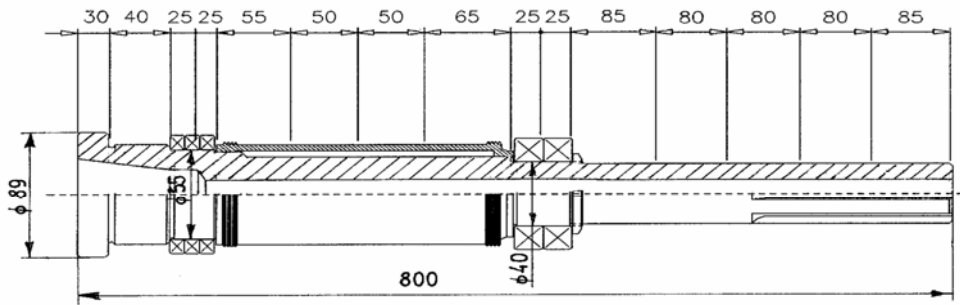


Fig. 2 Experimental model of main spindle assembly with ball bearings with angular contact

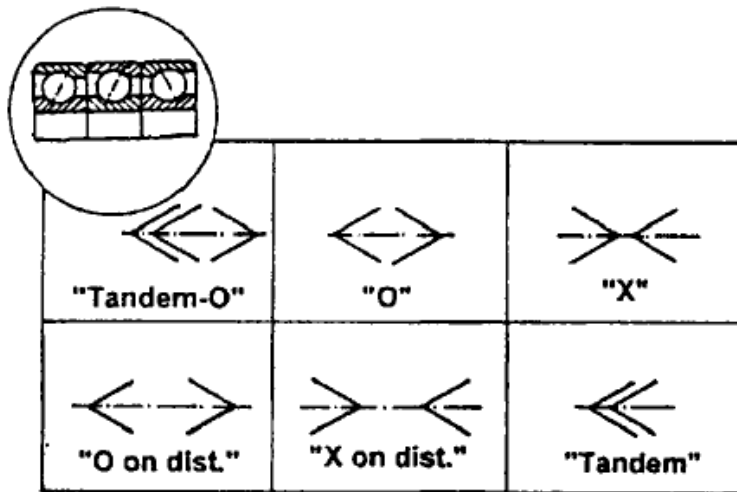


Fig. 3 Variants of the front-end bearing arrangements of the spindle assembly

4. RESULTS AND DISCUSSION

Circular frequency „p“ of the excitation force is considered in the range from 0 to 40000 Hz. This range ensures that four main spindle resonant areas are included. Higher resonant areas are out of range in which circular frequencies of the excitation force are exploited and for that reason not taken into consideration. Main vibrations forms and natural frequencies depend on the parameters of the system; these are the inner characteristics of the system, independent on outside effects.

Change of the preload value cause insignificant change in the natural frequencies values. It can therefore be concluded that bearing preload has little influence on the lowest natural frequencies of the system. Furthermore, change of the preload value does not practically influence the main vibrations forms; biggest displacements through first and second natural frequencies are happening at the end of the spindle, where the greatest load can be expected (Fig. 4), because of the significant length of the spindle end. Each natural frequency is separated into two parts due to the gyroscopic moment action (i.e. because of the main spindle rotation).

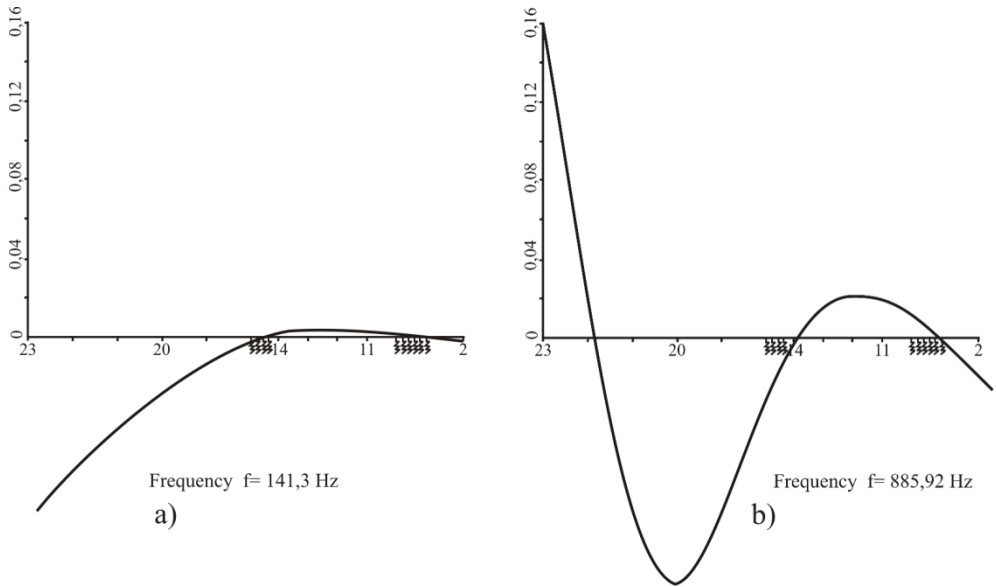


Fig. 4 Main vibrations forms: a) I vibration form b) II vibration form

In dynamic behaviour analysis the software packages use beam shaped finite elements. The values for the first two natural frequencies obtained with different software systems are shown in Table 1.

Table 1 Natural frequency values in Hz for different bearing arrangements

Software system	Type of finite element	Freq. [Hz]	Bearing arrangement				
			<<>	< >	<>	> <	>>
ANSYS	beam	f_{01}	139,5	140,3	139,8	138,7	140,5
		f_{02}	862,7	854,5	854,1	834,6	854,4
VRETENO	beam	f_{01}	141,2	141,1	140,2	140,6	140,1
		f_{02}	886	886	880,4	886,6	880,4

Experimental identification of the dynamic behavior was done for five bearing arrangements by using the sine and for "Tandem-0 variant by using the impulse excitation force.

Comparison for f_{01} obtained by computer aided modeling and by experimental identification with sine excitation force, for different bearing arrangements is shown in Table 2. In experimental identification it was assumed that the natural frequency is equal to the resonant frequency.

Table 2 Comparison of the f_{01} , for computer aided modeling and experimental identification

Bearing arrangements	f_{01} [Hz]		Difference [%]	
	Experiment	Exp.	Ansys	Vreteno
<<>	115,15	0	21,15	22,71
< >	114,19	0	22,86	23,74
<>	115,21	0	21,35	21,96
> <	113,25	0	22,40	24,77
><	113,35	0	23,95	23,95

Obtained higher deviation values in the Table 2 can be explained by the small stiffness of the quill of the main spindle and its influence on natural frequencies, which is not taken into account in computer modeling. Experimental investigation by pulse excitation force on subassembly of existing quill, quill and other elements of the experimental model showed that second natural frequency of the subassembly is: 125.3 Hz, when measured at the top of existing quill and 125.7 Hz, measured at the top of quill. These results show that a low value of the first natural frequency of the main spindle assembly is a consequence of other elements of the considered structure. Having in mind that housing is a very specific structure (a classical housing does not exist as such; only a carrying bush), comparison of results obtained by pulse excitation force of the main spindle [20] is carried out. Obtained values of the natural frequencies were $f_{01}=285$ Hz and $f_{02}=832.9$ Hz [24]. By application of the software system VRETENO, with very small supports stiffness, following values of natural frequencies are obtained: $f_{01}=280.9$ Hz and $f_{02}=874.9$ Hz. Deviation of the modeled data from experimental values for first natural frequency is +1,44 %, and -5.04 % for second natural frequency, which is completely satisfactory.

The second modal parameter - damping – was experimentally determined by more than one method. In the case of the sine excitation force ζ . was determined from amplitude-frequency characteristic (ζ_{sr}) and from corresponding real and imaginary part of the transfer function (ζ) and, in the case of the impulse excitation, by using the RTA software.

Assumed that spindle assemblies can be considered as systems with small uniform damping and that damping practically does not depend on the frequency, the values of the logarithmic damping decrement δ were determined from the experimentally obtained static characteristics, which have small hysteresis.

Comparison of these values with $\delta= 2\pi\zeta$ {, where ζ was experimentally determined using the sine excitation force, is shown in Table 3 for different bearing arrangements. Based on presented results one can conclude that the value for ζ can be obtained directly, or through determination of the value for δ . In other words this confirms the small uniform damping hypothesis and the neglectable dependency of damping on frequency in assemblies considered.

Table 3 Comparison of the damping δ obtained by static identification by using the sine excitation force

Bearing arrangements	Damping			Difference [%]	
	$\delta_1=2\pi\xi_1r$	$\delta_2=2\pi\xi_2$	δ_{st}	$(\delta_{st}-\delta_1)/\delta_1*100$	$(\delta_{st}-\delta_2)/\delta_2*100$
<<>	0,0777	0,074	0,0749	-3,6	1,22
< >	0,0688	0,0645	0,0507	-26,3	-21,39
<>	0,0735	0,0772	0,07	-4,76	-9,33
> <	0,0677	0,0668	0,0482	-28,8	-27,8
><	0,0645	0,0648	0,0604	-6,36	-6,79

Main spindle stability is determined by Nyquist diagrams, i.e. by amplitude-phase characteristics. On the considered main spindle assembly, reaction of the excitation force radially directed to node 1 is observed, as well as reaction in node 23 (Fig. 3) at coordinate $\delta_{58}=u_{23}$. On Figures 5, 6 and 7, phase-frequency, amplitude-frequency and amplitude-phase characteristics of the system in node 23 for different specification approaches of the damping system are shown on Figure 5, 6 and 7. It can be seen that by using the logarithmic decrement approach, highest peak values are obtained by the amplitude-frequency characteristic.

Segments where amplitude-phase characteristics are on the negative part of the real axis are decreasing when the logarithmic decrement is increasing, which confirms that the stability of the vibrations stationary regime is increasing. Maximal coordinates on the negative part of the imaginary axis present reciprocal damping module of the system.

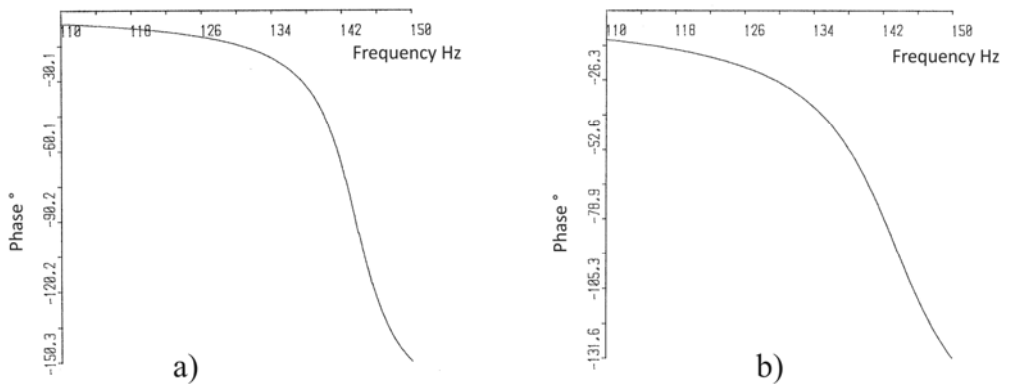


Fig. 5 Phase frequency characteristic in the node 23 at damping specification by a) „ δ “; b) „ α “ and „ β “

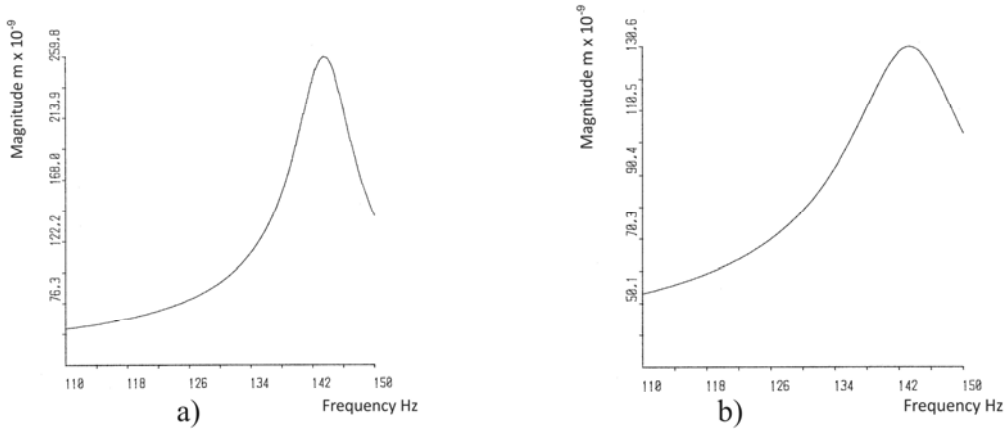


Fig. 6 Amplitude frequency characteristic in the node 23 at damping specification by a) „ δ^α ”; b) " α " and " β "

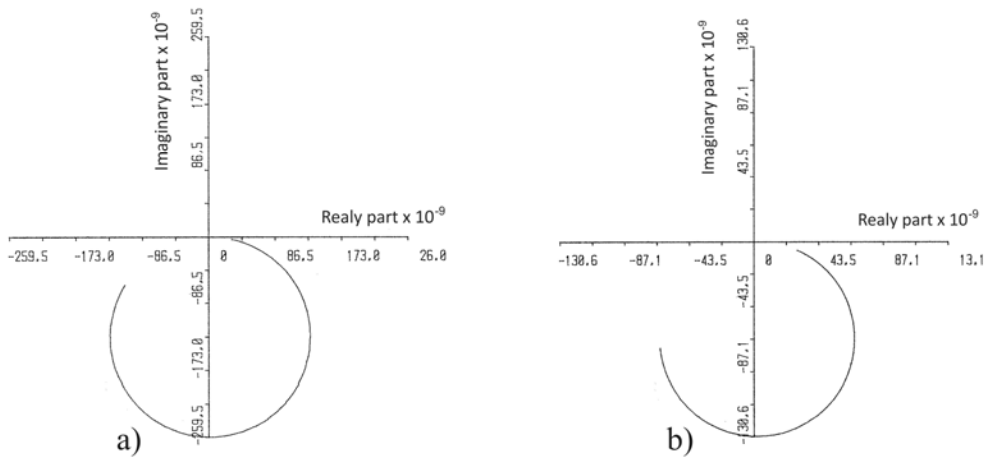


Fig. 7 Amplitude phase characteristic in the node 23 at damping specification by a) „ δ^α ”; b) " α " and " β "

5. CONCLUSION

The methodology of complex experimental research presented in this paper has been applied to the analysis of high-speed spindle assemblies with several bearing arrangements. It is worth noting that this methodology has been, also, successfully used for low-speed machine tool spindle assembly analysis [20]. The comparison of the experimentally obtained results with results obtained by computer aided modeling gives satisfactory results. Based on results obtained one can conclude that, by using available software systems for calculation and analysis, relevant characteristics of the designed spindle assembly solution can be obtained even at the design phase. The above results show, also, that the software system VRETENO satisfies all requirements, compared with other software system and with experimental identification. Also these results approve the usage of the extended technical (Timoshenko) beam theory and confirm the hypothesis that the mechanical systems considered have small uniform and proportional damping.

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PRIMJENA KOMPOZITA OD KARBONSKIH VLAKANA U AUTOMOBILSKOJ INDUSTRIJI

Dejan Jeremić¹, Nebojša Radić²

Rezime: Kompozitni materijali se već dugi niz godina koriste u automobilskoj industriji. Nesporne su prednosti kompozitnih struktura u odnosu na metalne strukture, kao što su: bolji odnos čvrstoće i mase, smanjeno vrijeme za održavanje tokom eksploatacije, produženi životni vijek automobila, smanjen ukupan broj strukturalnih dijelova i manjih podsklopova, manji broj veznih elemenata, veća otpornost na koroziju i oštećenja usled zamora materijala, itd. U radu je prikazan kratak pregled korišćenja kompozitnih materijala u automobilskoj industriji, a poseban pažnja je posvećena karbonskim vlaknima. Dat je pregled savremenih dostignuća u oblasti njihovog projektovanja i proizvodnje.

Ključne riječi: kompozitni materijali, karbonska vlakna, projektovanje, proizvodnja

IMPLEMENTATION OF CARBON FIBER IN THE AUTOMOTIVE INDUSTRY

Abstract: Composite materials have been used in the automotive industry for many years. Advantages of composite structures versus metal structures are indisputable, such as: better relationship strength and mass, reduced time to maintain during exploitation, extended car lifetime, reduced the total number of structural components and smaller subassemblies, less number of fasteners, greater resistance to corrosion and damage caused by fatigue of materials, etc. The paper gives a brief overview of the use of composite materials in the automobile industry, and special attention is given to carbon fiber. Current breakthroughs in the field of design and production are presented.

Keywords: composite materials, carbon fiber, design, production

1. UVOD

Upotreba kompozitnih materijala za pravljenje trkačkih automobila bilo je značajno otkriće u automobilskoj industriji, zato što su prvobitni trkački automobile bili napravljeni od aluminijumske šasije, koja je bila podložna pucanju. Kasnih 1980-ih, upotreba naprednih kompozitnih materijala izazvala je revoluciju u svijetu automobilske industrije. Takvi kompozitni materijali su obezbjedili pogodna rješenja za šasije trkačkih

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automobila, tako da oni nisu postali samo lakši, već čvrsti i robusni, nudeći vozaču više sigurnosti u slučaju sudara.



Sl.1 Šasija sportskog automobila [5]

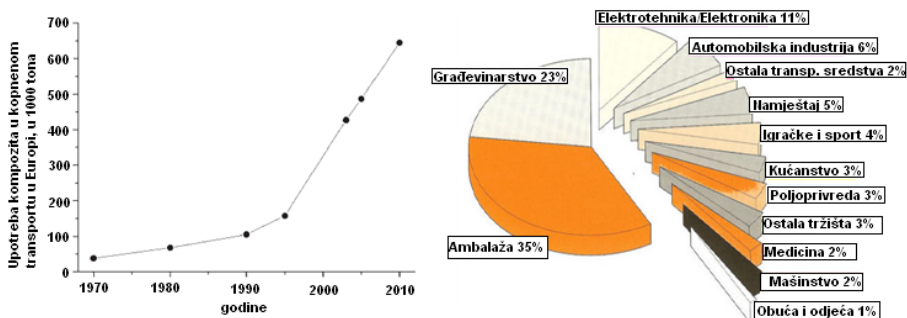
Zbog upotrebe ovih materijala u proizvodnji sportskih automobila kao i njihove rastuće isplativosti, polako ali sigurno, danas u 21.vijeku, korišćenje kompozitnih materijala u proizvodnji automobila je postao standard. Prvi kompozitni materijali uključuju i fiberglas koji je razvijen 1940-ih nije našao svoje mjesto u automobilskoj industriji tog vremena, zbog ograničenosti tadašnje auto tehnike. Danas fiberglas ima primjenu gotovo svuda, uključujući daske za surfovanje, zastakljivanje, brodogradnju, kao i izradu šasije automobila (sl.1).

Kompozitni materijali se prave kombinacijom dva ili više materijala sasvim različitih osobina. Pojedinačni materijali sjedinjeni u jedinstveni material koji ima sopstvene osobine, ne mješaju se na način da gube svoje sopstvene osobine. To je ono što kompozitni materijal čini snažnijim od materijala korišćenih za njegovo dobijanje. U napravljenom kompozitnom materijalu (obično od dva materijala), jedan se naziva matrica, koji okružuje i drži jato fragmenata mnogo jačeg materijala, koji se naziva ojačanje i predstavlja drugi materijal. Materijali ojačanja i matrice prolaze proces oblikovanja u kome se kombinuju i sjedinjuju. Postoji više metoda oblikovanja, uključujući oblikovanje presovanjem, vakuumsko oblikovanje i između ostalog oblikovanje smolom. Korišćeni materijali u automobilskoj industriji za izradu kompozitnih materijala su: aluminijum, čelik, ojačana silikonska guma, a najviše karbonska vlakna.

Automobilski proizvođači koriste metod oblikovanja presovanjem za izradu šasija, u kojoj je kompozitni materijal transformisan u lisnato oblikovano jedinjenje ili u grupno oblikovano jedinjenje. Prvo jedinjenje je plastični list ojačan neprekidnim vlaknima, a drugo jedinjenje je plastični grumen kombinovan sa kratkim vlaknima. Skorije inovacije u sferi naprednih kompozitnih materijala u automobilskoj industriji dovele su do upotrebe plastike ojačane karbonskim vlaknima, različitih varijacija kompozita, uključujući vlakna aramida i karbonska vlakna u matrici epoksidne smole. Automobili Formule 1 s početka 1990-ih su imali šasije napravljene od plastike ojačane karbonskim vlaknima. U procesu proizvodnje smola ojačana karbonskim vlaknima se polaže u kalup, koji je stavljen u presu visokog pritiska i temperature. Ovaj proces presovanja i pečenja konačno dovodi do dobijanja kompozitnog materijala.

2. KOMPOZITNI MATERIJALI U AUTOMOBILSKOJ INDUSTRIJI

Već postoji veliki broj kompozita koji se koriste u automobilske industriji. Polimerni kompoziti pojavili su se u automobilima ubrzo nakon završetka Drugoga svjetskog rata. Upotreba im je u početku bila ograničena na male i sporedne komponente. Veliki korak naprijed bilo je vozilo *Chevrolet Corvette*, proizvedeno 1953., čiji su dijelovi karoserije bili izrađeni od poliestera ojačanog staklenim vlaknima. U Istočnoj Njemačkoj se 1950-ih počeo proizvoditi *Trabant*, koji predstavlja početak upotrebe biljnih vlakana jer mu je šasija bila napravljena od pamučnih vlakana u poliesterskoj matrici. U kasnim 1970-ima zbog potrebe za manjom masom automobila razvijene su mnoge nove primjene kompozitnih materijala te je upotreba znatno povećana. Kompoziti, koji su do tada uglavnom izgrađivali kozmetičke dijelove, počeli su se ozbiljno razmatrati kao materijal za strukturne komponente. Izgrađivali su nosače hladnjaka, potpore za prenos, lisnate opruge i točkove. Injekciono presovanje primijenjeno je 1984. u izgradnji drugoga visokoserijskog automobila čija je cijela karoserija bila izgrađena od kompozita, *Pontiaca Fiero*. Početkom 1990-ih posredno presovanje pokazalo se kao pogodan postupak proizvodnje karoserije.



Sl.2 Porast upotrebe polimernih kompozita [1],[2]

Danas su rijetki dijelovi automobila koji nisu napravljeni od kompozitnih materijala. Naglasak se stavlja u prvom redu na dobit, ali i na zaštitu okoline. Stoga se provode brojna istraživanja i sve više raste upotreba biomaterijala u kompozitima.

Za modele kod kojih cijena nije ograničavajući faktor upotrebljavaju se kompoziti od epoksidne duromerne matrice i ugljeničnih vlakana. Osim razvoja lakših kompozita s boljim mehaničkim osobinama, radi se na razvoju upotrebe svih komponenata u kompozitu [1],[2].

3. PROIZVODNJA I PRIMJENA KARBONSKIH VLAKANA (Carbon fiber)

Carbon fiber su u prijevodu i praksi ugljenična odnosno, kako je svima draže reći, karbonska vlakna. Formiraju se pod velikom temperaturom i kao takva sadrže između 93% i 95% karbona. Postoje tri vrste: ona standardne (250 GPa), srednje(300 GPa), i visoke elastičnosti (> 300 GPa). Otpor na istezanje, odnosno vlačna čvrstoća se proteže od 2000 do 7000 MPa. Također imaju i veliku toplotnu otpornost.

Karbonska vlakna već se dugi niz godina smatra čudnovatim materijalom koji se sve masovnije koristi u automobilske industriji zbog svojih prednosti – izuzetno velike

čvrstoće i male težine (mase). Pored očitih prednosti svoje čvrstoće u odnosu na masu, te mogućnosti oblikovanja u različite oblike, ovaj kompozitni materijal ima i svoju cijenu koja ograničava njegovu masovnu upotrebu u automobilske industriji. Razvoj automobilske tehnologije je izuzetno velik, pa je njemački proizvođač automobilskih dijelova i sklopova ZF napravio novi veliki korak u smjeru intenzivnijeg korišćenja karbonskih vlakana u konstrukciji vozila. Tvrtka ZF je napravila dio prednjeg vješanja, tačnije nogu MacPhersona od karbonskih vlakana. Prema izjavi stručnjaka ZF-a novi sistem za vješanje je puno lakši, jer su nosač točkova i osovina izrađeni iz karbonskih vlakana, dok je zavojna opruga izrađena iz stakloplastike (sl.3). To je u biti vrlo slično rješenje koje se niz godina koristi i kod automobila Corvette.



Sl.3 ZF-ovam noga MacPhersona [4]

Cijeli pokrov izveden je iz posebno konstruirane plastike. ZF je MacPherson sistem za vješanje izrađen iz karbonskih vlakana konstruisao za male automobile koji bi se do 2014. godine trebali naći u prodaji, ali stručnjaci ZF-a objašnjavaju da se ista konstrukcija bez problema može koristiti i na većim automobilima. Na kritiku nekih stručnjaka, kako u ZF-u misle inače skupi materijal kao što je karbonska vlakna koristiti na malim i jeftinim automobilima, iz njemačkog proizvođača objašnjavaju da za to nema prepreke. Zahvaljujući novom materijalu od kojeg je napravljeno vješanje može se znatno više uštedjeti na jednostavnijem sklapanju, jer je ovaj ovjes izrađen iz manjeg broja dijelova nego klasičnim materijalima[4]. Karbon je jedan od najlakših i najtvrdih materijala orijentiranih prema performansama, uz to, on je jedan od najljepših performans materijala.

Kompozitni materijali sve više zauzimaju mjesto metalu. Najočigledniji napredak kompozitni su materijali ostvarili u automobilske industriji, posebno u području trkačkih vozila. Vjerovatno jedan od najpoznatijih kompozitnih materijala u svijetu automobilizma je plastika, ojačana s karbonom (CFRP- *Carbon-fiber-reinforced polymer*), lagana, čvrsta, a kao završni proizvod ima strukturu saća na sebi.

Posmatramo materijal koji je napravljen od kombinacije vlakana i polimera. Naravno, tu ima i karbona, ali on čini samo pola tog materijala. Ta tri materijala spojena s otopinom ljepila, koja se obično bazira na epoxy-u, čine CFRP. Generalno je prihvaćeno da se ta kombinacija materijala jednostavno zove karbon. Vlakna karbona se dobivaju iz jednog od dva prethodnika. Prethodnik, u znanstvenom smislu, bio bi biohemijska supstanca koja je direktna posljedica reakcije dva spoja. Iz te reakcije je stvoren stabilniji proizvod, u ovom slučaju su to karbonska vlakna. Karbon nastaje od spoja dvaju prethodnika, njih zovemo PITCH bazirana vlakna i PAN (poliakrilonitrile) bazirana vlakna.

PITCH bazirana vlakna imaju niska mehanička svojstva, kao rezultat toga oni se generalno ne koriste za materijale kod kojih je potrebna čvrstoća. PAN bazirana vlakna imaju visoki stepen čvrstoće te su vrlo lagana.

Prvi u nizu dobijanja karbona je oksidacija PAN baziranih vlakana. Ovo uključuje grijanje na oko 300 stepeni Celzijusa. Kao rezultat toga molekule vodonika, unutar vlakana, evolviraju i to mjesto zauzima kiseonik, koji je prirodno puno stabilniji. Ovaj proces izmjenjuje molekularnu strukturu vlakana u puno stabilniju strukturu, a vlakna mijenjaju boju od bijele prema smeđoj i na kraju postaju crna.



Sl.3 Dijelovi od karbonskih vlakana [6]

Drugi dio procesa zove se karbonizacija. Ovo je još jedan proces koji uključuje grijanje, ponovno na 300 stepeni Celzijusa. Na kraju ovog procesa imamo gotovo 100% čisti karbon. Važno je napomenuti da temperature koje se koriste u ovom dijelu procesa, određuju stepen kvalitete karbonskih vlakana [6].

Karbon zagrijavan pri temp. 1500-2000 °C bit će otporniji na istezanje (5,650 N/mm² ili 5,650MPa) i tada se dobije High Tensile Strength Carbon Fiber T-700, a pri temp. 2500-3000 °C imat će veću elastičnost (531 kN/mm² ili 531 GPa). Ime ovoga je High Modulus Carbon Fiber, 10% je jači te 20% čvršći od onog T-700. Treći je High Strength Unidirectional Carbon Fiber ET Epoxy i čini kompromisizmeđu prethodna dva.

Sljedeći korak zove se površinski tretman koji uključuje formiranje hemijskih veza na površini karbonskih vlakana i omogućava bolju povezanost s ostalim vlaknima. Na kraju svega, koristi se ljepilo koje štiti vlakna u daljnjim procesima obrade. Sada imamo kompletan proizvod. Da bismo dobili vlakna u fazu u kojoj ih možemo koristiti kao materijal, vlakna se moraju povezati u nizove. Ovo je također prilika da se odredi čvrtoća krajnjeg proizvoda, kako bi se mogao pravilno klasificirati. Na primjer, 3K karbon je napravljen od 3000 vlakana u jednom nizu, on je tri puta čvršći od 1K karbona, ali je i tri puta teži. U nekim primjenama se koristi čak i 320K karbon.

Nizovi se sada pletu u platno s kockastim uzorkom pa je upravo to trenutak kada materijal započinje poprimiti prepoznatljivu formu sa svojim crnim sjajem i sačastim uzorkom. Izgled platna zavisi od debljine nizova i stila, kao i od čvrstoće nizova.



Sl.4 Plahte karbona [6]

Od ove točke kao i svaki drugi CFRP, plahte karbona (sl.4) nanose se u slojevima u kalupe iz kojih se vadi završni proizvod. Broj slojeva karbonskih plati određuje snagu završnog proizvoda. Nakon što se krajnji proizvod izvadi iz kalupa, krajnji rezultat je proizvod koji je čvrst, lagan, otporan na koroziju i zamor materijala. On može biti hauba, sjediste, krilo ili bilo koji dio limarije automobila.

Kao generalna usporedba, karbon ima otprilike četiri i pol puta manje gustoće od čelika visoke gustoće, no čvrstoća karbona je 3.5, a čelika visoke gustoće 1.3. U osnovi to znači da je karbon četiri i pol puta lakši te tri puta čvršći. U usporedbi sa stakloplastikom, karbon je također superioran, posebno kada se usporede težina i čvrstoća. Nažalost, kao i svi materijali bazirani na vlaknima, karbon nije vrlo otporan na iznenadne udarce. Uz to je skup u usporedbi s ostalim materijalima koji se koriste u automobilskoj industriji, no kroz vrijeme će se to vrlo vjerojatno promijeniti, s daljnjim razvojem proizvodnog ciklusa.

Najvažnije osobine karbonskih vlakana :

- velika čvrstoća (ovisno o klasi)- mala težina- velika elastičnost (ovisno o klasi)
- visoka termička otpornost- smanjuju vibracije
- dimenzionalna stabilnost- elektromagnetski štiti- dostupniji, jeftiniji, prilagodljiviji nego ikad prije.

Imaju oni i negativne strane :

- abrazivna neotpornost
- propusnost X zraka
- kompliciran rad s njima
- male temp. izdržljivosti smola s kojima se radi
- komplicirano za legiranje sa nekim materijalima

U proizvodni proces odlazi dobar dio novca kod kupovine karbonske haube. Ostatak novca jednostavno odlazi na činjenicu da je to navjerojatan izum. Nikada prije svijet nije vidio materijal koji ima toliko prednosti nad metalom i postojećim kompozitnim materijalima, uključujući kevlar. Jedini pravi nedostatak karbona je njegova visoka cijena.

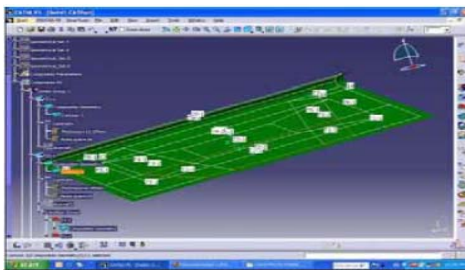


Sl.5 Karoserija automobila Z30 [7]

Na prvi pogled bi se isto moglo reći i za novi projekt Rocky Auto tuning kuće iz Japana (sl.5). Ovaj Z30 bio je prikazan na Yokohama Nostalgic izložbi automobila 2010 godine. Kompletno je izrađen od karbona. Kada u pitanje dođe proizvodnja dijelova, koji čine vaše vozilo lakšim i čvršćim, jednostavno ne postoji bolji materijal za taj posao od karbona.

4. PROJEKTOVANJE I INTEGRACIJA SA PROIZVODNJOM

Projektovanje kompozitnih dijelova i sklopova danas je mnogo olakšano razvojem savremenih CAD softvera koji imaju posebne module za kreiranje svakog pojedinog sloja kompozitnog dela, uključujući i sendvič konstrukcije. Projektant može da koristi određene materijale iz ranije formiranih kataloga materijala sa svim njihovim mehaničkim i fizičkim karakteristikama. Slojeve izabranog materijala projektant vezuje za ranije oblikovane trodimenzionalne entitete (solid ili površinski model),[8]. Trenutno je na tržištu najkompletniji softver za projektovanje složenih kompozitnih dijelova softver CATIA firme Dassault Systemes.



Sl.6 Savremeni CAD softver za projektovanje kompozitnih struktura [8]

Poboljšanja u proizvodnji kompozitnih sklopova su ostvorena zahvaljujući tehnološkim inovacijama koje su omogućile da se originalan i isti CAD softver koji se koristi tokom procesa projektovanja koristi za definisanje parametara u proizvodnji. Korišćenjem originalnih datoteka koje je prethodno koristio projektant tokom projektovanja nekog sklopa za kreiranje proizvodnih parametara mašina u fabrici eliminiše višestruko pretvaranje projektnih parametara datih u jednom obliku u druge oblike koje je ranije zahtijevao proizvodni postupak fabrike (npr. ručno slaganje slojeva laminata ili maloserijsko automatizovano mašinsko slaganje). Neki od vodećih svjetskih proizvođača sofisticiranih mašina za slaganje slojeva laminata su se oslonile na CAD/CAM softver za projektovanje i izradu CATIA. Istovremeno su za operative sisteme svojih novih mašina umesto Unix-a izabrale rasprostranjeniji Microsoft Windows.

5. ZAKLJUČAK

Nesporna je uloga koju savremeni kompozitni materijali imaju u automobilskoj industriji. Njihovom primjenom automobili su postali bezbjedniji, brži, možda skuplji za izradu, ali jeftiniji u eksploataciji, itd. Strana iskustva pokazuju da je neophodna automatizacija procesa izrade ako se želi dobiti jeftinija a kvalitetnija kompozitna struktura. Primjena kompozitnih materijala u budućnosti zavisice od osvajanja i usvajanja novih tehnologija proizvodnje kompozita i njihove primjene na novim

konstrukcijama, kao i smanjenja vremena izrade velikih kompozitnih sklopova i cijene korišćenja novih materijala primjenom novih metoda proizvodnje. Istovremeno, sadašnje i nove generacije projekatata nužno će se prilagoditi filozofiji projektovanja kompozitnih automobilskih struktura. Daljim razvojem u oblasti automatizacije i robotizacije proizvodnje kompozitnih dijelova i sklopova neminovno će se primjena kompozitnih struktura sa automobilske industrije raširiti i na druge grane.

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UTICAJ HABANJA BURGIIJA NA AKSIJALNU SILU BUŠENJA

Obrad Spaić¹, Budimirka Marinović²

Rezime: Kako vrijednosti parametara habanja reznih alata direktno utiču na karakteristike stanja, i izlazne tehno-ekonomske efekte obradnog procesa, identifikacija habanja alata u procesu obrade ima izuzetan značaj, jer se na bazi triboloških mjernih signala, mogu razviti sistemi upravljanja i optimizacije obradnog procesa. S obzirom na poteškoće direktnog mjerenja habanja reznih alata, kao alternativa, razvijen je veći broj indirektnih metoda, kojim se habanje alata procjenjuje na osnovu promjene signala mjerljivih parametara tokom procesa, a stoje u određenim korelacionim vezama sa intenzitetom, karakterom i brzinom habanja reznih alata. Umjesto analitičkih i eksperimentalno-analitičkih (regresionih) modela habanja reznih alata, u posljednje vrijeme, sve više svjetskih i domaćih istraživača za postavljanje modela habanja reznih alata primjenjuje vještačku inteligenciju. U ovom radu je postavljen model habanja reznih alata na osnovu eksperimentalno uspostavljenih korelacionih veza između aksijalne sile bušenja, kao najvjernijeg nosioca informacija o fenomenu habanja, i širine pojasa habanja ledne površine, primjenom vještačkih neuronskih mreža.

Ključne riječi: Habanje, direktne i indirektno metode mjerenja, neuronske mreže

INFLUENCE OF WEARING DRILLS ON DRILLING AXIAL FORCE

Abstract: *As wearing parameters of cutting tools affect on the state characteristics and techno-economic effects of the machining process, the identification of tool wearing in process is extremely important because the tribological based measurement signals can develop control systems and optimization of processes. Because of the difficulty of direct measurement of cutting tool wear, as an alternative, they developed indirect methods. These methods estimate tool wear on the basis of measurable parameters of signal changes during the process, and these parameter are in correlation with the intensity of relationships, character and speed of cutting tool wear. Lately, more and more national and international researchers apply artificial intelligence as models tool wearing, instead of analytical and experimental-analytical methods. This paper defines a model of cutting tool wear based on experimental correlations between the axial force, as the most trusted provider of information about the phenomenon of wear and wearing largeness, using artificial neural networks.*

Keywords: Wearing, direct and indirect measuring systems, Neural network

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1. UVOD

Postojanost, kao osnovni faktor kvaliteta svih reznih alata, u najvećoj mjeri zavisi od karaktera, intenziteta i brzine habanja reznih elemenata, tako da praćenje habanja reznih elemenata alata daje najvjerniju sliku o stanju alata u realnom vremenu, jer je habanje alata primarni generator slučajnih poremećaja s direktnim uticajem na sigurnost, kvalitet i ekonomičnost procesa obrade.

Na osnovu istraživanja Liang Y. S. [1] procjenjuje da je 20% zastoja u obradi rezanjem izazvano nepredviđenim trošenjem alata.

Praćenje stanja alata u realnom vremenu, pored blagovremene zamjene alata, omogućava, kako upravljanje procesima habanja alata, tako i automatizaciju obradnih i tehnoloških procesa u proizvodnim linijama.

Identifikacija istrošenosti i blagovremena zamjena reznog alata, naročito u masovnoj i velikoserijskoj automatizovanoj proizvodnji, isključuje mogućnost lošeg kvaliteta koji nastaje usljed nekontrolisanog habanja i smanjuje proizvodne troškove (povećava ekonomičnost obrade), jer se eliminišu troškovi koji potiču iz dvije krajnosti: ranijih (čestih) i kasnijih (sa razorenim reznim klinom) zamjena alata.

Kako habanje alata direktno utiče na najvažnije izlazne efekte procesa rezanja, to poznavanje modela funkcije habanja ima izuzetan značaj i može se koristiti za [2]:

- proučavanje i analizu procesa habanja,
- predviđanje stanja i trenutka zatupljenja alata,
- optimizaciju procesa habanja i
- upravljanje procesom habanja, a time i procesima obrade.

Modeli funkcije habanja, razvijeni na osnovu znanja o fenomenu habanja, mogu se grupisati u dvije grupe i to [3]:

- analitičke i
- eksperimentalno analitičke (regresione).

Zbog velikog broja uticajnih faktora, kao i često nepoznatog međusobnog djelovanja mnogih pojava koje prate proces habanja, definisanje funkcije habanja jednostavnim matematičkim modelom koji bi bio primjenljiv u širokom području tehnoloških uslova i režima rezanja predstavlja dosta dugu, skupu i često nedovoljno pouzdanu proceduru.

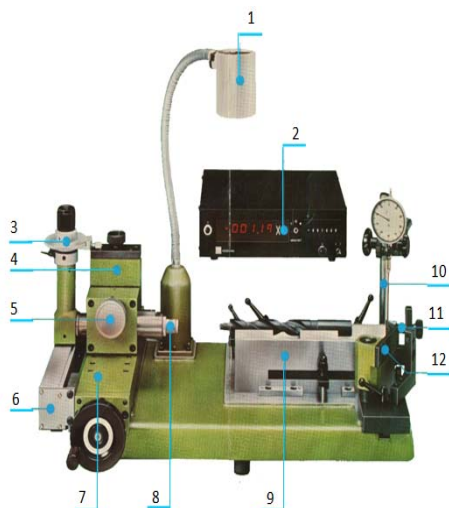
Zbog toga, u posljednje vrijeme, sve više svjetskih i domaćih istraživača za postavljanje modela funkcije habanja alata primjenjuje vještačku inteligenciju.

Tako su Gosh N. i drugi [4], u cilju dobijanja informacija o habanju alata u procesu rezanja, razvili model za praćenje stanja alata pomoću fuzije senzora zasnovan na neuronskim mrežama.

2. VANPROCESNO I PROCESNO MJERENJE HABANJA REZNIH ALATA

Sistemi za mjerenje parametara habanja alata mogu se svrstati u dvije grupe mjernih sistema: vanprocesne i procesne.

Sušтина vanprocesnih mjernih sistema sastoji se u tome što se mogu koristiti tek nakon prekida procesa rezanja i skidanja reznog alata sa obradnog sistema, off-line. Za vanprocesno mjerenje parametara habanja može se koristiti više optičkih, elektronskih ili kombinovanih mjernih uređaja. Jedan od uređaja za mjerenje geometrijskih elemenata reznih alata i vanprocesno, direktno mjerenje parametara habanja (GÜHRING PG 100) prikazan je na slici 1.



Sl. 1 Uređaj za mjerenje geometrijskih elemenata reznih alata

Osnovni dijelovi uređaja:

1. Halogena lampa,
2. Digitalni pokazivač mjerne veličine,
3. Podesivi okulator sa skalom za mjerenje uglova,
4. Mjerna jedinica za vertikalno mjerenje dužina,
5. Podešavanje oštrote slike,
6. Elektronski sistem za mjerenje dužina,
7. Mjerna jedinica za horizontalno mjerenje dužina,
8. Promjenljiva optika,
9. Kombinovani prizmatični nosač,
10. Mjerna jedinica za mehaničku kontrolu,
11. Mjerna jedinica za mjerenje ekscentričnosti,
12. Mjerna jedinica za mjerenje razlike visine sječiva.

Za mjerenje habanja alata pomoću procesnih senzora koristi se više metoda među kojima su najznačajnije direktne i indirektno. U direktne metode spadaju sve one tehnike mjerenja pomoću kojih se direktno, odnosno neposredno mjeri habanje u toku odvijanja procesa obrade.

Kod indirektnih metoda mjerenje habanja se vrši tokom rezanja i to mjerenjem različitih parametara procesa vezanih za trošenje alata (sile rezanja, vibracije, temperatura, obrtni moment ...).

Osnovu za razvoj senzorske tehnike u indirektnim metodama mjerenja habanja alata čini skup raznovrsnih signala koji potiču iz jedinica obradnog sistema, a koji su funkcionalno povezani sa parametrima habanja alata određenim korelacionim vezama. Ovi signali predstavljaju nosioce informacija o veličini i brzini habanja elemenata reznog klina. Dakle, na ovaj način se dobijaju informacije o veličini habanja mjerenjem karakteristika procesa rezanja koje se relativno lakše mjere u odnosu na direktno mjerenje parametara habanja [5]. Njihova najznačajnija karakteristika vezana je za mogućnost praćenja istrošenosti u realnom vremenu uz kontinuirani ili "on-line" režim nadzora, čime se osiguravaju potrebni uslovi inteligentnog vođenja obradnog procesa. Zbog toga su, danas, indirektni mjerni sistemi najčešći izbor u konstrukciji i razvoju automatizovanih sistema nadzora habanja reznih alata.

Veliki broj istraživača koristi sile i otpore rezanja kao nosioce informacija o habanju alata. Tako Lin J. T. i drugi [6] pokazuju da jednačina sile rezanja, koja dovodi do habanja alata, daje približno tačno predviđanje vrijednosti habanja alata. Spaić O. i drugi [7] postavili su matematički model aksijalne sile kao nosioca informacija o fenomenu habanja pri bušenju čelika velike tvrdoće i čvrstoće ZB od brzoreznog čelika proizvedenog metalurgijom praha.

3. PRIMJENA NEURONSKIH MREŽA U MODELIRANJU HABANJA REZNIH ALATA

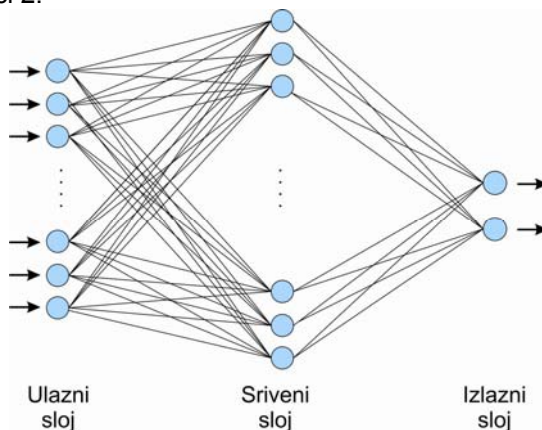
Neuronske mreže (n/m) kao alat uspješno rješava probleme vezane za klasifikaciju i predviđanja kod kojih postoji zavisnost između ulaznih i izlaznih varijabli bez obzira na složenost te zavisnosti.

Kreirane su tako da funkcionišu na osnovu dva principa preuzeta iz nervnog sistema [4]:

- Obrada informacija se obavlja pomoću paralelne distributivne arhitekture sastavljene od međusobno povezanih jednostavnih procesnih jedinica – neurona;
- Učenje (treniranje, ne programiranje) se zasniva na osnovu određenog broja riješenih primjera - problema za koje se specijalizuju.

Arhitektura n/m je formirana od većeg broja neurona koji su raspoređeni u slojeve povezujući izlaze jednih sa ulazima drugih. Veza sa radnom okolinom se ostvaruje preko ulaznih neurona koji prihvataju informacije iz sredine i izlaznih neurona koji generišu signale u akcije. Oni neuroni koji nisu u direktnom kontaktu sa okruženjem, a prenose signalie unutar mreže iz okruženja čine skrivene slojeve i služe za internu interpretaciju informacija o radnom okruženju.

S obzirom da analizirani slučaj pripada skupini problema predviđanja, u radu je primjenjena Back-Propagation Neuron network, čija je arhitektura, sa jednim skrivenim slojem, prikazana na slici 2.



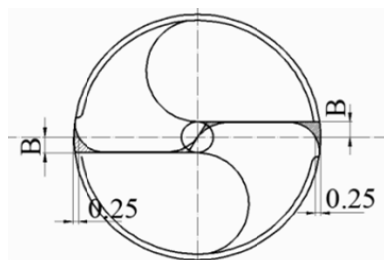
Sl. 2 Arhitektura Back-Propagation Neuron Network

3.1 Eksperimentalna istraživanja

Eksperiment je izveden pri bušenju slijepe rupe dubine $l=3d$ u epruvtama od hrom-molibdenovog legiranog alatnog čelika za poboljšanje Č.4732, termički obrađenim na tvrdoću 43–45 HRC, zavojnim burgijama (ZB) DIN 338, $\Phi 6.0$, od brzoreznog čelika sa 8% Co proizvedenog konvencionalnom metalurgijom (S2-9-1-8), naoštrenim krstasto (KO). Konstrukcija ZB izvedena je na osnovu preporuka iz literature za bušenje teškoobradljivih materijala – kaljenih čelika i stečenog iskustva, a proizvedene su tehnologijom brušenja.

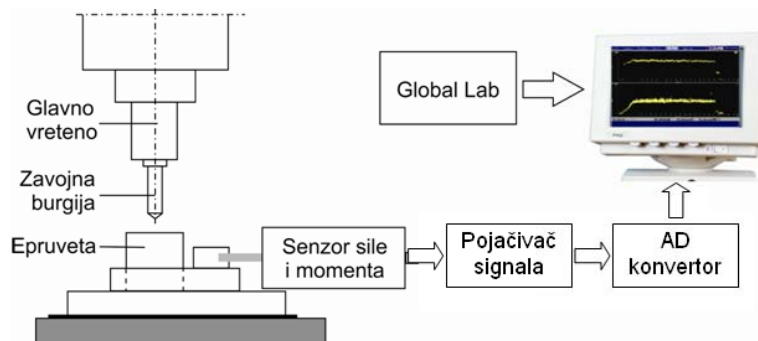
Ispitivanje je izvedeno pri brzini rezanja $v=9,42$ m/min i koraku $s=0.027$ mm/o i $s=0.107$ mm/o. Za hlađenje i podmazivanje upotrebljavan je 8%-tni rastvor teolina H/VR, količine 1 l/min.

Kao kriterij habanja izabrana je srednja vrijednost širine pojasa habanja leđne površine oba glavna sječiva, ilustrovano na slici 3, čije su vrijednosti mjerene optičkim uređajem GÜHRING PG 100, (slika 1).



Sl. 3 Habanje zavojne burgije

Mjerenje aksijalne sile bušenja vršeno je Piezo dinamometrom za mjerenje sile i obrtnog momenta TIP 9271A, integrisanim sa univerzalnom glodalicom i povezanim sa softverom Global Lab za akviziciju podataka, slika 4.



Sl. 4 Šema akvizicije podataka pri izvođenju eksperimenta

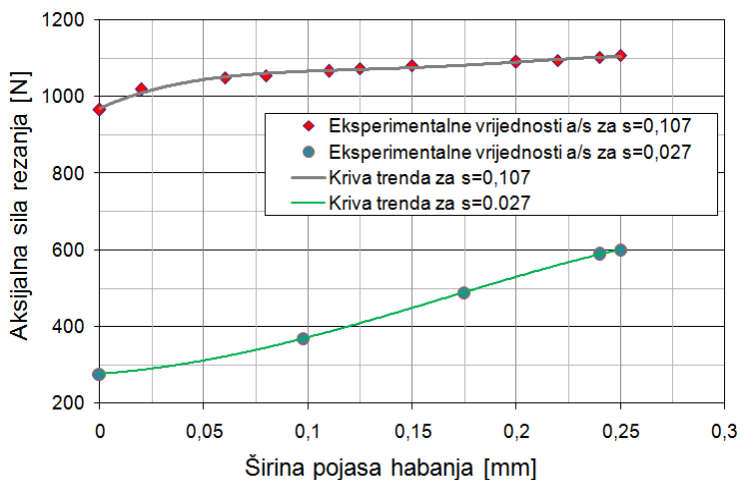
U svim mjernim tačkama prije mjerenja aksijalne sile izvršeno je mjerenje širine pojasa habanja leđne površine oba sječiva i izračunata srednja vrijednost B_d . Očitavanje vrijednosti aksijalne sile u mjernim tačkama vršeno je nakon ulaska vrha ZB u materijal, ne uzimajući u obzir eventualnu promjenu parametara habanja. Tako je pri prvom mjerenju aksijalne sile (oštrim ZB) srednja vrijednost širine pojasa habanja $B_d=0$. Posljednje mjerenje aksijalne sile izvršeno je pri dužinama bušenja pri kojoj je srednja vrijednost širine pojasa habanja iznosila $B_{d_{max}}=0.25$ mm ($\approx 0.04 D$).

Maksimalna srednja vrijednost širine pojasa habanja leđne površine oba sječiva $B_{d_{max}}=0.25$ mm ($\approx 0.04 D$) je unaprijed definisana kao kriterij zatupljenja.

Ostala mjerenja izvršena su pri dužinama bušenja pri kojima se srednja širina pojasa habanja nalazila u intervalu: $0 < B_{d_i} < B_{d_{max}}$.

Na osnovu rezultata mjerenja definisane su krive zavisnosti širine pojasa habanja i aksijalne sile bušenja, odnosno uspostavljena je korelaciona veza između širine pojasa habanja i aksijalne sile bušenja. Za definisane krive zavisnosti, primjenom softvera Microsoft Excel 2007, definisane su krive trenda, kao i polinomne jednačine koje opisuju te krive, ilustrovano na slici 5.

Definisanjem polinomnih jednačina krivih trenda zavisnosti aksijalne sile i dužine bušenja, obezbjeđen je dovoljan broj podataka za treniranje neuronske mreže.



Sl. 5 Krive trenda zavisnosti aksijalne sile bušenja od širine pojasa habanja

3.2 Modeliranje sile rezanja

Treniranje Back-Propagation n/m, iz softverskog paketa MATLAB 6.0, izvedeno je sa dva ulazna parametra i to: širinom pojasa habanja i korakom, i aksijalnom silom bušenja (F) kao izlaznim parametrom. Normirane vrijednosti parametara prikazane su u tabeli 1.

Tabela 1. Stvarne i normirane vrijednosti parametara za treniranje n/m

Ulazni parametri				Izlazni par.		Ulazni parametri				Izlazni par.	
s[mm/o]		B _d [mm]		F[N]		s[mm/o]		B _d [mm]		F[N]	
Stv.	Nor.	Stv.	Nor.	Stv.	Nor.	Stv.	Nor.	Stv.	Nor.	Stv.	Nor.
0.027	2.7	0.00	0	275.70	0.230	0.107	10.7	0.00	0	969.64	0.808
0.027	12.7	0.01	1	280.42	0.234	0.107	20.7	0.01	1	991.54	0.826
0.027	27.7	0.02	2	286.35	0.239	0.107	30.7	0.02	2	1009.45	0.841
⋮						⋮					
0.027	252.7	0.25	25	600.00	0.500	0.107	260.7	0.25	25	1104.58	0.920

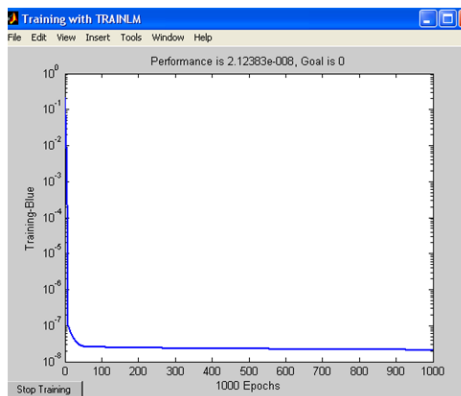
Treniranjem formirane n/m najbolje rezultate je postigla mreža čiji su parametri prikazani tabelom 2, a tok konvergencije na slici 6.

Vrijednosti aksijalne sile dobijene treniranjem n/m, kao i greške treniranja, za odgovarajuće ulazne parametre i zadati broj epoha (1000) prikazane su u tabeli 3, iz koje se vidi da je greška treniranja reda veličine od 10^{-4} do 10^{-6} . Navedeni podaci pokazuju da je formirana n/m dobro obučena i da se može primijeniti kao „crna kutija“ za simuliranje podacima koji nisu učestvovali u treniranju.

Simuliranje obučene n/m izvedeno je standardnim vrijednostima koraka iz intervala [0.027, 0.107], odnosno koracima 0.033, 0.042, 0.053, 0.067 i 0.084 mm/o, i širinom pojasa habanja.

Tabela 2. Parametri formirane n/m

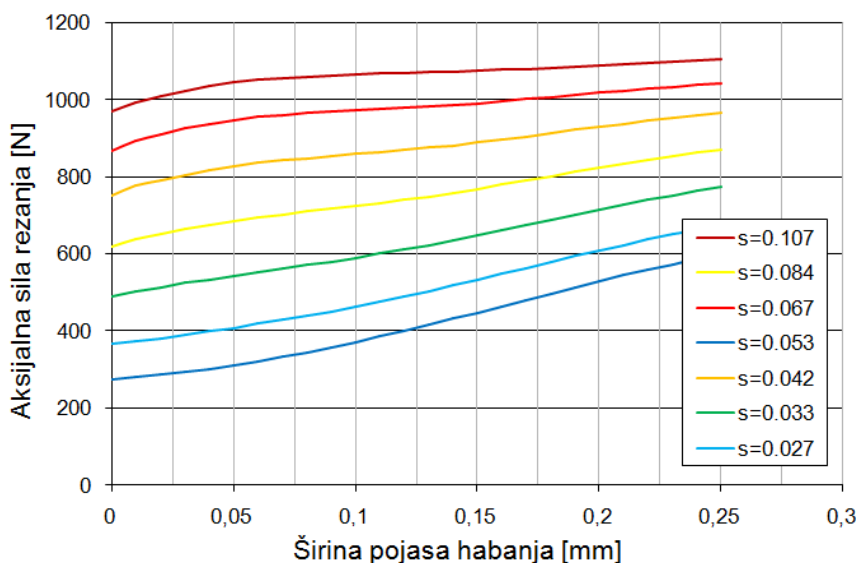
Parametar mreže		Usvojeno obilježje
Trening funkcija		TRAINLM
Funkcija učenja		LEARNGDM
Funkcija performansi n/m		MSE
Broj slojeva		3
Broj neurona	I sloj (ulazni)	2
	II sloj (skriveni)	42
	III sloj (izlazni)	1
Transfer funkcija	I sloj	TANSIG
	II sloj	
	III sloj	
Broj epoha		1000



Sl. 6 Tok konvergencije n/m

Tabela 3. Vrijednosti aksijalne sile i greške treniranja n/m

Red. broj	Ulazne vrijednosti					Trenirane vrijed.	Red. broj	Ulazne vrijednosti					Trenirane vrijed.
	s [mm/o]	B _d [mm]	F [N]	F [N]	Greška treniranja			s [mm/o]	B _d [mm]	F [N]	F [N]	Greška treniranja	
1.	2.7	0	0.230	0.23	-5.278e-006	27.	10.7	0	0.808	0.808	-6.807e-006		
2.	12.7	1	0.234	0.234	4.939e-006	28.	20.7	1	0.826	0.826	3.0202e-005		
3.	27.7	2	0.239	0.239	-1.632e-005	29.	30.7	2	0.841	0.841	-1.988e-005		
...		
26.	252.7	25	0.500	0.500	-0.0001452	52.	260.7	25	0.920	0.920	-0.00091046		



Sl. 7 Rezultati dobijeni simuliranjem n/m

Rezultati simuliranja, odnosno vrijednosti aksijalne sile u zavisnosti od širine pojasa habanja, za različite vrijednosti koraka, nakon vraćanja na stvarne vrijednosti, prikazane su dijagramom na slici 7, pri čemu su za korak $s=0.027$ mm/o i $s=0.107$ mm/o uzimani podaci dobijeni eksperimentom.

Sa dijagrama na slici 7 se jasno vidi da su u potpunosti dobijeni očekivani rezultati jer su vrijednosti aksijalne sile bušenja za simulirane standardne korake logično raspoređene između vrijednosti aksijalne sile bušenja pri koraku $s=0.027$ mm/o i $s=0.107$ mm/o, koje su dobijene eksperimentom.

4. ZAKLJUČAK

Na osnovu eksperimentalnih rezultata pri bušenju čelika velike čvrstoće i tvrdoće ZB Ø6, od brzoreznog čelika S2-9-1-8, naoštrenom krstasto, pri brzini rezanja $v=9,42$ m/min uspostavljen je model za aksijalnu silu bušenja u zavisnosti od širine pojasa habanja, primjenom vještačkih neuronskih mreža, za sve standardne korake iz dijapazona obuhvaćenog eksperimentom, odnosno upostavljena je zavisnost između vrijednosti habanja mjenjenih direktnim i indirektnim metodama.

Vrijednosti aksijalne sile dobijene simuliranjem obučenih neuronskih mreža, logično su raspoređene između vrijednosti aksijalne sile bušenja pri koracima pri kojima su izvedena eksperimentalna ispitivanja. Ovo nedvosmisleno potvrđuje da se neuronske mreže mogu adekvatno koristiti za modeliranje aksijalne sile kao pouzdanog nosioca informacija o fenomenu habanja reznih alata, u zavisnosti od uticajnih parametara.

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MODELIRANJE AKSIJALNE SILE REZANJA PRIMJENOM NEURONSKIH MREŽA

Obrad Spaić¹, Zdravko Krivokapić², Slavoljub Grče³

Rezime: Najvjerniju sliku o stanju alata u realnom vremenu daje praćenje habanja reznih elemenata alata. S obzirom na poteškoće direktnog mjerenja istrošenosti tokom procesa proizvodnje, razvijen je veći broj indirektnih metoda, kojim se istrošenost alata procjenjuje na osnovu promjene signala mjerljivih parametara koji stoje u određenim korelacionim vezama sa intenzitetom, karakterom i brzinom habanja reznih alata. Jedan od najpouzdanijih i najčešće primjenjivanih nosioca informacija o habanju alata u procesu rezanja su sile i otpori rezanja. Na osnovu eksperimentalno uspostavljene zavisnosti između sile rezanja i uticajnih parametara na habanje alata u radu je postavljen model za aksijalnu silu rezanja kao pouzdanog nosioca informacija o fenomenu habanja alata, primjenom vještačkih neuronskih mreža.

Ključne riječi: habanje, zavojne burgije, direktne i indirektno metode mjerenja, aksijalna sila, neuronske mreže

MODELING OF AXIAL CUTTING FORCE USING NEURAL NETWORKS

Abstract: *The most realistic picture on tool condition is provided by the real-time monitoring of the cutting elements wear. Having in mind the difficulties related to the direct measurement of wear during the production process, a number of indirect methods have been developed. These methods assess the level of tool wear using the change of the measurement parameters signal and they have a certain level of correlation with the intensity, character and the pace of tool wearing. One of the most reliable and most commonly used sources of information on tool wear during the cutting process is forces and cutting resistance. The model for axial cutting force as the holder of information of the tool wear phenomenon by applying the artificial neural network has been established and it was based on the experimentally defined dependence between the cutting force and parameters which have significant influence for tool wearing.*

Keywords: *wearing, twist drills, direct and indirect methods of measurement, axial force, neural network*

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1. UVOD

Habanje alata je složen proces praćen fizičko-hemijskim pojavama na kontaktnim površinama alata sa predmetom obrade i odrezanom strugotinom, na čiji intenzitet imaju uticaj brojni faktori kao što su obrađivani materijal, materijal alata, elementi režima rezanja, geometrija alata itd.

Habanje reznih elemenata alata odvija se neprekidno u svim trenucima procesa, i pri svim tehnološkim uslovima i režimima obrade [1].

Prema eksperimentalnim ispitivanjima između vrijednosti sila rezanja i parametara habanja postoje određene funkcionalne veze, tako da se na osnovu izmjerene vrijednosti sile rezanja i prethodno uspostavljene zavisnosti mogu procijeniti vrijednosti parametara habanja alata.

Za definisanje matematičkog modela za silu rezanja, kao najtačnija metoda još uvijek se primjenjuje eksperimentalno-analitička metoda (regresiona analiza). Međutim zbog složenosti procesa obrade rezanjem, ni primjenom eksperimentalno-analitičke metode, nije moguće obuhvatiti sve relevantne faktore i njihov uticaj. Zbog toga je, pri rješavanju problema vezanih za simulaciju procesa obrade rezanjem, neophodna integracija naučnih saznanja i savremenih tehnologija zasnovane na vještačkoj inteligenciji.

Za simulaciju i modeliranje procesa obrade rezanjem najčešće primjenjivani sistem vještačke inteligencije su vještačke neuronske mreže, zbog osnovne osobine da generalizuju podatke, odnosno da pruže odgovor na pitanja koja im u fazi učenja nisu postavljena.

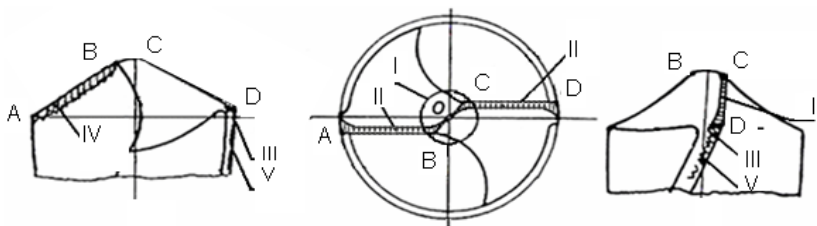
Koristeći ove tehnologije, sve više domaćih i stranih istraživača na osnovu uspostavljene korelacije između raznovrsnih parametara procesa obrade rezanjem prate promjenu parametara od interesa sa promjenom ulaznih veličina, i dolaze do korisnih informacija i zaključaka o ponašanju sistema pod konkretnim uslovima obrade.

Tako je O. Spaić razvio familiju neuronskih mreža za predviđanje stanja alata u zavisnosti od uticajnih parametara [2], a N. Gosh i drugi [3] model za praćenje stanja alata pomoću fuzije senzora zasnovan na neuronskim mrežama. Jakub Gajewski i Józef Jonak [4] istražuju mogućnost primjene vještačkih neuronskih mreža za klasifikaciju karakteristika tipičnih za istrošen alat. Odgovarajuća klasifikacija ovih signala omogućila bi identifikaciju stanja alata u složenijim mašinskim sistemima i olakšala stvaranje sistema za njegovu kontrolu.

2. HABANJE REZNIH ALATA

Relativno visoki pritisci i visoke temperature na kontaktnim površinama spregnutih parova (alata, strugotine i površine rezanja) predstavljaju osnovne uslove za nastanak i intenzivan razvoj procesa habanja reznih alata, kao krajnje negativne pojave.

Proces habanja zavojnih burgija u toku bušenja daleko je složeniji od ostalih alata za obradu rezanjem. Kod burgije se može uočiti pet oblasti na kojima se pojavljuje habanje u toku bušenja i to u predjelu poprečnog sječiva, sa tačkama B i C (I); duž leđne površine, neposredno uz glavno sječivo (II); po cilindričnoj spoljnoj površini (rubu), u blizini spoljnjih tačaka A i D (III); duž grudne površine, neposredno uz glavno sječivo (IV) i po cilindričnoj spoljnoj površini (rubu), uz reznu stranu zavojnog žljeba (V), ilustrovano na slici 1.



Sl. 1. Oblasti habanja zavojne burgije

3. MJERENJE PARAMETARA HABANJA REZNIH ALATA

Za mjerenje parametara habanja alata mogu se koristiti dvije grupe mjernih sistema (tehnika), i to [5]:

- vanprocesni i
- procesni mjerni sistemi.

Sušтина vanprocesnih mjernih sistema sastoji se u tome što se mogu koristiti za mjerenje parametara habanja tek poslije prekida procesa rezanja i skidanja reznog alata sa obradnog sistema (of-line). Za vanprocesno mjerenje parametara habanja koriste se različiti optički, elektronski ili kombinovani mjerni uređaji.

U posljednje vrijeme prvorazredni značaj dobija razvoj procesnih mjernih sistema, a posebno razvoj industrijskih procesnih davača (senzora) habanja alata, koji generišu signale o vrijednostima parametara habanja u toku odvijanja procesa bez njegovog prekidanja (on-line).

Za mjerenje parametara habanja alata pomoću procesnih senzora postoji više metoda, među kojima su najznačajnije: direktne, i indirektne, kontaktne i beskontaktne, neprekidne i povremene (periodične), pri čemu se, u svim metodama, mogu koristiti različiti principi mjerenja, kao što su: mehanički, optički, pneumatski, električni, akustički, radioaktivni, elektronski i drugi [1].

Kod direktnih procesnih metoda mjerenje parametra habanja na reznom alatu vrši se neposredno u toku odvijanja procesa obrade, što je u najvećem broju slučajeva vrlo otežano pa su i senzori habanja relativno složeni.

Kao alternativa složenim direktnim metodama razvile su se indirektne metode mjerenja, jer su im principi i tehnika mjerenja relativno jednostavniji, a osnovu im čini skup raznovrsnih signala koji potiču iz jedinica obradnog sistema (mašina, alat, predmet obrade), a funkcionalno su povezani sa parametrima habanja određenim korelacionim vezama. Ovi signali, predstavljaju nosioce informacija o veličini i brzini habanja reznih elemenata alata, a relativno se lakše mjere u odnosu na direktno mjerenje parametara habanja.

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 (energija zvučnih oscilacija odnosno broj signala akustične emisije), snaga rezanja, rastojanje između nosača alata i obrađene površine itd. [5].

J.T. Lin, D. Bhattacharyya i V. Kecman [6] dokazali su da se, mjerenjem sile rezanja, habanje alata može pratiti bez prekidanja procesa rezanja, a O. Spaici i drugi [7], primjenom regresione analize, postavili su model za silu rezanja, kao najvjernijem nosiocu informacija o fenomenu habanja.

Mjerenje sila rezanja

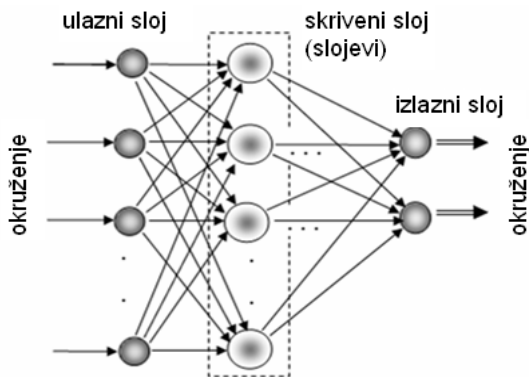
Značajna prednost mjerenja sila (otpora) rezanja, kao indirektno metode mjerenja habanja je i u visokom stepenu razvoja mjerne tehnike (dinamometara), koja, po jednostavnosti konstrukcije, gabaritima i pouzdanosti rezultata mjerenja, zauzima relativno visoko mjesto u klasi procesnih mjernih sistema u proizvodnim linijama obrade.

Mana i ove metode indirektnog mjerenja habanja sastoji se u tome što se vrlo često javlja rasipanje eksperimentalnih rezultata u širokim intervalima oko srednjih vrijednosti i što na funkcionalnu vezu $F=f(B)$ utiče niz drugih neželjenih faktora.

4. PRIMJENA NEURONSKIH MREŽA U MODELIRANJU STANJA ALATA

Vjestačke neuronske mreže vrše obradu informacija uz pomoć paralelne distribuirane arhitekture sastavljene od većeg broja jednostavnih procesnih jedinica-neurona raspoređenih u slojeve i povezanih u obliku mreže tako da izlaze iz jednih neurona povezuju sa ulazima u druge. Učenje (treniranje) vještačkih neuronskih mreža vrši se na osnovu određenog broja riješenih primjera za koji se specijalizuju.

Neuroni su raspoređeni u slojeve tako da neuroni u prvom (ulaznom) sloju primaju signale iz okruženja i predstavljaju ulaz za cijelu mrežu, dok signali izlaznog sloja predstavljaju cjelokupni izlaz mreže, ilustrirano na slici 2. Neuroni koji nisu u direktnom kontaktu sa okruženjem a prenose unutar mreže signale iz radnog okruženja čine skrivene slojeve. Njihov zadatak je da primljene signale sa ulaza obrade izdvajajući osobine i šeme karakteristične za unesene podatke, i važne podatke dalje upute izlaznom sloju mreže koji proizvodi konačne rezultate obrade.



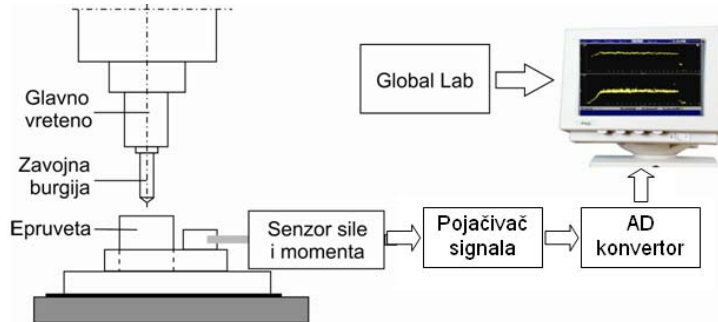
Sl. 2. Slojevita neuronska mreža bez povratnih veza [2]

5. MODELIRANJE AKSIJALNE SILE BUŠENJANA PRIMJENOM NEURONSKIH MREŽA

Eksperiment je izveden zavojnim burgijama DIN 338 Ø10.0, od brzoreznog čelika proizvedenog metalurgijom praha S-390, naoštrenim krstasto, pri bušenju slijepo rupe dubine $l=3d$ u epruветama od hrom-molibdenovog alatnog čelika za poboljšanje Č.4732 termički obrađenim na tvrdoću 43 – 45 HRc. Prilikom izvođenja eksperimenta broj obrtaja i korak su varirani na dva nivoa ($n=250$ i $n=500$ o/min, i $s=0.027$ i $s=0.107$ mm/o).

Mjerenje aksijalne sile bušenja izvedeno je u pet mjernih tačaka Piezo

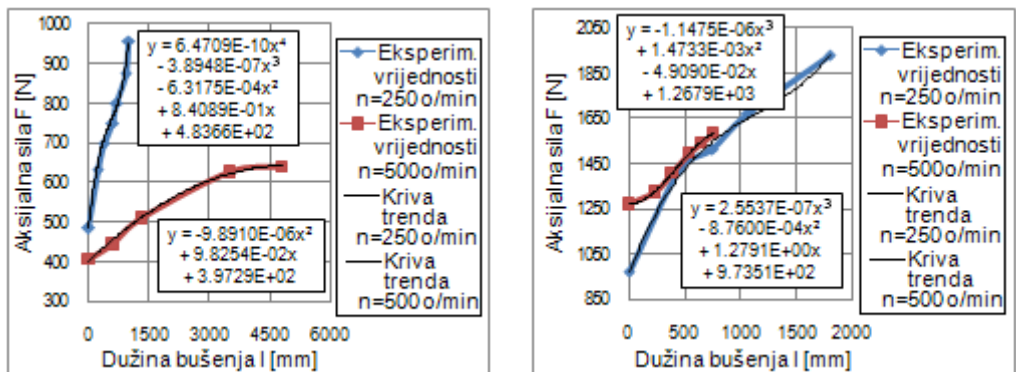
dinamometrom za mjerenje sile i obrtnog momenta TIP 9271A, integrisanim sa univerzalnom glodalicom i povezanim sa softverom Global-lab za akviziciju podataka, ilustrirano na slici 3.



Sl. 3. Šema akvizicije podataka pri izvođenju eksperimenta

U svim mjernim tačkama mjerenje aksijalne sile vršeno je nakon ulaska vrha ZB u materijal, ne računajući visinu vrha u ukupnu dužinu bušenja. Tako je pri prvom mjerenju aksijalne sile (oštrim ZB) dužina bušenja $l=0$. Posljednje mjerenje aksijalne sile izvršeno je pri dužini bušenja pri kojoj je srednja vrijednost širine pojasa habanja oba sječiva iznosila $Bd_{max}=0.35$ mm (≈ 0.04 d), koja je unaprijed definisana kao kriterij zatupljenja. Ostala mjerenja izvršena su pri dužinama bušenja pri kojima se srednja širina pojasa habanja nalazila u intervalu: $0 < Bd_i < Bd_{max}$.

Na osnovu rezultata eksperimenta konstruisane su krive zavisnosti aksijalne sile od dužine bušenja i režima rezanja. Za definisane krive zavisnosti, primjenom softvera Microsoft Excel 2007, definisane su krive trenda, kao i polinomne jednačine koje ih opisuju i prikazane dijagramima na slici 4.



Sl. 4. Krive zavisnosti aksijalne sile od dužine bušenja za $s=0.027$ i $s=0.107$

Definisanjem polinomnih jednačina krivih trenda zavisnosti aksijalne sile i dužine bušenja, obezbijeđen je dovoljan broj podataka za ulazne parametre neuronskih mreža.

Treniranje Feed-forward backpropagation neuronske mreže, iz softverskog paketa MATLAB 6.0, izvedeno je sa 2 ulazna parametara i to: brojem obrtaja i dužinom bušenja i aksijalnom silom bušenja (F) kao izlaznim parametrom, dok je korak smatran

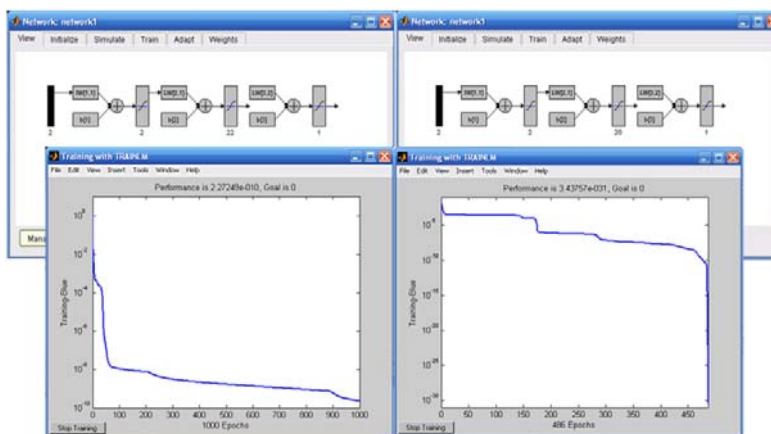
konstantnom veličinom. Tako su formirane dvije neuronske mreže NM1 sa standardnim korakom $s=0.027$ mm/o i NM2 sa standardnim korakom $s=0.107$ mm/o.

Da bi neuronska mreža posjedovala dobra svojstva generalizacije, odnosno da male promjene ulaznih signala ne bi izazivale velike promjene na izlazu neuronske mreže, primjenjeno je proširivanje obučavajućeg skupa broja obrtaja dodavanjem šuma niskog nivoa.

Najbolju konvergenciju postigle su neuronske mreže čiji su parametri prikazani u tabeli 1, dok su arhitektura i tok konvergencije formiranih neuronskih mreža, prikazani na slici 5.

Tabela 1. Parametri formiranih neuronskih mreža

Parametar mreže		Usvojeno obilježje NM1	Usvojeno obilježje NM2
Trening funkcija		TRAINLM	TRAINLM
Funkcija učenja		LEARNGDM	LEARNGDM
Funkcija performansi n/m		MSE	MSE
Broj slojeva		3	3
Broj neurona	I sloj (ulazni)	2	2
	II sloj (skriveni)	22	20
	III sloj (izlazni)	1	1
Transfer funkcija	I sloj	TANSIG	TANSIG
	II sloj		
	III sloj		
Broj epoha		1000	1000



Sl. 5. Arhitektura i tok konvergencije NM1 i NM2

Normirani podaci za obučavanje, rezultati i greške obučavanja NM1 i NM2 prikazani su u tabeli 2, iz koje se vidi da je NM1 obučena uz maksimalnu grešku reda veličine 10^{-6} , a NM2 čak 10^{-16} , tako da se mogu primijeniti kao "crna kutija" za simuliranje podacima koji nisu učestvovali u treniranju.

Simuliranje neuronskih mreža izvedeno je standardnim brojevima obrtaja iz dijapazona $250 < n < 500$ (280, 315, 355, 400 i 450) [o/min] i dužinom bušenja $l=0\div 1000$ mm za NM1, i $l=0\div 800$ mm za NM2. Normirani podaci za simuliranje neuronskih mreža prikazani su u tabeli 3.

Tabela 2. Normirani podaci za obučavanje, rezultati i greške obučavanja NM1 i NM2

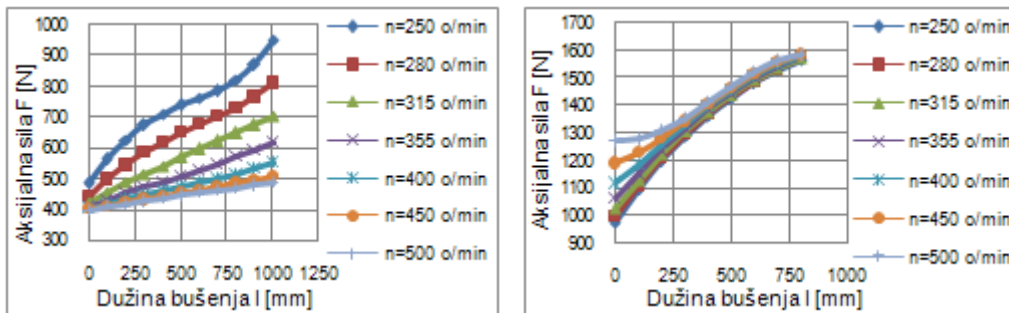
Red. br.	Ulazne vrijednosti						Trenirane vrijed. F[N]		Greška treniranja	
	l [mm]		n [o/min]		F[N]		NM1	NM2	NM1	NM2
	NM1	NM2	NM1	NM2	NM1	NM2				
1.	0	0	250	250	0.4837	0.6084	0.4837	0.6084	5.3818e-008	6.6613e-016
2.	100	100	260	260	0.5611	0.6831	0.5611	0.6831	-4.4166e-007	2.2204e-016
3.	200	200	270	270	0.6245	0.7477	0.6245	0.7477	2.4094e-006	2.2204e-016
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
⋮	1000	800	350	330	0.9504	0.9793	0.9504	0.9793	1.1954e-007	3.3307e-016
⋮	0	0	500	500	0.3973	0.7924	0.3973	0.7924	-1.2839e-007	8.8818e-016
⋮	100	100	510	510	0.4070	0.7979	0.407	0.7979	-2.6229e-008	2.2204e-016
⋮	200	200	520	520	0.4165	0.8174	0.4165	0.8174	6.1117e-007	1.1102e-016
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
⋮	1000	800	600	580	0.4857	0.9900	0.4857	0.99	1.1968e-006	-2.2204e-016

Tabela 3. Normirani podaci za simuliranje neuronskih mreža

Neur. mreža	Red. broj	l [mm]	n=280 [o/min]	n=315 [o/min]	n=355 [o/min]	n=400 [o/min]	n=450 [o/min]
NM1	1.	0	280	315	355	400	450
	2.	100	290	325	365	410	460
	3.	200	300	335	375	420	470
	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	11.	1000	380	415	455	500	550
NM2	1.	0	280	315	355	400	450
	2.	100	290	325	365	410	460
	3.	200	300	335	375	420	470
	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	9.	800	360	395	435	480	530

Rezultati simuliranja, odnosno vrijednosti aksijalne sile u zavisnosti od dužine bušenja, nakon vraćanja na stvarne vrijednosti, prikazane su dijagramima na slici 6, sa koje se vidi da pri koraku $s=0.107$ mm/o i dužini bušenja većoj od 300 mm promjena broja obrtaja ne utiče značajno na vrijednost aksijalne sile, kao i da su u potpunosti dobijeni očekivani rezultati, jer su vrijednosti aksijalne sile dobijene simuliranjem

obučenih neuronskih mreža logično raspoređene između vrijednosti dobijenih eksperimentom.



Sl. 6. Rezultati simuliranja NM1 ($s=0.027 \text{ mm/o}$) i NM2 ($s=0.107 \text{ mm/o}$)

6. ZAKLJUČAK

Pri rješavanju problema vezanih za modeliranje, simulaciju i praćenje procesa obrade, sve više se primjenjuju savremene tehnologije, među kojim su najčešće primjenjivane vještačke neuronske mreže, koje omogućavaju predviđanje promjena parametara od interesa, u zavisnosti od promjene ulaznih veličina.

Simuliranjem obučenih neuronskih mreža standardnim brojevima obrtaja iz dijapazona obuhvaćenog eksperimentom i dužinom bušenja do zatupljenja, dobijeni su očekivani rezultati, jer su vrijednosti aksijalne sile bušenja za simulirane standardne brojeve obrtaja logično raspoređene između vrijednosti aksijalne sile bušenja pri brojevima obrtaja pri kojima su izvedena eksperimentalna ispitivanja, što ukazuje da je moguće modeliranje (predviđanje) aksijalne sile u zavisnosti od dužine bušenja primjenom neuronskih mreža.

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EKSPERIMENTALNA VERIFIKACIJA RAZLIČITIH TEORIJSKIH PRILAZA PRI DEFINISANJU DGD

Milija Krašnik¹, Dragiša Vilotić², Leposava Šiđanin³, Žarko Petrović⁴

Rezime: Deformabilnost materijala predstavlja mogućnost trajne promjene oblika i dimenzija obratka bez pojave pukotina, ili drugih oblika oštećenja strukture. Ovo svojstvo, koje se numerički valorizuje veličinom efektivne granične deformacije, zavisi od vrste materijala, polazne strukture i uslova obrade. U ovom radu su prikazani rezultati koji se odnose na definisanje DGD u procesima zapreminskog deformisanja, zasnovani na primjeni različitih teorijskih prilaza pri određivanju srednjih vrijednosti β -faktora i graničnih deformacija.

Ključne riječi: Deformabilnost, β -faktor, Granična deformacija, DGD, Hladno sabijanje

EXPERIMENTAL VERIFICATION OF DIFFERENT THEORETICAL APPROACHES FOR DEFINING FLD

Abstract: Workability of materials is the possibility of permanent changes in shape and dimensions of work pieces without cracking or other forms of damage to the structure. This property, which numerically valorized by size of limit effective strain, depends on type of material, the initial structure and processing conditions. This paper shows results related to the defining of FLD in bulk metal forming processes, based on the application of various theoretical approaches for determining of mean values of β – factor and limit strain.

Keywords: Workability, β -factor, Limit strain, FLD, Cold upsetting

1. UVOD

Ključni pojam u području obrade i korišćenja metalnih materijala preko koga se uspostavlja odnos između ponašanja materijala unutar obradnog sistema, parametara procesa i spoljašnjih uslova u toku procesa obrade plastičnim deformisanjem je deformabilnost. Iako se u prošlosti pojam deformabilnosti na različite načine shavato i interpretirao, ali i često dovodio u vezu sa plastičnošću, čini se da je najpotpuniju definiciju dao Kolomogorov [1], prema kojoj deformabilnost materijala predstavlja mogućnost trajne promjene oblika u određenim uslovima obrade bez pojave pukotina, lokalizacije deformacije, ili nekog drugog, neželjenog obika oštećenja površine, odnosno unutrašnje strukture obratka.

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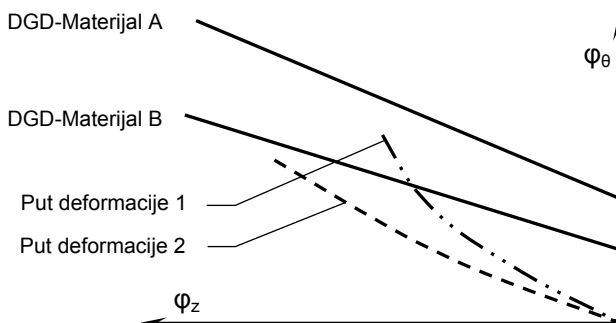
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Deformabilnost materijala zavisi od većeg broja faktora, koji se generalno mogu podijeliti u dvije grupe: faktori materijala i faktori uslova obrade [2-4]. Implicitan oblik ove funkcije predstavljen je izrazom (1):

$$D_M \equiv \varphi_e^g = f \left(H_M, S_M, T_O, \varphi, T_\sigma \dots \right) \quad (1)$$

Kao pokazatelj deformabilnosti može poslužiti bilo koja veličina koja kvantitativno može da opiše stepen oštećenja strukture materijala u određenim uslovima obrade [3]. Međutim, opšte je prihvaćeno da se za numerički pokazatelj deformabilnosti materijala uzima vrijednost efektivne deformacije u kritičnoj zoni deformisanja u trenutku nastanka pukotine.

Grafička interpretacija jednačine (1) predstavlja dijagram granične deformabilnosti (DGD), čije definisanje može biti zasnovano na različitim metodološkim prilazima. Načelno postoje dvije metodologije pri određivanju DGD u procesima zapreminskog deformisanja. Prva se odnosi na određivanje krive granične deformabilnosti kao funkcije zavisnosti glavnih deformacija, $\varphi_\theta = f(\varphi_z)$, u trenutku razaranja materijala (Slika 1).



Sl.1 Šematski prikaz DGD za procese zapreminskog deformisanja - $\varphi_\theta = f(\varphi_z)$ [3]

Prezentovana metodologija određivanja DGD za različite procese i uslove deformisanja prisutna je u mnogim radovima. Hartley i sar. [5], su istraživali graničnu deformabilnost u procesu hladnog sabijanja cilindričnih uzoraka koničnim pločama. U radovima [6-7],- predstavljeni su rezultati numeričko-eksperimentalnog određivanja granične deformabilnosti za proces sabijanja cilindričnih uzoraka sa uzdužnim površinskim defektom. Istražujući uticaj nukleacije i rasta mikrošupljina na uključcima sa aspekta graničnih mogućnosti sabijanja cilindričnih uzoraka, Ragab [8] je za potrebe definisanja DGD koristio identičnu metodologiju. Isti prilaz definisanja DGD zabilježen je i kod drugih autora [9-12].

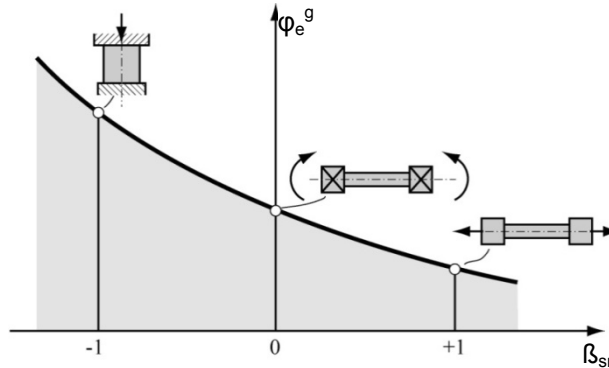
Drugi metodološki pristup koji se koristi pri određivanju DGD zasnovan je na uspostavljanju direktne zavisnosti efektivne granične deformacije φ_e^g sa generisanim naponskim stanjem u kritičnoj zoni deformisanja. Uticaj naponskog stanja na graničnu deformabilnost se valorizuje preko pokazatelja naponskog stanja β , koji je definisan odnosom invarijanti tenzora napona:

$$\beta = \frac{I_1}{\sqrt{3 \cdot |J_2|}} = \frac{3\sigma_m}{\sigma_e} = \frac{\sigma_1 + \sigma_2 + \sigma_3}{\frac{\sqrt{2}}{2} \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}} \quad (2)$$

Kolmogorov je u radu [13] hronološki prezentovao naučna dostignuća koja su omogućila razvoj i usavršavanje metodologije definisanja DGD, zasnovane na direktnoj povezanosti graničnih deformacija i naponskog stanja - $\varphi_e^g = f(\beta)$.

U radu [14], Abdel-Rahman predstavlja relativno pouzdan prilaz za aproksimativno definisanje DGD, korišćenjem samo dva mehanička testa (jednoosno zatezanje i jednoosno sabijanje). Funkcionalna zavisnosti između efektivne deformacije φ_e i pokazatelja naponskog stanja β je linearnog karaktera.

Međutim, prema ovoj metodologiji, osnovni oblik krive granične deformabilnosti, definiše se primjenom tri osnovna (monotona) modela deformisanja (jednoosno zatezanje $\beta = +1$, uvijanje $\beta = 0$ i jednoosno sabijanje cilindra $\beta = -1$), slika 2.



Sl.2 DGD - $\varphi_e^g = f(\beta)$ – osnovni modeli deformisanja [2, 4]

Ovakav koncept omogućava da se na relativno jednostavan i pouzdan način identifikuje naponsko-deformaciono stanje u zoni razaranja, odnosno odrede tri tačke DGD. Detaljnije definisanje DGD postiže se primjenom novih modela deformisanja. Međutim, kako se uglavnom radi o nemonotonim, dominantnim procesima plastičnog deformisanja, prilikom određivanja apscisne koordinate u DGD neophodno je izračunati srednju vrijednost β -faktora.

Cilj istraživanja predstavljenih u ovom radu je kvantitativno utvrđivanje nivoa saglasnosti u pogledu srednjih numeričkih vrijednosti pokazatelja naponskog stanja (β_{sr}) i graničnih deformacija (φ_e^g) pri korišćenju različitih teorijskih prilaza za njihovo određivanje. Za realizaciju navedenog cilja korišćeni su podaci eksperimentalnih istraživanja u procesima sabijanja cilindra i konusa ravnim pločama. Takođe, jedan od ciljeva istraživanja je da se, kroz definisanje DGD, identifikuju granične mogućnosti deformisanja čelika C45E u uslovima normalizovanog polaznog mikrostrukturnog stanja.

2. TEORIJSKI ASPEKTI METODOLOGIJE DEFINISANJA DGD

Lociranje mjesta pojave pukotina je prva aktivnost pri analizi deformabilnosti testiranog materijala. U procesima slobodnog sabijanja pojava pukotina je karakteristična za slobodne površine uzorka. Ustvari presjek ekvatorijalne ravni uzorka i slobodne površine predstavlja zonu deformisanja u kojoj dolazi do kritičnog oštećenja strukture materijala.

Identifikacija naponsko-deformacionog stanja u procesu slobodnog sabijanja

Uzimajući u obzir činjenicu da na slobodnim površinama uzorka u procesima slobodnog sabijanja ne dolazi do generisanja radialne komponente napona, niti su prisutni mehanizmi trenja zbog nemogućnosti ostvarivanja kontakta sa alatom, identifikacija naponsko-deformacionog stanja u području kritičnog oštećenja obratka je olakšana.

Komponente napona na mjestu pojave pukotine definišu se izrazima (3 i 4) [4]:

$$\sigma_z = \pm \sigma_e \cdot \left[1 - \left(\frac{1+2\alpha}{2+\alpha} \right) + \left(\frac{1+2\alpha}{2+\alpha} \right)^2 \right]^{\frac{1}{2}} \quad (3)$$

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

Predhodne jednačine omogućavaju definisanje pokazatelja naponskog stanja β u slijedećem obliku:

$$\beta = \frac{\sigma_r + \sigma_\theta + \sigma_z}{\sigma_e} = - \frac{1 + \frac{1+2\alpha}{2+\alpha}}{\sqrt{1 - \frac{1+2\alpha}{2+\alpha} + \left(\frac{1+2\alpha}{2+\alpha} \right)^2}} \quad (5)$$

gdje su:

σ_r , σ_θ i σ_z – komponente glavnih napona u pravcu r , θ i z osa,
 σ_e – efektivni napon.

Koeficijent α predstavlja odnos priraštaja deformacija (6):

$$\alpha = \frac{d\varphi_\theta}{d\varphi_z} \quad (6)$$

Za primjenu predhodnog izraza neophodno je odrediti put deformacije, $\varphi_\theta = f(\varphi_z)$. U ovom radu tražena zavisnost je aproksimirana polinomom drugog reda:

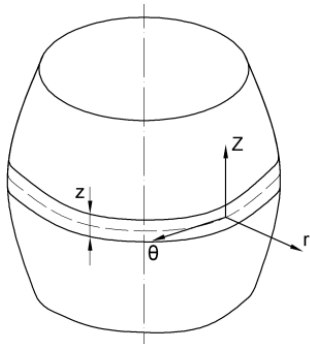
$$\varphi_\theta = f(\varphi_z) = A\varphi_z + B\varphi_z^2 \quad (7)$$

gdje su:

A i B koeficijenti aproksimirane funkcije.

Komponente glavnih deformacija φ_z , φ_θ i φ_r u kritičnoj zoni uzorka određuju se na osnovu visine markiranog pojasa Z (Sl. 3) i prečnika uzorka u ekvatorijalnoj ravni, uz korišćenje uslova nestišljivosti:

$$\varphi_z = \ln \frac{Z_i}{Z_0}, \quad \varphi_\theta = \ln \frac{D_i}{D_0}, \quad \varphi_r = -(\varphi_z + \varphi_\theta) \quad (8)$$



gdje su:

Z_0 i D_0 – početne vrijednosti visine markiranog pojasa i prečnika uzorka,
 Z_i i D_i – vrijednosti visine markiranog pojasa i prečnika uzorka poslije i -te faze sabijanja.

Sl.3 Cilindrični uzorak poslije deformisanja

Efektivna deformacija na mjestu pojave pukotina određuje se obrascem (9):

$$\varphi_e = \frac{\sqrt{2}}{3} \sqrt{(\varphi_z - \varphi_\theta)^2 + (\varphi_\theta - \varphi_r)^2 + (\varphi_r - \varphi_z)^2} \quad (9)$$

Istorija deformisanja

Istorija deformisanja predstavlja zavisnost efektivne deformacije od pokazatelja naponskog stanja $\varphi_e = f(T\sigma) = f(\beta)$. U uslovima monotonog deformisanja (osnovni modeli) ne dolazi do varijacija β -faktora. Međutim, u nemonotonim procesima, promjene naponskog stanja u toku plastičnog deformisanja se moraju identifikovati i uzeti u obzir pri definisanju DGD, jer je utvrđeno da je količina nastalih oštećenja mikrostrukture materijala proporcionalna ostvarenom stepenu deformacije, a intenzitet nastajanja zavisi od naponskog stanja [1]. Zbog toga se, kao mjerodavna apciska kordinata pri definisanju DGD koristi srednja vrijednost pokazatelja naponskog stanja β .

Izrazi za određivanje β_{sr} su različiti i zavise od teorijskog prilaza koja se koristi za njihovo definisanje. Prema deformacionoj teoriji β_{sr} se može odrediti na osnovu izraza (10), [2]:

$$\beta_{sr} = \frac{1}{\varphi_e^g} \int_0^{\varphi_e^g} \beta(\varphi_e) d\varphi_e \quad (10)$$

Za određivanje β_{sr} , ako se kritično oštećenje materijala generiše na slobodnoj površini uzorka, kao što je slučaj kod procesa slobodnog sabijanja, koristi se i metodologija koja je bazirana na teoriji tečenja metala [2, 15-18]. U ovom slučaju srednja vrijednost β -faktora određuje se na osnovu graničnih vrijednosti deformacija:

$$\beta_{sr} = \frac{2}{\varphi_e^g} (\varphi_1^g + \varphi_2^g) \quad (11)$$

gdje su: φ_1 i φ_2 - komponente glavnih logaritamskih deformacija u zoni pojave pukotina, φ_e^g - efektivna deformacija u trenutku razaranja uzorka.

Efektivna granična deformacija određuje se numeričkom integracijom (12):

$$\varphi_e^g = \frac{2}{\sqrt{3}} \int_0^{\varphi_z^g} [1 + A + 2B\varphi_z + (A + 2B\varphi_z)^2]^{1/2} d\varphi_z \quad (12)$$

Eksperimentalna verifikacija predhodno izloženog prilaza, za različite materijale, potvrđena je u radovima Alexandrova i Vilotića [15-18].

3. EKSPERIMENTALNA ISTRAŽIVANJA

Eksperimentalna istraživanja realizovana su u dvije faze. U prvoj fazi, primjenom osnovnih modela deformisanja, definisan je DGD za čelik C45E. Druga faza odnosi se na istraživanje granične deformabilnosti normalizovanih konusnih uzoraka u procesu sabijanja ravnim pločama.

Osnovni modeli deformisanja

Sabijanje cilindričnih uzoraka ravnim pločama realizovano je inkrementalno, sve do pojave pukotina na slobodnoj površini. Za eksperimentalna istraživanja korišćeni su uzorci polaznih dimenzija $\varnothing 20 \times 25$ mm (slika 4a).



a)



b)

Sl.4 Sabijanje cilindra ravnim pločama: a) polazni uzorak, b) deformisani uzorak

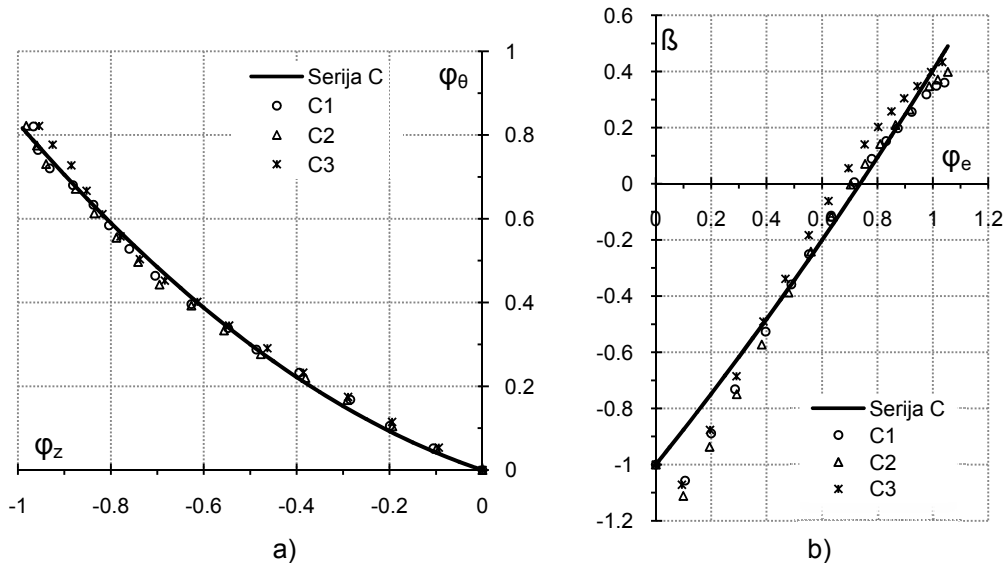
Identifikacija deformacionog stanja na mjestu kritičnog oštećenja mikrostrukture izvršena je primjenom izraza (8), a regresionom analizom određena je zavisnost glavnih deformacija $\varphi_\theta = f(\varphi_z)$ na mjestu pojave pukotina u obliku polinoma drugog reda, uz uvažavanje graničnog uslova da je na početku sabijanja $\varphi_\theta = \varphi_z = 0$:

$$\varphi_\theta = -0.3718\varphi_z + 0.4574\varphi_z^2 \quad (13)$$

Grafička interpretacija prethodne jednačine sa pojedinim eksperimentalnim tačkama ($\varphi_\theta, \varphi_z$) prikazana je na slici 5a.

Koristeći aproksimativnu funkciju (13) i obrazac (5), određene su vrijednosti pokazatelja naponskog stanja po fazama sabijanja, odnosno istorija deformisanja u obliku polinoma drugog reda (sl. 5b):

$$\beta = 0.1803\varphi_e^2 + 1.2234\varphi_e - 1 \quad (14)$$



Sl.5 Sabijanje cilindra ravnim pločama: a) put deformacije, b) istorija deformisanja

Testovi jednoosnog zatezanja i uvijanja realizovani su u uslovima monotono deformisanja. Obradom eksperimentalnih rezultata dobijeni su slijedeći podaci:

- Jednoosno zatezanje $\beta = +1$ $\varphi_e^g = 0.0780$
- Uvijanje $\beta = 0$ $\varphi_e^g = 0.6212$

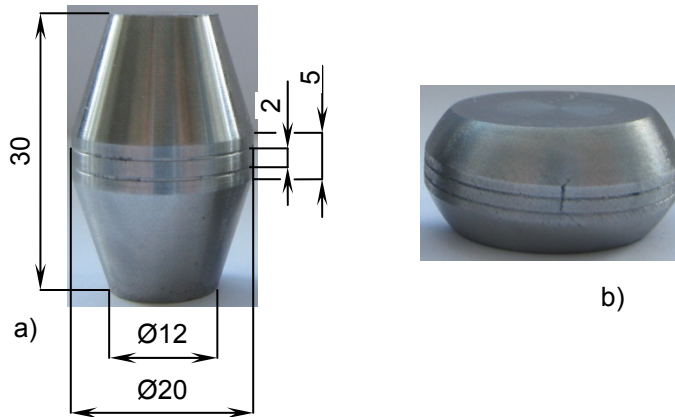
Na slici 6 su prikazane fotografije epruveta deformisanih u procesima jednoosnog zatezanja i uvijanja.



Sl.6 Deformisane epruvete: a) jednoosno zatezanje, b) uvijanje

Sabijanje konusnog uzorka ravnim pločama

Za potpuniju karakterizaciju deformabilnosti čelika C45E kreiran je model sabijanja konusnog uzorka ravnim pločama. Polazni oblik i dimenzije novog modela (Sl. 7a) su definisani tako da obezbijede dominantan uticaj zateznih komponenti napona na razvoj oštećenja strukture i pojavu pukotine.

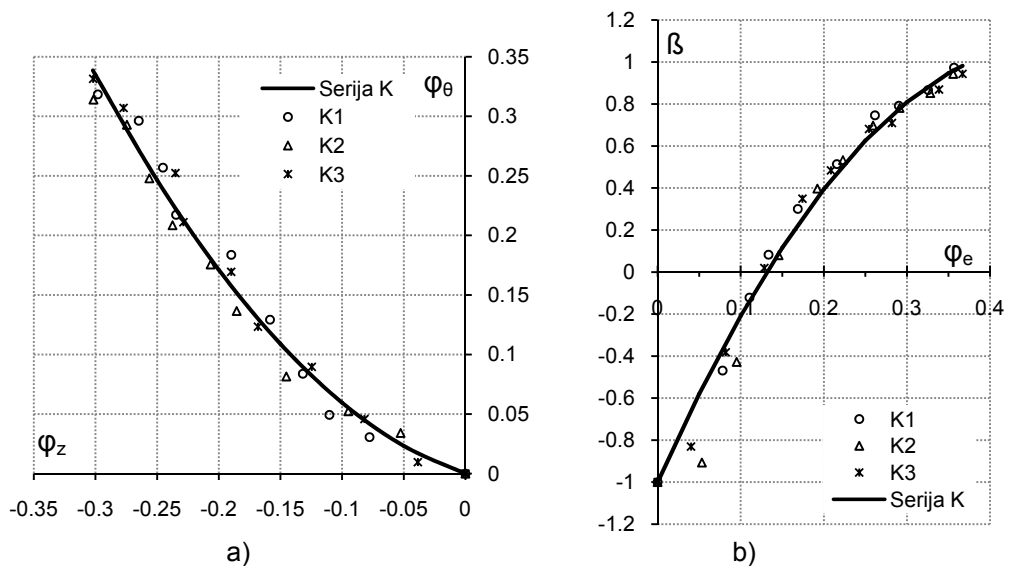


Sl.7 Sabijanje konusnog uzorka ravnim pločama:
a) polazni uzorak, b) deformisani uzorak

Realizacija eksperimenta i obrada rezultata pri sabijanju konusnog uzorka ravnim pločama je identična kao u procesu sabijanja cilindra. Grafički prikazi puta deformacije (15) i istorije deformisanja (16) dati su na slici 8.

$$\varphi_{\theta} = -0.3360\varphi_z + 2.5986\varphi_z^2 \quad (15)$$

$$\beta = -9.4133\varphi_e^2 + 8.8553\varphi_e - 1 \quad (16)$$



Sl.8 Sabijanje konusa ravnim pločama: a) put deformacije, b) istorija deformisanja

Srednje vrijednosti pokazatelja naponskog stanja i granične deformacije

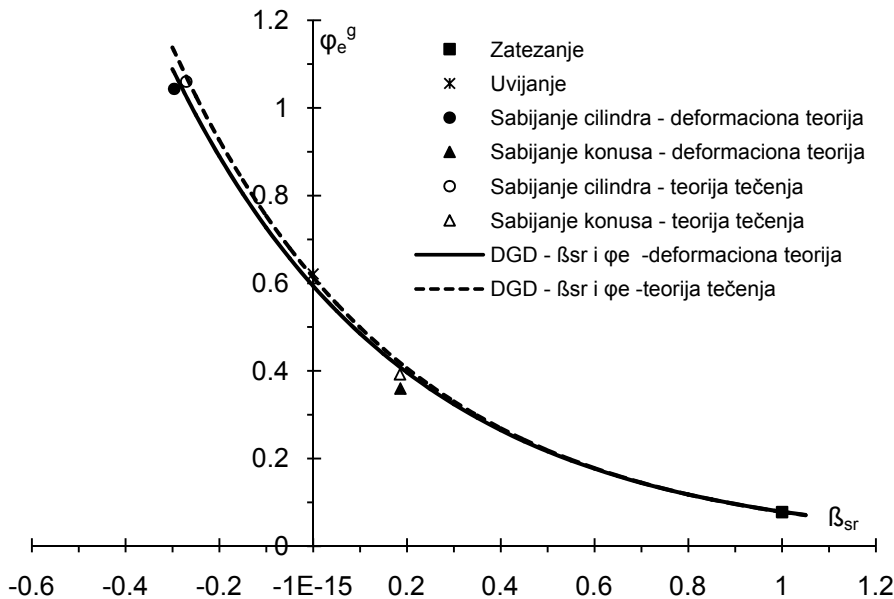
Srednje vrijednosti β -faktora za procese sabijanja cilindričnog i konusnog uzorka su, na osnovu različitih teorijskih prilaza, određeni pomoću obrazaca (10) i (11). Granična efektivna deformacija je izračunata na osnovu graničnih vrijednosti pojedinih deformacionih komponenti (obrazac 9), odnosno numeričkom integracijom izraza (12). Rezultati su prikazanu u tabeli 1.

Tabela 1 Uporedni prikaz vrijednosti β_{sr} i φ_e^g

Sabijanje cilindra					Sabijanje konusa				
N_0	Deformaciona teorija		Teorija tečenja		N_0	Deformaciona teorija		Teorija tečenja	
	β_{sr}	φ_e^g	β_{sr}	φ_e^g		β_{sr}	φ_e^g	β_{sr}	φ_e^g
C1	-0.3167	1.0421	-0.2770	1.0584	K1	0.2041	0.3565	0.2030	0.3943
C2	-0.3090	1.0539	-0.2966	1.0801	K2	0.1445	0.3556	0.1633	0.3889
C3	-0.2649	1.0341	-0.2371	1.0469	K3	0.2073	0.3668	0.1780	0.3963
Serijska C	-0.2963	1.0434	-0.2707	1.0601	Serijska K	0.1862	0.3595	0.1851	0.3919

Dijagram granične deformabilnosti za čelik C45E

Na osnovu prezentovanih eksperimentalno-numeričkih podataka, definisan je DGD za čelik C45E. Na slici 9 dat je uporedni prikaz krivih granične deformabilnosti u zavisnosti od primjenjenog teorijskog prilaza pri određivanju β_{sr} i φ_e^g . Rezultati istraživanja za pojedinačne uzorke predstavljeni su kroz srednje vrijednosti serija za testirane modele deformisanja.



SI.9 DGD za čelik C45E- Komparativni prikaz pri određivanju β_{sr} i φ_e^g primjenom različitih teorijskih prilaza

4. ZAKLJUČAK

Analizom različitih prilaza u metodologiji definisanja DGD može se zaključiti da su u osnovi oba fokusirana na uspostavljanje funkcionalnih zavisnosti između graničnih deformacija i naponskog stanja u zoni kritičnog oštećenja strukture materijala. Koristeći zavisnost $\varphi_{\theta} = f(\varphi_z)$ to se čini posredno. DGD konstruisan na ovaj način, može se primjeniti samo za modele i uslove u kojima je definisan.

Neposredno povezivanje graničnih deformacija sa naponskim stanjem u zoni deformisanja preko pokazatelja naponskog stanja, izraženo relacijom $\varphi_e^g = f(\beta)$, predstavlja znatno uopšteniji način definisanja DGD. Ovakav prilaz omogućava potpunije sagledavanje kompleksne problematike granične deformabilnosti materijala uzimajući u obzir obradni sistem, tj. uslove obrade.

Rezultati eksperimentalnih istraživanja su potvrdili visok nivo saglasnosti u pogledu numeričkih vrijednosti β_{sr} -faktora i graničnih deformacije φ_e^g , bez obzira na teorijski prilaz koji se koristio za njihovo određivanje. Prisutne razlike su posljedica nepostojanja adekvatne mjerne opreme za identifikaciju deformacionog stanja u toku eksperimentalnih istraživanja.

Sa praktičnog aspekta, određivanje β_{sr} i φ_e^g primjenom teorije tečenja je mnogo prihvatljivije, u odnosu na prilaz koji je baziran na deformacionoj teoriji, jer se ne zahtjeva identifikaciju naponskog stanja, što je u uslovima nemonotonog deformisanja od velikog značaja. Osim toga, ovakav prilaz dopušta da se pri realizaciji eksperimentalnih istraživanja određeni uslovi ne kontrolišu (npr. uticaj kontaktnog trenja).

Međutim, u slučaju redizajniranja tehnološkog postupka izrade metalne komponente, neidentifikovanje istorije procesa deformisanja može dovesti do loših procjena i pogrešnih rješenja. Zbog toga se generalno može konstatovati da praćenje promjena naponskog stanja u zoni pojave kritičnih oštećenja omogućava kompletniju i pouzdaniju analizu granične deformabilnosti.

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INFLUENCE OF FRICTION AND NUMBER OF DEFORMATION PHASES ON FORMABILITY OF STEEL C45E

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Sergei Alexandrov⁵, Dragiša Vilotić⁶

Summary: Upsetting is one of the most widely used processes in bulk metal forming and it is often included into multi-stage hot or cold bulk metal forming operations. In these processes billets of simple geometry, which are in most cases cylindrical or prismatic shape, are applied. Upsetting processes also represent one of the basic methods for determination of Forming limit diagram (FLD). This paper investigates formability of the steel C45E in cold upsetting of cylindrical billets with flat plates. Influence of friction and number of deformation phases on effective strain at the fracture is analysed. Experimental results are imposed in Forming limit diagram.

Key words: Material formability, Forming limit diagram, Upsetting

1. INTRODUCTION

In metal forming, shape of the billet is changed by imposing very large forces and pressures to the workpiece material by tools and dies. During this process cracks or other material damage can occur if workpiece deformation is higher than critical. Therefore, it is essential to determine critical value of deformation which certain material can undergo in order to avoid defects in production. The capability of the material to undergo large deformations without cracking is known as formability. This material property is influenced by material type, microstructure, processing temperature, strain rate, stress state... [1].

One of the important factors that has a significant influence on the level of formability is friction. Characterisation of friction is most commonly done by two models: Coulomb friction model and Constant friction model [2].

Forming limit diagram (FLD) represents an empirical formability criterion that is based on experimental investigation. There are two variants of FLD: strain based FLD and stress based FLD, [3, 4, 5]. Strain based FLD represents a relation between

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principal strains at free surface at the moment of crack appearance. Stress based FLD is a relation between the strain to fracture and triaxiality ratio at the location of ductile fracture initiation.

Effective strain at the fracture (φ_e^l) is a quantitative measure of formability. Material formability for a given material (defined initial structure, cold conditions, and quasi static deformation) can be expressed as:

$$\varphi_e^l = F(\beta) \quad (1)$$

where β is triaxiality stress ratio at the location of fracture initiation. Stress ratio can be determined from:

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

where $\sigma_x, \sigma_y, \sigma_z$ are the normal stresses in three orthogonal directions (x, y, z); $\sigma_1, \sigma_2, \sigma_3$ are the principal normal stresses and σ_e is the effective stress.

Forming limit diagram represent graphical interpretation of equation (1) and usually diagram is obtained experimentally by employing basic tests elaborated in [1]:

- uni-axial tensile test, $\beta = +1$
- torsion test, $\beta = 0$
- uni-axial compression test, $\beta = -1$

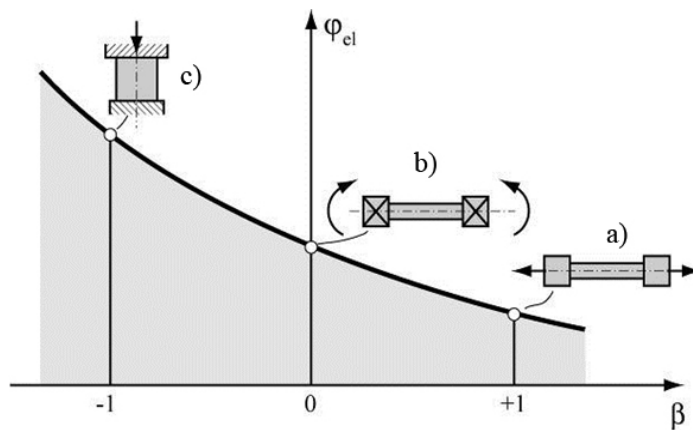


Fig. 1 Forming limit diagram: a) uni-axial tension test, b) torsion test, c) uni-axial compression test

Stress indicator (β), for non-monotonous cases, changes its value during deformation and average value is inserted into FLD diagram [6,7]. Average value of stress indicator is expressed as:

$$\beta_{av} = \frac{1}{\varphi_e^l} \int_0^{\varphi_e^l} \beta(\varphi_e) d\varphi_e \quad (3)$$

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

By employing several expressions from [1], and [7], stress indicator (β) at the free surface at the cylinder can be determined by:

$$\beta = \frac{\sigma_r + \sigma_\theta + \sigma_z}{\sigma_e} = - \frac{1 + \frac{1+2\alpha}{2+\alpha}}{\sqrt{1 - \frac{1+2\alpha}{2+\alpha} + \left(\frac{1+2\alpha}{2+\alpha}\right)^2}} \quad (4)$$

where $\sigma_r, \sigma_\theta, \sigma_z$ are stress components in directions r , θ and z .

Coefficient α is defined as:

$$\alpha = \frac{d\varphi_\theta}{d\varphi_z} \quad (5)$$

Strain path can be expressed as:

$$\varphi_\theta = f(\varphi_z) = A\varphi_z + B\varphi_z^2 \quad (6)$$

where A and B are coefficients of regressive curve.

In the present paper an experimental study on formability of steel C45E is described. Forming limit diagram was determined using three basic tests (Rastegaev test, torsion test and collar cylinder test) and results of upsetting cylindrical billets by flat plates are imposed in FLD. The main object was to determine the influence of friction and number of deformation phases on material formability.

2. EXPERIMENTAL INVESTIGATION

Experimental investigation of formability of steel C45E was conducted in Laboratory for Technology of Plasticity at Faculty of Technical Science, Novi Sad. Experiment was performed in two phases. In the first phase, Forming limit diagram (FLD) for steel C45E using three basic tests (Rastegaev test, torsion test and collar cylinder test) was determined. Investigation of material formability in upsetting of cylinder by flat plates using different upsetting conditions was carried out in the second phase.

2.1 Experimental determination of FLD

Forming limit diagram for steel C45E was determined by following tests:

- (i) Rastegaev test
- (ii) Torsion test
- (iii) Collar cylinder test

Rastegaev test method was researched in [8]. The initial dimensions of billet were $\varnothing 20 \times 26$ mm. At the top and bottom of billets' surfaces shallow cylindrical grooves (0.3 mm depth) were made and filled with stearin before testing to reduce friction.

In torsion test stress indicator is $\beta = 0$ and strain to fracture was determined by equation (7):




$$\varphi_e^I = \frac{R \cdot \alpha}{\sqrt{3} \cdot L} \quad (7)$$

where R is test tube radius, α is twisting angel, L is measured length of test tube. Initial dimensions of test tube were $\varnothing 10 \times 100$ mm.

Methodology for formability parameters determination in collar cylinder test is presented in [9].

Values of strain to fracture and triaxiality ratio for Rastegaev test, torsion test and collar cylinder test are presented in table 1.

Table 1 Test results for steel C45E

Test	β_{av}	φ'_e	Photos of specimens
Rastegaev test (RT)	-0.94	1.74	
Torsion test (T)	0.00	0.73	
Collar cylinder test (CC)	+1.21	0.32	

2.2 Material formability at upsetting of cylinder by flat plates

The objective of this experiment was to determine the influence of friction and number of deformation phases on material formability. In experiment, four series of cylindrical billets were made and used. In figure 1 cylindrical billet before deformation is presented. Initial dimensions of billets for all four series were $\varnothing 18 \times 24 \text{ mm}$.



Fig. 2 Initial shape of cylindrical billets $\varnothing 18 \times 24 \text{ mm}$

Each billet had a marked zone $Z = 4 \text{ mm}$ (Figure 2) around equatorial plane which was used for determination of local strain. Upsetting of billets was performed incrementally on hydraulic press (Sack&Kiesselbach, 6.3MN, 0.1mm/s tool velocity) by flat dies. Two types of incremental upsetting as well as friction conditions (with and without lubrication) were applied. Incremental upsetting was performed with strain value $\varphi_h \approx 0.05$ and $\varphi_h \approx 0.1$ without lubrication (Series 1 and 3), and with lubrication by mineral oil (Series 2 and 4). Deformation φ_h refers to the billet's height. Compression was carried out until the crack occurred.

After each deformation phase, local strains were calculated based on height of marked zone Z and diameter in equatorial plane D :

$$\varphi_z = \ln \frac{Z}{Z_0} \tag{8}$$

$$\varphi_x = \ln \frac{D}{D_0} \tag{9}$$

Average strain values for each series are presented in table 2. Strain path curves for all four series, based upon these data, are presented in figure 3. In figure 4 billets after deformation are shown.

Table 2 Average values of strains

No.	Series 1 $\varphi_h \approx 0.05$ no lubrication (S1)		Series 2 $\varphi_h \approx 0.05$ with lubrication (S2)		Series 3 $\varphi_h \approx 0.1$ no lubrication (S3)		Series 4 $\varphi_h \approx 0.1$ with lubrication (S4)	
	φ_z	φ_x	φ_z	φ_x	φ_z	φ_x	φ_z	φ_x
1.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.	-0.09	0.06	-0.09	0.05	-0.11	0.05	-0.15	0.05
3.	-0.20	0.13	-0.19	0.12	-0.18	0.12	-0.23	0.11
4.	-0.29	0.20	-0.31	0.18	-0.25	0.18	-0.33	0.17
5.	-0.37	0.26	-0.40	0.24	-0.33	0.25	-0.42	0.23
6.	-0.42	0.33	-0.47	0.31	-0.37	0.31	-0.53	0.29
7.	-0.48	0.38	-0.55	0.37	-0.42	0.36	-0.59	0.34
8.	-0.52	0.45	-0.61	0.43	-0.47	0.42	-0.66	0.40
9.	-0.57	0.52	-0.68	0.50	-0.50	0.48	-0.71	0.46
10.	-0.65	0.59	-0.74	0.55	-0.56	0.54	-0.79	0.52
11.	-0.69	0.64	-0.83	0.62	-0.60	0.59	-0.83	0.58
12.			-0.90	0.68	-0.66	0.65	-0.89	0.64
13.			-0.95	0.72	-0.70	0.71	-0.93	0.69
14.			-1.02	0.79			-0.98	0.74

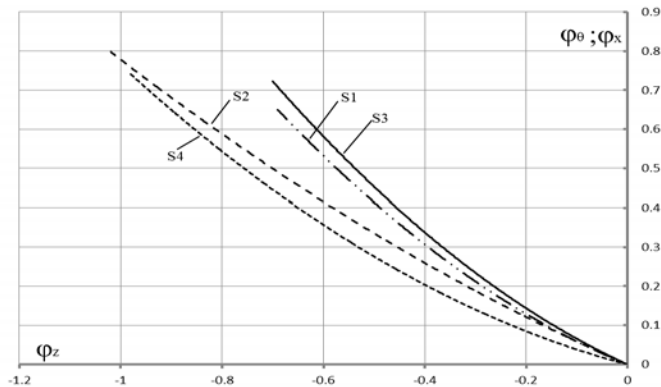


Fig. 3 Strain path for four different series of upsetting

Strain path data for all billets series were used as input parameters for calculation of values of the triaxiality ratio at different upsetting conditions. The history of triaxiality ratio for all four series of billets is presented in figure 5. The average value of triaxiality ratio was calculated by means of equation (3) and these data along with appropriate values of strains are inserted in the forming limit diagram for steel C45E, figure 6. Figure 7 shows influence of friction and number of deformation phases on strain to fracture φ_e' .



Fig. 4 Billets after upsetting processes

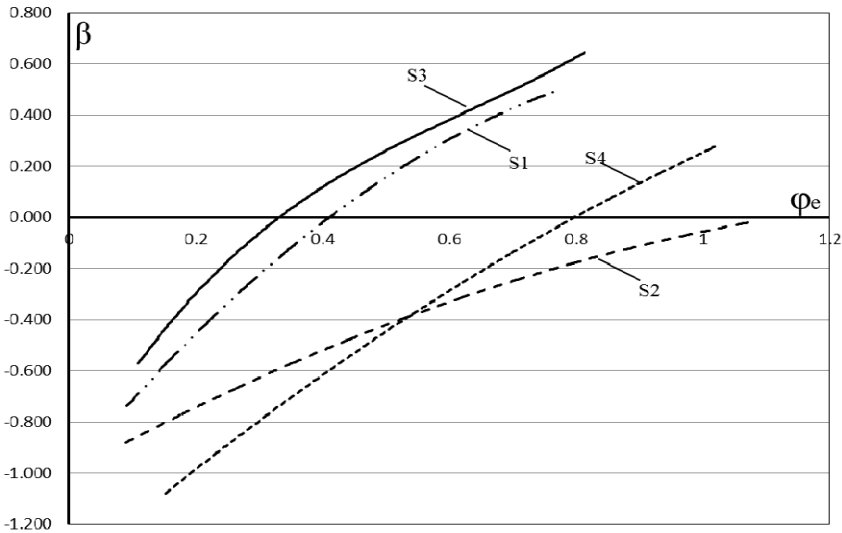


Fig. 5 History of triaxiality ratio for billets series S1, S2, S3, S4

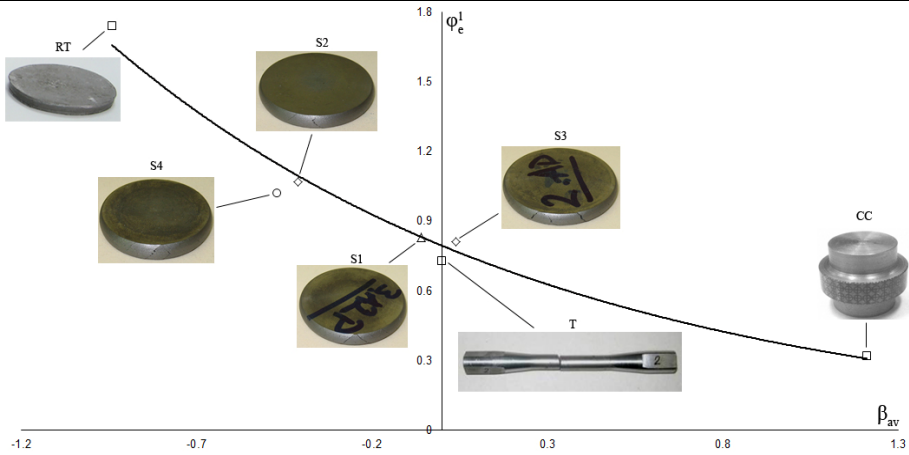


Fig. 6 Forming limit diagram of steel C45E

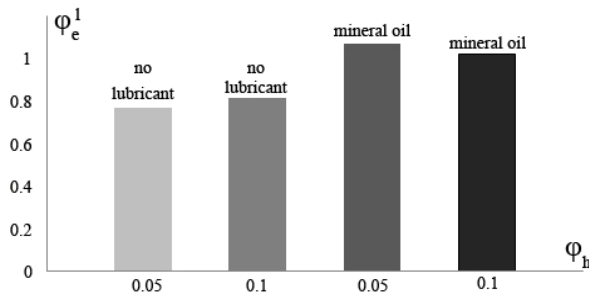


Fig. 7 Influence of friction and number of deformation phases on strain to fracture φ_e^I

3. CONCLUDING REMARKS

In this paper results of upsetting of cylindrical billet by flat plates are presented. Upsetting was conducted incrementally in different conditions of friction until crack occurred. Deformation increment was 5% and 10% depending on series (percentage refers to the billet height). Object of investigation was to determine influence of lubrication and value of deformation increment on material formability, i.e. on strain to fracture φ_e^I and triaxiality ratio β_{av} .

It can be concluded that there is a difference in forming conditions between series without lubrication and series in which lubrication by mineral oil was applied (Figure 3). It can be seen that value of strains φ_z and φ_x are approximately 30% higher in case when lubrication was applied. Difference between forming conditions is more obvious in diagram for history of triaxiality ratio (Figure 5). Figure 6 shows that friction has significant influence on values of strain φ_e^I and triaxiality ratio β_{av} , but influence of value of deformation increment on formability parameters is negligible. Influence of friction on strain to fracture is more obvious in figure 7. From figure 6 it can also be concluded that forming conditions for billets series S1 and S3 are similar to the torsion test billets.

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MOGUĆNOSTI INTERAKTIVNOG UPRAVLJANJA MAŠINAMA ALATKAMA U OKRUŽENJU VR

Aleksandar Košarac¹, Saša Prodanović², Milan Zeljković³

Rezime: Virtualno projektovanje proizvoda predstavlja jedan od savremenih prilaza u razvoju proizvoda. Pored same vizualizacije ono obuhvata i čitav niz provjera u okruženju virtualne realnosti. Izvođenje različitih testiranja u okruženju virtualne realnosti prije proizvodnje prototipa, može povećati produktivnost i skratiti vrijeme razvoja.

Kao ilustraciju mogućnosti izvođenja različitih testiranja u pomenutom okruženju, u radu se prikazuje simulacija procesa koji se izvršava u 3D virtualoj sceni, a kojim se upravlja PLC kontrolerom, kao i iz Matlab/Simulink okruženja. Kao interfejs između virtualnog svijeta i Matlab/Simulink okruženja koristi se VR Toolbox, a između Matlab/Simulink okruženja i programabilnog logičkog kontrolera OPC standard.

Ključne riječi: Virtualna realnost, PLC kontroler, OPC standard, Matlab/Simulink

POSSIBILITIES FOR INTERACTIVE CONTROL OF MACHINE TOOLS IN THE VIRTUAL REALITY ENVIRONMENT

Abstract: The virtual product development is a modern approach in the product development process. Apart from the visualization itself, the virtual product development encompasses the whole range of testing in the virtual reality (VR) environment. Different testing performed in the virtual reality environment before prototype production can increase productivity and decrease development time.

As an illustration of possibilities of performing different kind of testing in VR environment, this paper shows simulation in the VR environment of the process controlled by programmable logical controller (PLC) and MATLAB/SIMULINK.

As an interface between VR and MATLAB/SIMULINK environment VR Toolbox library is used, and between MATLAB/SIMULINK and PLC controller that is OPC standard.

Keywords: Virtual Reality, PLC controller, OPC standard, MATLAB/SIMULINK

1. UVOD

U skladu sa razvojem informacionih tehnologija razvijaju se i savremeni prilazi u razvoju proizvoda, a sve u cilju skraćenja procesa razvoja proizvoda i minimizaciji broja fizičkih prototipova. Jedan od tih prilaza je i razvoj virtualnih proizvoda, koji, sem vizualizacije, omogućava i čitav niz provjera proizvoda u okruženju virtualne realnosti [2].

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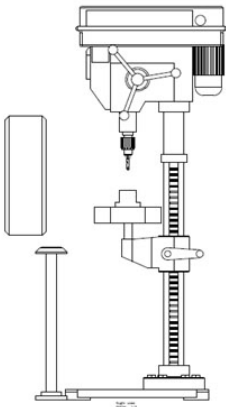
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Osnovna ideja ovoga rada je simulacija upravljanja procesima koji se realizuju na mašini alatki u 3D virtualnom okruženju. Pri tome je virtualni model mašine alatke, djelimično automatizovane stubne bušilice, povezan sa realnim PLC kontrolerom pomoću OPC servera. Model ne obuhvata dinamičku simulaciju, stanje sistema mijenja pojava diskretnih događaja. Rezultat simulacije su kretanja koja alat izvodi u 3D virtualnom okruženju u zavisnosti od vrijednosti ulaznih promjenjivih. U ovom slučaju ulazne promjenjive su logičke (bulove) promjenjive koje predstavljaju stanje senzora, tastera, prekidača koje aktivira korisnik u okruženju VR.

Simulacija se može koristiti pri demonstraciji rada mašine alatke, te za testiranje upravljačkog algoritma na interaktivnim realističnim modelima mašina alatki u okruženju VR, pri čemu procesom upravlja realni programabilni logički kontroler.

2. DEFINISANJE ZADATKA



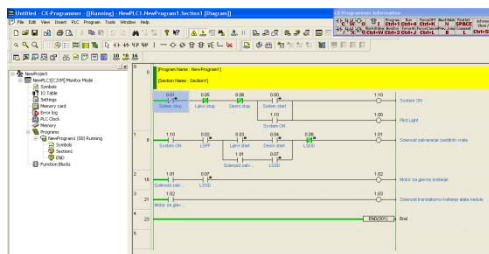
Slika 1. Stubna bušilica

Primjer koji se razmatra u radu je stubna bušilica, prikazana na slici 1. Potrebno je kreirati virtualnu scenu koja sadrži model bušilice, senzore, tastere, prekidače i druge elemente informacionog kola tako da korisnik može upravljati glavnim, pomoćnim i dopunskim kretanjima. Takođe, potrebno je dati moguće rješenje za djelimičnu automatizaciju procesa bušenja na ovoj mašini, što podrazumjeva definisanje potrebnog broja ulaza, aktuatora, kao i program napisan za PLC kontroler. Neophodno je razviti model u Matlab/Simulink okruženju, koji zajedno sa PLC kontrolerom upravlja virtualnim modelima u skladu sa definisanim početnim uslovima.

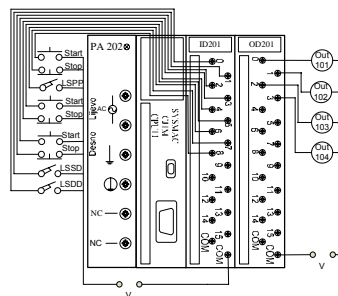
U nastavku se daje kratak opis ciklusa bušenja na razmatranoj mašini alatki [8]. Pripremak se postavlja u stezni pribor, pri čemu se aktivira senzor LSPP (*Limit Switch Part in Place*). Nakon što rukovaoc pritisne istovremeno dva tastera, alat započinje glavno kretanje (obrtanje burgije) i istovremeno pomoćno kretanje (pravolinijsko pomjeranje burgije, odnosno glavnog vretena bušilice duž z ose na dole). Pogon pomoćnog kretanja je automatizovan kinematskim parom zupčanik – zupčasta letva. Zupčasta letva povezana je sa cilindrom dvostranog dejstva, kojim upravlja monostabilni klipni razvodnik 5/2, pri čemu je aktiviranje razvodnika električno. Kada alat dostigne krajnji donji položaj koji odgovara završetku bušenja, aktivira se senzor, odnosno granični prekidač LSDD (*Limit Switch Drill Down*). U tom trenutku prestaje napajanje elektromagneta kojim se aktivira monostabilni 5/2 klipni razvodnik, te opruga vraća klipni razvodnik u početni položaj. Tada počinje povratni hod, tj. kretanje alata na gore. Nakon dolaska alata u krajnji gornji položaj, aktivira se granični prekidač i cio sistem se isključuje. Ukoliko pripremak nije postavljen u stezni pribor, dakle senzor prisustva predmeta ne detektuje prisustvo predmeta, proces ne može započeti. U cilju povećanja sigurnosti rukovaoca, predviđena su i zaštitna vrata koja se automatski zatvaraju nakon što se postavi pripremak i to prije nego što počne kretanje alata. Zaštitna vrata se otvaraju u trenutku kada se završi proces bušenja. Pritiskom dugmeta stop, zaustavlja se obrtanje alata, započinje pravolinijsko kretanje naviše, nakon čega se otvaraju zaštitna vrata.

3. PLC KONTROLER OMRON

Za potrebe rada koristi se programabilni logički kontroler proizvođača OMRON, serije CJ1 koji pripada klasi mikrokontrolera [5]. Ovaj tip PLC kontrolera se koristi u mnogim oblastima industrije, na CNC mašinama alatkama za upravljanje pojedinim modulima, mašinama različitih namjena, pri pakovanju, u postupcima rukovanja različitim materijalima, u automatizovanim postrojenjima itd. Grupa proizvoda CJ serije je namjenjena za upotrebu od jednostavnih sekvencionalnih kontrola do snažnih i brzih modela koji mogu da upravljaju sistemima sa velikim brojem ulazno/izlaznih jedinica. Potpuna modularnost u komponovanju ovog PLC-a daje mogućnost primjene širokog spektra centralnih procesorskih jedinica (CPU), koje su potpuno kompatibilne i mogu se brzo i jednostavno kombinovati sa bilo kojim drugim modulom PLC-a. Centralna procesorska jedinica CPU11, koja se koristi kod ovog uređaja, je namjenjena za manje sisteme, kao što su automatizovane mašine, uređaji za kontrolu itd. Kontroler posjeduje digitalnu ulaznu jedinicu sa 16 priključnih mjesta, te digitalnu relejnu izlaznu jedinicu sa 16 priključnih mjesta. Za povezivanje PLC kontrolera sa računarom koristi se standardni interfejs RS 232. Za programiranje PLC –a koristi se grafički programski jezik leder dijagram (*LD, Ladder Diagram*) CX Programmer, slika 2, kao zajednička platforma za programiranje CS/CJ/C/CV serije OMRON-ovih kontrolera [4]. Na slici 3. prikazano je ožičavanje U/I modula za primjer koji se razmatra.



Slika 2. Leder dijagram

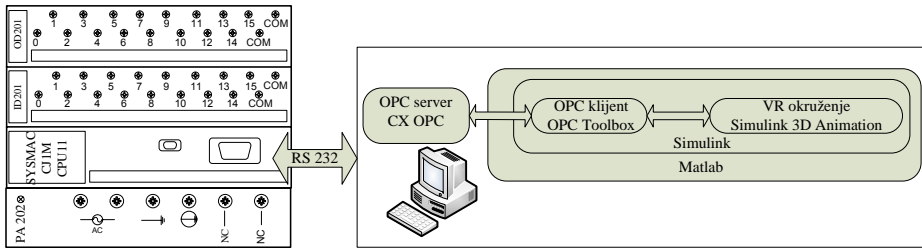


Slika 3. Ožičavanje ulaznog i izlaznog modula za slučaj fizičkog modela

4. PRIMJENA OPC STANDARDA ZA RAZMJENU PODATAKA IZMEĐU MATLAB-A I PROGRAMABILNOG LOGIČKOG KONTROLERA

U cilju razmene podataka između programabilnog logičkog kontrolera i okruženja virtualne realnosti potreban je odgovarajući interfejs. Kao rješenje moguće je primjeniti OPC standard, (skraćenica *OLE for Process Control*), koja označava Microsoft-ovu tehnologiju OLE *Object Linking and Embedding* [1], [7]. U ovom slučaju koristi se CX OPC server koji daje mogućnost za povezivanje i razmjenu podataka između OMRON-ovih PLC kontrolera serije CS/CJ/C/CV i CP i aplikacija koje rade u Microsoft okruženju i imaju podršku za OPC standard. CX-Server OPC podržava sve Omron komunikacione protokole. Treba napomenuti da je moguće koristiti i neka druga softverska rješenja, kao na primjer Matrikon OPC koji ima podršku za komunikaciju sa PLC kontrolerima proizvođača OMRON. Sa druge strane Matlab/Simulink posjeduje biblioteku OPC Toolbox koja omogućava pristup OPC serveru u realnom vremenu. Drugim riječima, korišćenjem ove biblioteke mogu se u realnom vremenu čitati podaci

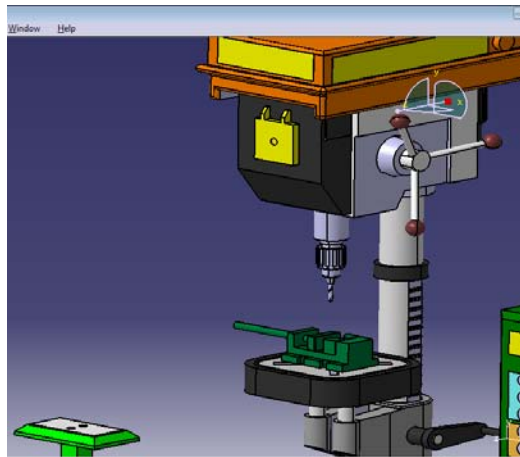
koje OPC server preuzima sa kontrolera, ili slati podaci iz Matlab-a prema PLC kontroleru. Na slici 4. prikazan je način razmjene podataka između PLC i Matlab-a.



Slika 4. Razmjena podataka između PLC kontrolera i Matlab-a [3]

5. KREIRANJE MODELA BUŠILICE U CATIA PROGRAMSKOM SISTEMU I VIRTUALNE SCENE KORIŠTENJEM VRML JEZIKA

S obzirom na to da je virtualna scena složena, za izradu 3D modela koristi se CATIA programski sistem opšte namjene, slika 5, uz uvažavanje činjenice da se isto moglo uraditi korištenjem bilo kog drugog CAD programskog sistema, koji omogućava snimanje datoteke u .wrl formatu. Pri izradi modela potrebno je unaprijed planirati sva kretanja koja izvode pojedini dijelovi, odnosno podsklopovi u VR okruženju, kako bi se na odgovarajući način formirali roditelj-dijete odnosi, kao i voditi računa o orijentaciji osa koordinatnog sistema u Matlabu.



Slika 5. Model stubne bušilice u CATIA programskom sistemu

Za kreiranje virtualne scene koristi se VRML (*Virtual Reality Modeling Language*) jezik, koji je pogodan za laku konverziju sa drugim 3D formatima [6]. VRML predstavlja ISO standard za interaktivnu, trodimenzionalnu Web grafiku, odnosno kreiranje virtuelnih svjetova na Web-u. Virtualna scena ne podrazumjeva samo objekte koje se nalaze i vide na sceni, tu su još i osvjetljenja, pozadina, pozicije kamere, naredbe za definisanje putanje između čvorova, skript čvorovi kojima se lako definiše

ponašanje čvorova, kao i još mnogo toga, a sve kako bi se korisniku omogućile različite interakcije, kao i upravljanje objektima u VR okruženju. U prethodnim razmatranjima [2], [3] objašnjena je primjena različitih čvorova za definisanje geometrijskih oblika, opisivanje svojstava, kao i čvorova za grupisanje i njihovih polja.

Ne ponavljajući ranije rečeno, u radu se daje kratko pojašnjenje specifičnih mehanizma za komuniciraju između čvorova, bitnih sa sa stanovišta ovog rada.

S obzirom da VRML ima specifičnu namjenu - opisivanje trodimenzionalnih scena i objekata, potrebne su mu mnoge karakteristike generaliziranih programskih jezika. Sam jezik nije objektno orjentisan, ali pomoću Prototype mehanizama moguće je izvesti objektno orjentisani model tj. enkapsulaciju i "reusability". To podrazumjeva korištenje prototipova (čvor PROTO), koji omogućavaju definisanje novih čvorova od strane korisnika. Korištenjem prototipova definišu se objekti na sceni koji se "ponavljaju", kao što su senzori prisustva predmeta, zaštitnih vrata, taster i prekidači kojima se rukuje mašinom i dr. Neki čvorovi generišu događaje u odnosu na promjenu okruženja ili korisničke akcije. Ovi čvorovi se nazivaju senzori (Anchor, Collision, CylinderSensor, PlaneSensor, ProximitySensor, SphereSensor, TimeSensor, TouchSensor, VisibilitySensor) i predstavljaju osnovne elemente koji obezbjeđuju interakciju sa korisnikom. U radu je korišten *TouchSensor* koji detektuje interakciju miša sa geometrijom. Upravljanje događajima vrši se korištenjem naredbe *ROUTE*, odnosno pisanjem posebne skripte. Nakon što korisnik izvrši događaj (klik mišem u ovom slučaju) na neki geometrijski oblik, naredbom *ROUTE* definišu se putanje između čvorova koji generišu događaje i onih koji ih primaju. Pri tome se dati geometrijski oblik, senzor i naredba *ROUTE* nalaze u istom čvoru za grupisanje.

VRML datoteke se prikazuju u VRML browser-ima koji mogu biti samostalne aplikacije ili VRML plugin html browser, pri čemu su neki od najpopularnijih VRML browser-a *Cortona VRML Client*, *Blaxxun Contact*, *Cosmo Player* i drugi. Za potrebe ovoga rada virtualna scena se prikazuje u aplikaciji *Simulink 3D Animation Viewer*, koje je dio biblioteke *Simulink 3D Animation*.

6. MATLAB SIMULINK MODEL

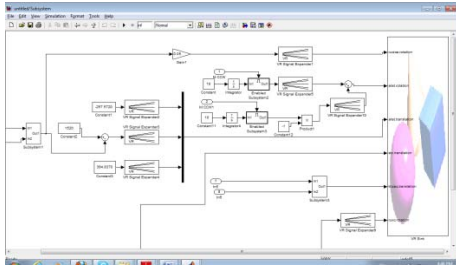
Kretanjem kinematskih modula kao osnovnih kinematskih cjelina, se upravlja iz Simulink okruženja, slika 6. Pri tome se za vezu između Simulinka i virtualne scene, date na slici 8, koriste *VR Sink* i *VR Source* blokovi biblioteke *Simulink 3D Animation*. Za vezu sa PLC kontrolerom koriste se blokovi *OPC Configuration*, *OPC Read* i *OPC Write* biblioteke *OPC Toolbox*.

VR Sink blok "upisuje" vrijednosti sa svojih portova u virtualni svijet preko polja definisanih u dijalog boksu Block Parameters, slika 9.

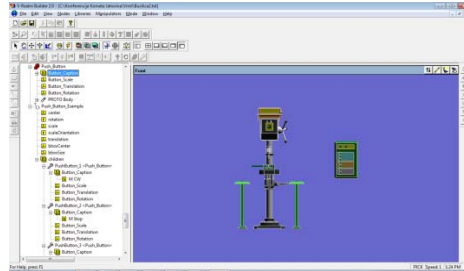
VR Sink blok je zadužen za prikaz virtualne scene u aplikaciji *Simulink 3D Animation Viewer*. Aplikacija se pokreće nakon što korisnik dvaput klikne lijevom dugmetom miša se na blok *VR Sink*. Ulazi u blok *VR Sink* direktno mijenjaju karakteristike objekata u virtualnoj sceni.

Definisanje karakteristika virtualnih objekata koji se mijenjaju omogućuje odabir opcije „Simulation > Block Parameters...” iz menija u aplikaciju *Simulink 3D Animation Viewer*. Na desnoj strani prozora dato je stablo za virtualnu scenu koja je definisana u VRML fajlu, čije je ime prikazano u lijevom dijelu prozora. Unutar ovog stabla prikazana je struktura VRML fajla. Blokovi sa nazivima označeni su crvenom strelicom i dostupni su iz Matlab-ovog okruženja. Blokovi bez naziva, ali čija djeca imaju nazive također su označena crvenom strelicom. Polja blokova koja se mogu mijenjati imaju uz

naziv kvadratić. Selektovanjem kvadratića omogućava se promjena vrijednosti polja iz Simulinka (istovremeno se na VR Sink s-bloku stvara ulaz s pripadajućim nazivom). Ako je potrebno izvršiti promjene u VRML datoteci, u aplikaciji Simulink 3D Animation Viewer odabere se opcija „File > Open in Editor“. Tada se .wrl datoteka otvara u V-Realm Builder VRML editor, koji je distribuiran s MATLAB-om, slika 7.



Slika 6. Blok dijagram – veza između Matlaba/SIMULINKA i VR okruženja

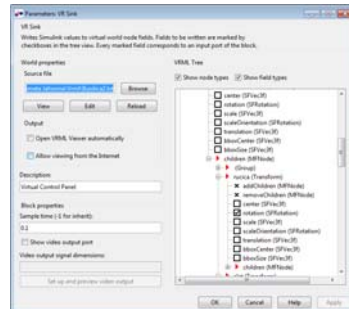


Slika 7. Virtualni svijet prikazan u V-Realm Builder editor

Određene izmjene VRML datoteke moguće je raditi i ručno, budući da je .wrl tekstualna datoteka, ali za to treba poznavati sintaksu VRML-a. Primjena VRML editora je sigurno ugodniji i lakši način rada, ali ne uvijek i dovoljan.

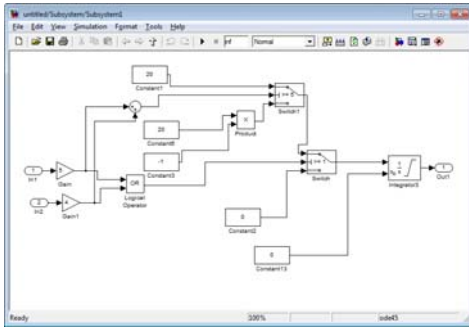


Slika 8. Virtualna scena

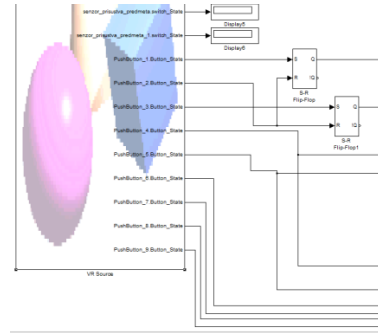


Slika 9. Definisanje parametara bloka VR Sink

Već je rečeno da Simulink model ne obuhvata dinamičku simulaciju, te da stanje sistema mijenja pojava diskretnih događaja. Međutim simulacija se mijenja u vremenu, što se naziva kontinuirana simulacija. Razlog za ovo leži u činjenici da poziciju alata određuje izlaz bloka Integrator, čije se vrijednosti mijenjaju kontinuirano u vremenu, slika 10.



Slika 10. Određivanje pozicije alata



Slika 11. VR Source blok

VR Source blok je veoma sličan izgledom bloku VR Sink, kroz ovaj blok može se pokrenut aplikacija Simulink 3D Animation Viewer, kao i urediti .wrl datoteka. Takođe, definisanje karakteristika virtualnih objekata može se vršiti na prethodno opisan način. Razlika je u tome što ovaj blok čita različite vrijednosti iz virtualnog svijeta i prosleđuje u Simulink model. Na slici 11. prikazan je VR Source blok, gdje se na izlazima nalaze vrijednosti logičkih promjenjivih koje predstavljaju stanje senzora, prekidača i tastera u virtualnoj sceni. Blokovi OPC Read i OPC Write komuniciraju sa OPC serverom, a OPC server sa PLC kontrolerom. Na slici 12. prikazane su adrese (tzv. tagovi) ulaznih, odnosno izlaznih terminala na PLC kontroleru koje se definišu na OPC serveru. OPC Write blok setuje (forsira) stanje bita na ulaznim terminalima u zavisnosti od početnih uslova (stanje senzora), dok blok OPC Read uzima vrijednosti sa izlaznih terminala kontrolera, što predstavlja upravljačke signale kinematskim modulima mašine alatke u virtualnom okruženju.

Name	Type	Address	Comment
* \Desni start	Point	Omron PLC/F:0.4/1/B	
* \Desni stop	Point	Omron PLC/F:0.6/1/B	
* \IN001 System start	Point	Omron PLC/F:0.0/1/B	
* \IN002 System stop	Point	Omron PLC/F:0.1/1/B	
* \IN003 LSPP obradak postavljen	Point	Omron PLC/F:0.2/1/B	
* \LSD0 alat u donjem položaju	Point	Omron PLC/F:0.8/1/B	
* \LSD0 zatvaranje zaštitnih vrata	Point	Omron PLC/F:0.7/1/B	
* \Ljevi start	Point	Omron PLC/F:0.3/1/B	
* \Ljevi stop	Point	Omron PLC/F:0.5/1/B	
* \OUT 017 System pilot light	Point	Omron PLC/1.10/1/B	
* \OUT018 zatvaranje zast vrata	Point	Omron PLC/1.1/1/B	
* \OUT019 Motor glavnog kretanja	Point	Omron PLC/1.2/1/B	
* \OUT020 kretanje alata nadole	Point	Omron PLC/1.3/1/B	

Slika 12. Adrese ulaznih i izlaznih terminala

7. ZAKLJUČAK

U radu su prikazane mogućnosti korištenja veze Matlab – PLC, pri čemu se kao interface za razmjenu podataka koristi OPC server. U okruženju virtualne realnosti mogu se, pored same vizualizacije, izvoditi različita testiranja i provjere proizvoda. Jedan od prilaza uključuje i upravljanje 3D virtualnim modelima primenom realnih

programabilnih logičkih kontrolera. Ovakav koncept može se koristiti u različite svrhe, testiranje razvijenog upravljačkog algoritma, skraćivanja vremena razvoja proizvoda i povećanja produktivnost, ali i u edukativne svrhe.

Za realizaciju je potrebna standardna PC platforma, što predstavlja prednost zbog niskih troškova.

Nedostatak je dosta složen postupak kreiranja ovakve scene budući da je potrebno poznavanje nekog od CAD alata (koji može eksportovati geometriju u .wrl format datoteke), VRML jezika, JavaScript, odnosno Java programskog jezika, Matlab-a, kao i poznavanje rada sa PLC kontrolerima, odnosno programiranje PLC kontrolera.

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KONFIGURISANJE VIRTUELNOG ROBOTA ZA OBRADU I PRIMENA U OFF-LINE PROGRAMIRANJU I EDUKACIJI

Saša Živanović¹, Zoran Dimić², Nikola Slavković³,
Dragan Milutinović⁴, Miloš Glavonjić⁵

Rezime: U radu je prikazan pristup primene virtuelnih robota koji se koriste za off-line programiranje i edukaciju studenata. Virtuelni robot je konfigurisan u Python programskom okruženju i integrisan je sa Axis korisničkim grafičkim interfejsom upravljačkog softvera EMC2, koji radi na PC Linux platformi. U radu se razmatraju aspekti primene u off-line programiranju i edukaciji.

Cljučne riječi: virtuelni robot, Python, EMC2

CONFIGURING OF VIRTUAL ROBOT FOR MACHINING AND APPLICATION IN OFF-LINE PROGRAMMING AND EDUCATION

Abstract: *This paper gives an application of virtual robots which are used for offline programming and students' education. Virtual robot is configured in Python program environment and it is integrated with Axis GUI of the control system EMC2 which operates on Linux platform. This paper considers aspects of application in offline programming and education.*

Keywords: virtual robot, Python, EMC2

1. UVOD

U ovom radu se razmatra konfigurisanje virtuelnog robota za obradu koji predstavlja softversku implementaciju robota, kao simulacionih kinematičkih modela, koji mogu da izvršavaju programe u odabranom grafičkom okruženju, na isti način na koji to rade i stvarni roboti za obradu. Virtuelni robot je digitalni opis robota, obično sa uprošćenom geometrijom i koristi se za potrebe računarskih simulacija procesa obrade, off-line programiranje, kompletiranje virtuelnog tehnološkog sistema i edukaciju. Pojam virtuelnih obradnih sistema, je širok i obuhvata kompletne modele procesa obrade, noseće strukture, pogona, prenosnika, kinematičkog podsistema itd. [1]. To se sve integriše u jedinstveni sistem softvera, koji omogućava neki deo

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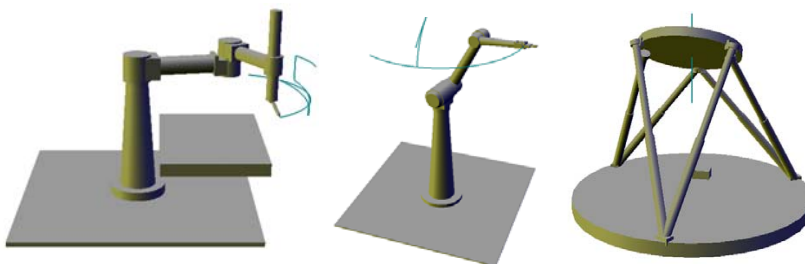
virtuelne proizvodnje [2]. Ovakva istraživanja obradnih sistema su intenzivna i imaju dosta kompletiranih rezultata [3,4,5,8]. Naš virtuelni robot pokriva samo kinematiku realnog robota. Postojeća grafička okruženja CAD/CAM sistema uobičajeno prikazuju simulaciju putanje alata. Međutim, cilj je ostvariti simulaciju rada virtuelnog obradnog sistema, ovde virtuelnog robota za obradu, koji se upravlja na isti način kao i stvarni robot i koji omogućava vjernu simulaciju kretanja robota tokom obrade. Osnovne prednosti primene ovakvih virtuelnih robota za obradu su: (i) ostvarivanje simulacije rada virtuelnog robota, kojom se mogu uočiti eventualne kolizije, koje mogu nastati u toku izvršenja programa, a koje se ne mogu uočiti samo na osnovu simulacije putanje alata; (ii) simulacija omogućava verifikaciju *off-line* programiranja na udaljenom programerskom mestu, bez angažovanja samog robota; (iii) može se koristiti za praćenje obrade u realnom vremenu sa udaljenog mesta, pošto je reč o simulaciji u realnom vremenu cele konfiguracije mašine; (iv) rad u virtuelnom okruženju je pogodan i sa aspekta obuke za programiranje troosnih i višeosnih obrada.

Konfigurisanje virtuelnog robota u ovom radu je razmatrano na primeru industrijskog robota LOLA50, instalisanog na Katedri za proizvodno mašinstvo Mašinskog fakulteta u Beogradu.

2. STANJE ISTRAŽIVANJA

Istraživanja u oblasti virtuelnih obradnih sistema su aktuelna u istraživačkim institucijama koja se bave razvojem numeričkih upravljačkih sistema. Pojava *softvera* otvorene arhitekture kao što je EMC (*Enhanced Machine Controller*) [6], u mnogome je doprinela značajnom unapredjenju razvoja nove generacije CNC upravljačkih sistema. Aktuelna verzija EMC2 softvera, ima mogućnost da se postojeći grafički interfejs Axis, integriše sa virtuelnim obradnim sistemom, čime je omogućen prikaz kretanja kompletne mašine u virtuelnom Python 3D okruženju. Na taj način se mogu uočiti eventualne kolizije koje mogu nastati u toku izvršenja programa.

Istraživanja u oblasti upravljanja robotima i mašinama sa paralelnom kinematikom, su posebno interesantna, jer nemaju trivijalnu kinematiku, kao kod serijskih mašina alatki, već zahtevaju implementaciju inverznog kinematičkog problema u softver za upravljanje. Softver EMC2 se stalno unapređuje i dobija nove mogućnosti. Sa svakom novom verzijom povećava se i broj dostupnih realizovanih virtuelnih mašina alatki i robota. U selektoru dostupnih virtuelnih konfiguracija robota (*EMC Configuration Selector*) su dodati i primeri realizovanih virtuelnih robota, slika 1. To su dva robota sa serijskom kinematikom kao što su SCARA robot i PUMA robot i jedan robot sa paralelnom kinematikom kao što je Stjuart-Gočova platforma.



Sl.1 Virtuelni roboti u Python programskom okruženju [6]

EMC je od minimalističkog softverskog paketa za kontrolu rada mašina alatki izrastao u kompleksan softverski sistem sa svim osobinama koje poseduje jedan savremeni komercijalno raspoloživ CNC softver. Modularna struktura softverskog paketa doprinela je njegovoj fleksibilnosti, kako u primeni na mašinama sa raznolikom kinematikom, tako i u povezivanju sa različitim hardverskim i softverskim dodacima.

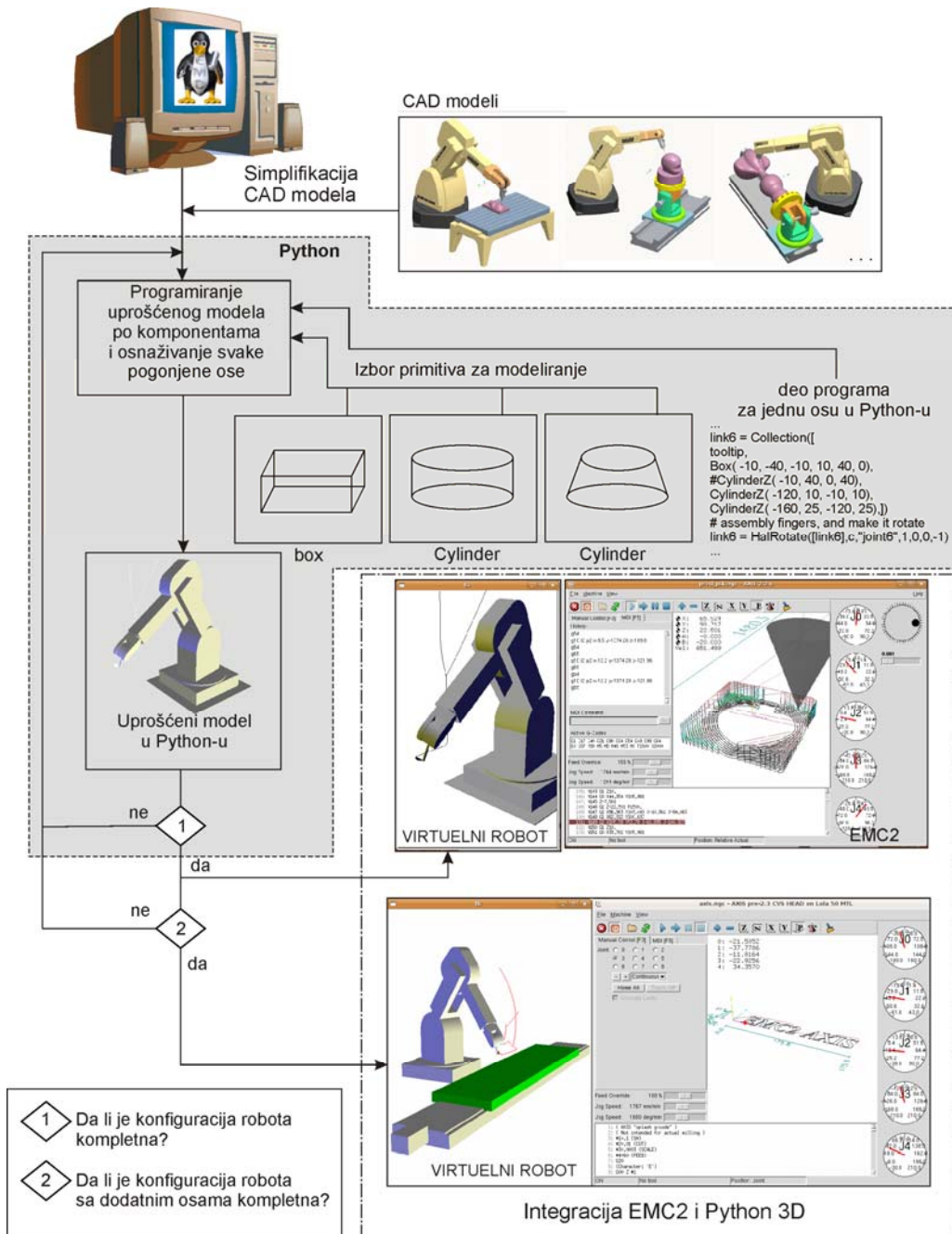
Dostupnost EMC je učinila da ekskluzivno pravo na izradu CNC-a više ne pripada vodećim svetskim firmama sa proizvodnjom i razvojem u ovoj oblasti. Sve više je univerzitetskih institucija u svetu koje su usvojile EMC kao koncept razvoja svojih upravljačkih sistema čime im je omogućeno istraživanje i razvoj upravljanja novim mašinama sa vrlo složenom kinematikom. Kada se kaže mašina, podrazumevaju se i mašine alatke i industrijski roboti, kojima se razvija novo upravljanje za novu namenu. Naime, primena EMC je u uslovima minimalnih ulaganja, odlično rešenje za revitalizaciju postojećih mašina i obradnih sistema, koji su sa zastarelim upravljanjem, ili potpuno bez upravljanja. Takođe, dostupnost EMC-a učinila ga je i odličnim za primenu u edukaciji.

3. KONCEPT KONFIGURISANJA VIRTUELNOG ROBOTA

Za konfigurisanje virtuelne mašine odabrano je Python 3D okruženje. Python je programski jezik koji se koristi za programiranje grafičkih korisničkih interfejsa i omogućava programiranje i povezivanje geometrijskih primitiva, kao i njihovu integraciju sa EMC Axis okruženjem. U njemu je programirano i samo okruženje Axis. Postupak modeliranja virtuelnog robota se ovde svodi na programiranje koordinata geometrijskih primitiva, za definisanje i povezivanje svih sklopova virtuelnog robota. Koncept konfigurisanja virtuelnog robota pokazan je na slici 2.

Komponente virtuelnog robota su značajno uprošćene i opisane pomoću elementarnih geometrijskih primitiva (Box, Cylinder, Sphera...). Položaj primitiva se programira u odnosu na zadati referentni koordinatni sistem. Primitivi, koji čine jednu celinu, grupišu se. Pokretni elementi se povezuju odgovarajućim vezama, obrtnim, ili translatornim. Svi parametri robota treba da budu korektno postavljeni na virtuelnom, kao i na stvarnom robotu, a smerovi osa postavljeni prema definisanom kinematičkom modelu. Tokom programiranja radi se jedna po jedna komponenta i odmah vrši provera da li je model u dostignutoj fazi u redu. Uočene greške se odmah ispravljaju, ponovo se vrši provera i ide na definisanje naredne komponente. Kada je konfiguracija robota kompletna i korektno konfigurisana dobijen je integrisan sistem EMC2 i Python 3D, koji u ovom slučaju predstavlja virtuelnog robota za obradu gde sva kretanja ostvaruje alat, obradak miruje. Moguće je da se razmatraju i druge konfiguracije robota sa dodatnim osama, koje se takođe mogu programirati u Pythonu i povezati sa osnovnom konfiguracijom virtuelnog robota, a potom integrisati sa upravljačkim jezgrom EMC2 softvera i Axis korisničkim grafičkim interfejsom, slika 2.

Kao rezultat se dobija virtuelni robot u Python 3D okruženju, integrisan sa grafičkim korisničkim interfejsom Axis. Virtuelni robot radi u Python 3D prozoru i omogućava kretanje osa robota za obradu, sa iscrtavanjem putanje alata. Ova simulacija je nastala kao rezultat izvršenja programa (G kôda) u realnom vremenu, na isti način kao da se vrši upravljanje stvarnom mašinom. Povezivanjem virtuelne mašine alatke sa upravljačkim jezgrom EMC2 kompletira se virtuelno grafičko okruženje za programiranje, upravljanje i simulaciju.

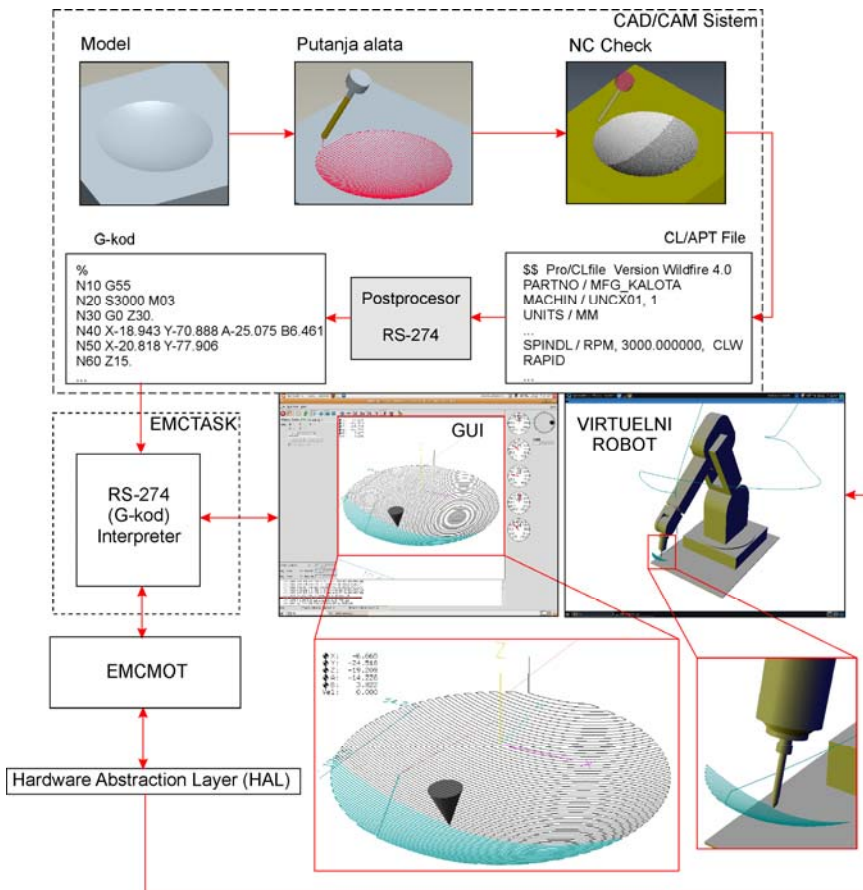


Sl.2 Koncept konfigurisanja virtuelnog robota

4. UPRAVLJANJE VIRTUELNOG ROBOTA I OFF-LINE PROGRAMIRANJE

Upravljački sistem robota je baziran na PC Linux platformi i upravljačkom softveru otvorene arhitekture EMC2 (Enhanced Machine Control) [6], koji je namenjen za upravljanje mašinama alatkama i robotima serijske i paralelne kinematike. EMC2 je izrađen na osnovi NIST-ove (National Institute of Standards and Technology) [7] RCS (Real-time Control System) metodologije i programiran je korišćenjem RCS biblioteke.

Pogodnost konfigurisanja virtuelnog robota se zasniva na činjenici da i virtuelni i stvarni robot koriste identičan sistem za upravljanje na bazi EMC2 upravljačkog softvera. Sistem za upravljanje i programiranje virtuelnog robota je pokazan na slici 3.



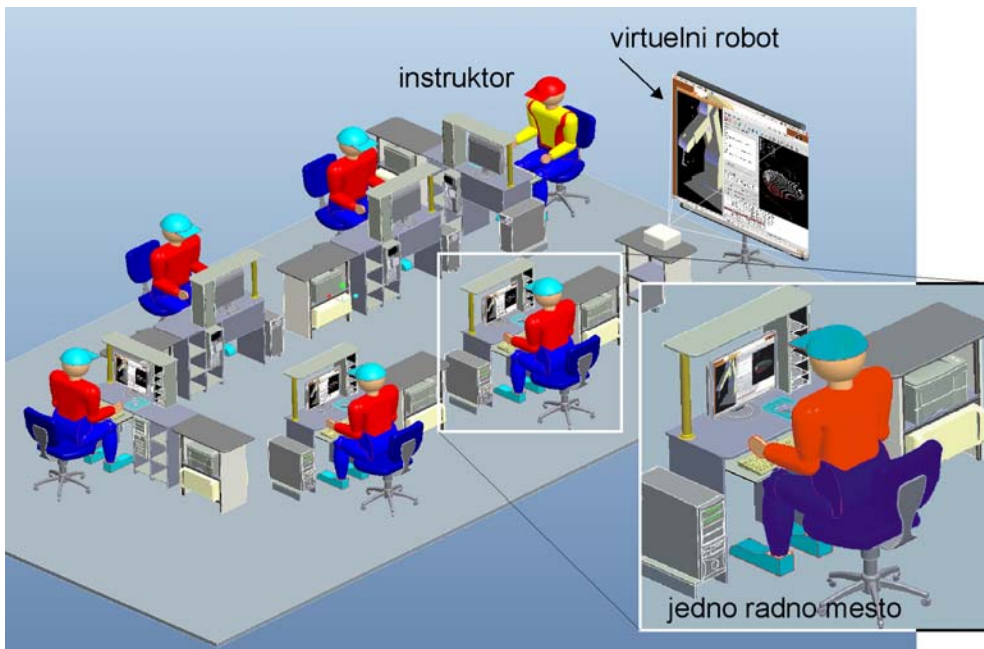
Sl.3 Upravljanje i programiranje virtuelnog robota [9,10]

Sistem za programiranje robota za obradu je uobičajen i ostvaruje se primenom raspoloživog CAD/CAM sistema. Polazi se od CAD modela za koji se u CAD/CAM sistemu generiše putanja alata (CLF – Cutter Location File). Za dobijenu putanju alata prvo se vrši njena verifikacija u raspoloživom softveru za simulaciju uklanjanja materijala, a zatim pristupa postprocesiranju CLF radi dobijanja G kôda za petoosnu vertikalnu glodalicu. Robot LOLA50 je konfigurisan kao petoosna mašina alatka konfiguracije X,Y,Z,A,B, gde X,Y,Z predstavljaju poziciju vrha alata, dok A i B,

predstavljaju uglove orijentacije alata. Za varijantu obradnog sistema kada sva kretanja izvodi robot konfigurisan je postprocesor za konfiguraciju mašine (X,Y,Z,A,B). Tako dobijeni G kôd se učitava u upravljački softver EMC2 gde se najpre vrši verifikacija progama na virtuelnoj mašini u realnom vremenu, slika 3, a zatim se upravljački signali sa sigurnošću mogu usmeriti ka realnom robotu kao petoosnoj vertikalnoj glodalici. Virtuelni robot je konfigurisan preko nekoliko klasa predefinisanih u objektno orijentisanom jeziku Python. Verifikacija programa u realnom vremenu na virtuelnoj mašini je neophodna zbog kinematike robota koja se bitno razlikuje od kinematike petoosnih mašina alatki (translatorne + 2 obrtne ose) čiji se G kôd preuzima. Takođe je vrlo značajna analiza postavljanja obratka u radni prostor veštine robota, tako da obrada bude izvedena do kraja, a da ni jedna osa ne dođe do kraja svog hoda. To se proverava upravo na virtuelnom robotu kao mašini, gde se vrši verifikacija G kôda, slika 3, sa pomeranjem segmenata i ispisivanjem putanje alata, kao da je reč o realnom robotu. Ukoliko dođe do prekoračenja hoda neke ose, vrši se korekcija postavljanja obratka u radni prostor i postupak ponavlja do ispunjenja svih uslova za obradu.

5. EDUKACIONI SISTEM ZA PROGRAMIRANJE ROBOTA ZA OBRADU

Ideja je da se oformi edukacioni sistem u vidu učionice sa 5 do 10 radnih mesta sa instalisanim virtuelnim robotima, video bimom i radnim mestom sa virtuelnim robotom za instruktora, slika 4. Instruktor pokazuje rad na virtuelnom robotu, koji je vidljiv i na video bimom, čime se omogućava uvežbavanje rukovanja i programiranja robotom, od strane polaznika. Sa verifikovanim programom se na kraju pristupa i obradi na realnom robotu LOLA50.

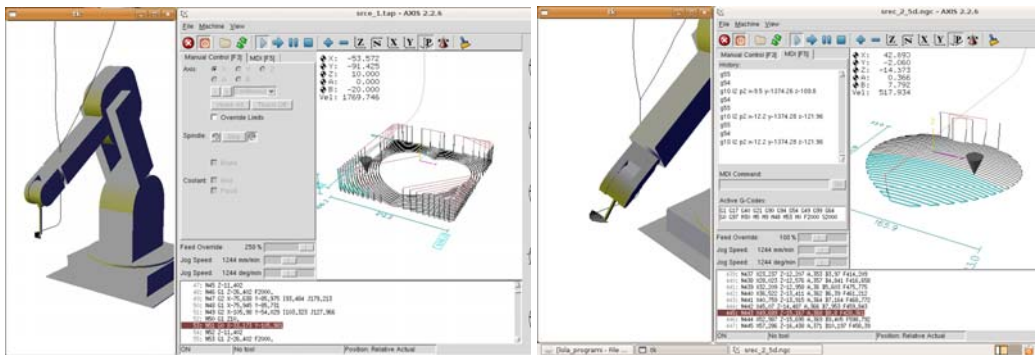


Sl.4 Edukacioni sistem za programiranje robota za obradu

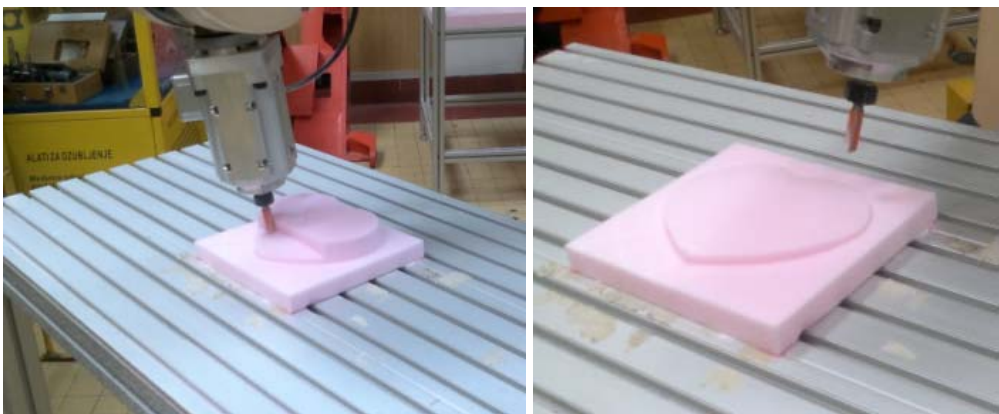
Robot LOLA50 i konfigurisani obradni sistem na bazi virtuelnog robota za obradu se već koristi u nastavi na predmetu Mašine alatke i roboti nove generacije na Mašinskom fakultetu Univerziteta u Beogradu. Studenti imaju prilike da steknu nova znanja iz oblasti višeosne obrade robotima i da to verifikuju radom na virtuelnom i stvarnom robotu. Programiranje robota je uobičajeno primenom G kôda, koji se dobija primenom CAD/CAM sistema Pro/Engineer Wildfire 5 (CreoElements/PRO).

6. VERIFIKACIJA VIRTUELNOG ROBOTA

Programi dobijeni off-line programiranjem robota u G kôdu, prvo se verifikuju na virtuelnom robotu, a potom i obradom na stvarnom robotu. Verifikacija je u radu pokazana na primeru obratka u obliku srca, sa sfernom površinom. Program je pripremljen primenom CAD/CAM sistema Pro/Engineer Wildfire 5 (CreoElements/PRO) i to prvo za predobradu, a posle i za završnu obradu, slika 5. Predobrada je realizovana troosnom, a završna obrada petoosnom obradom, vretenastim ravnim glodalom prečnika 12 mm. Primer obrade i obrađenog dela posle završne obrade pokazani su na slici 6.



SI.5 Verifikacija programa na virtuelnom robotu za troosnu predobradu i završnu petoosnu obradu



SI.6 Primer obrađenog dela višeosnom obradom

7. ZAKLJUČAK

Osnovni ciljevi, ostvareni u ovom radu, mogu se svesti na razvoj koncepta CNC upravljanja otvorene arhitekture, za obradni sistem na bazi robota, sa integrisanom virtuelnim robotom. Razvoj virtuelnih okruženja, za off-line programiranje i simulaciju rada su značajni za potrebe verifikacije programa. Drugi aspekt primene je obuka i edukacija za programiranje, što je posebno značajno za obrazovne ustanove. Na taj način i bez postojanja fizičkih resursa kao što su obradni sistemi za višeosnu obradu robotom, moguće je ostvariti obuku za njihovo programiranje, primenom odgovarajućih virtuelnih robota.

Konfigurisani virtuelni robot se već koristi u nastavi na Mašinskom fakultetu Univerziteta u Beogradu, u okviru laboratorijskih vežbi iz predmeta Mašine alatke i roboti nove generacije. U sklopu daljih istraživanja razmatraju se i realizacije virtuelnog robota sa dodatnim obrtnim i translatorskim osama.

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MATERIAL TYPE INFLUENCE ON STATIC AND DYNAMIC CHARACTERISTICS OF COMPOSITE SHAFTS

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Nenad Kostić⁵

Summary: *Characteristics of composites (stiffness, resistance, thermal expansion and other) can vary depending on the type of the material used, quantity, angle of fibre orientation, etc. In this paper the dynamic performance and cross-section deformation of shafts made of metals (steel and aluminum), composites (CFRP and GFRP) and hybrids of metals and composites have been studied.*

Results obtained show that improvements in dynamic performance and reduction of cross-section deformation of hybrid shafts over metallic and composite shafts are possible.

Keywords: composite materials, shafts, deformation, natural frequency

1. INTRODUCTION

Modern machine constructions, apart from introduction of new technologies in design and manufacture, demand application of new materials that may have higher specific strength and hardness compared to traditional materials. These criteria are met by composite materials, which values of impact tenacity, strength and hardness and especially of resistance to fatigue and vibratory and acoustical loads may be enhanced in relation to known metals and alloys. These features may be varied, according to needs, by selection of components, their quantity, allocation and orientation within the material. Due to their good characteristics, composite materials are increasingly used for manufacture of shafts today.

The shell theory is most frequently used for the analysis of characteristics of composite shafts. Most of the studies for analysis of shafts is based on classic theory of thin shells or on theory of thick shells.

Reis and Goldman [1] have applied the Finite Element Method (FME) to analyse the critical speed of thin walled laminate composite shafts and they have emphasised a great resistance of composite shafts under the action of dynamic load. *Lim and Darlow* [2] have presented an optimal calculation of composite drive shaft with

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variation of laminate diameter. *Lam* and *Loy* [3] have analyzed vibrations of laminate thin walled shaft, using the Loves' approximate theory and applying the shell theory.

A beam model is also used for analysis of dynamic characteristics of composite shafts. *Singh* and *Gupta* [4] have researched the vibratory characteristics of composite cylindrical shaft using *Timoshenko's* beam theory.

2. TYPES AND PROPERTIES OF COMPOSITES

Composite materials are obtained through combining two or more materials with the goal of creating a new material with controlled attributes and increased number of desirable characteristics.

Some of the many advantages of the composites are as follows:

- Tension resistance is four to six times higher compared to steel or aluminum,
- Increased impact resistance,
- Increased fatigue tolerance,
- Increased vibration resistance,
- They manifest low sensitivity to temperature changes and are very resistive towards corrosion,
- Long life cycle,
- Composites are eliminating the need for couplers, which are required when using metal parts, and. etc.

Composites can be classified in different ways and by different criteria. From the point of this paper, the corresponding division of the composite would be deployed into the three main groups:

- composites with discrete particles embedded in a matrix,
- fibre-reinforced composites,
- layered composite laminates.

The characteristics of composites depend largely on three factors:

- strength and chemical stability of the matrix,
- strength and elasticity of reinforcing fibres,
- bond strength between the matrix and fibres arming.

3. DEVELOPMENT OF MODELS FOR THE NUMERICAL ANALYSIS OF COMPOSITE SHAFTS

Dimensions of the shaft, analyzed in this paper are: length of the shaft is 1000 mm, mean radius is 50 mm, wall thickness of the ring cross section is 5 mm [5]. The shaft is supported at the ends and the middle of the span is subject to static load of 1000N [5], [6].

Basic characteristics of metal materials (steel and aluminum) and composite materials (CFRP and GFRP) are given in Table 1.

Table 1 Basic characteristic of material

Material	E_1 , MPa	E_2 , MPa	G_{12} , MPa	ν_{12}	ρ , kg/m ³
steel	210000	210000	83000	0,3	7830
aluminum	70000	70000	28000	0,28	2600
CFRP	130000	10000	7000	0,25	1500
GFRP	40300	6200	3000	0,20	1900

The labels in the table are: E_1 - longitudinal modulus; E_2 - transverse modulus; G_{12} - shear modulus, ν - Poisson's ratio, ρ -density of material.

The analyzed shaft was modelled by isoparametric square shell finite elements. It was divided into 8 elements in axial and 12 elements in circular direction [5]. The NeNastran 8.6 software was used for the analysis. Model of analyzed composite shaft is shown in the Fig.1.

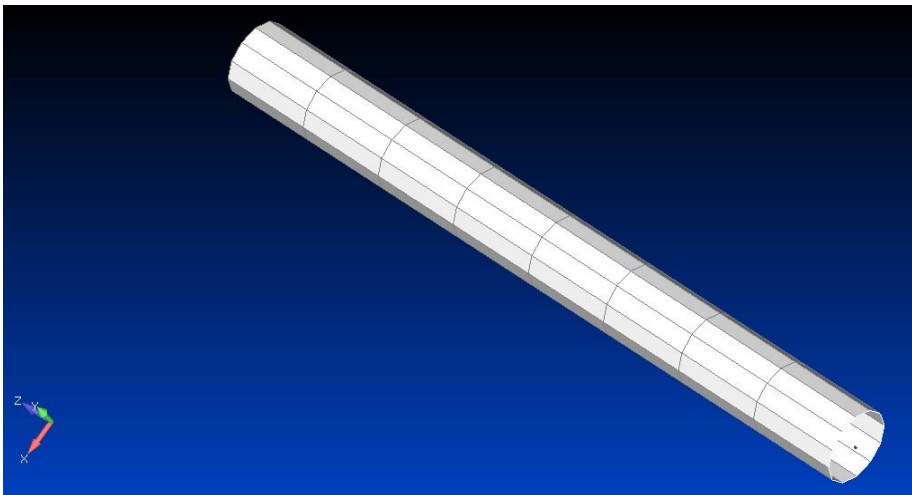


Fig. 1 Composite shaft model

Analyzed have been both deflections and deformations of shaft cross sections in the axial and circular direction. Comparative review of the values in the vertical plane of displacements for shafts made of steel, aluminum and composite CFRP and GFRP with fiber orientation at 0° and 90°, is shown in Fig. 2.

From the figure it can be concluded that the maximum amount of displacements, is in the case of composite shafts made of CFRP and GFRP with 90° fiber orientation, while slightly better results are in the case of composites orientation 0°.

In order to reduce shaft deformations, it is recommended to produce the hybrid shafts, obtained by mixing metals and composites.

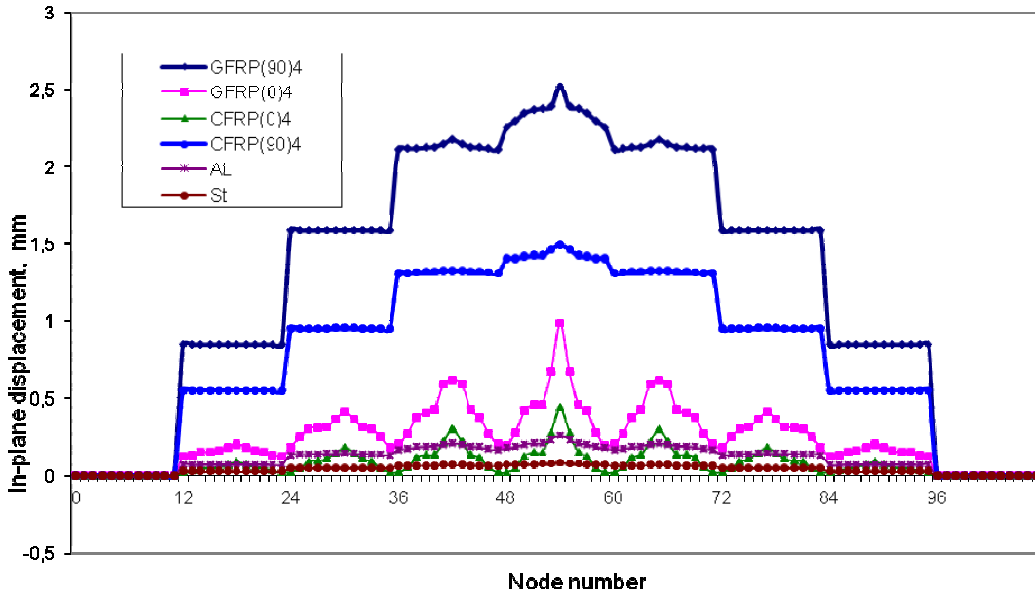


Fig. 2 Deflection and cross-section deformation shaft made of single material

Comparative review of the shaft displacement values and shaft deformations of cross sections obtained by a combination of steel (aluminum) and composite 0° orientation, are given in Figure 3.

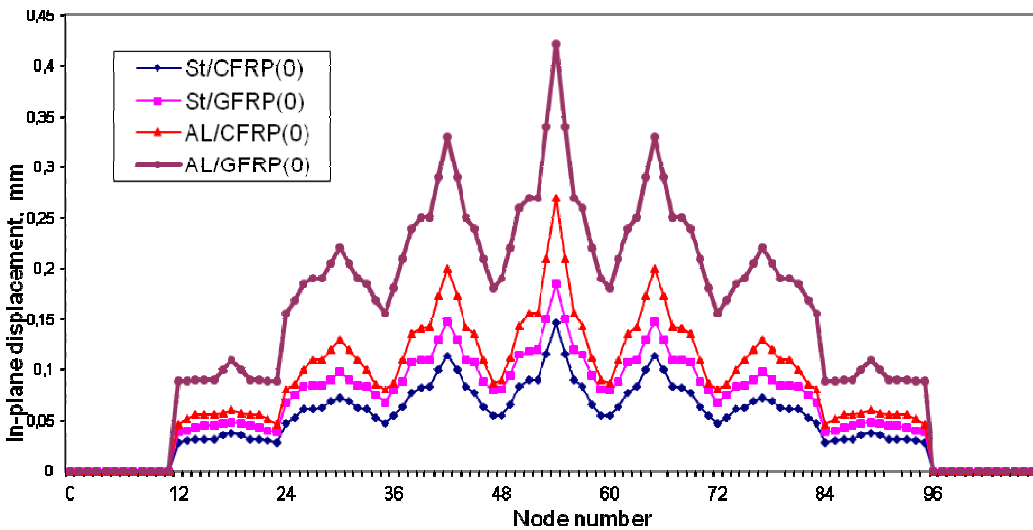


Fig. 3 Deflection and cross-section deformation hybrid shafts with 0° fibre angle

Interesting to analyze is the combination of metals (steel and aluminum) with composites of 90° orientation (Figure 4). In Figure 4 it can be seen that approximately the same quantity of displacements, as well as a form of cross-sections of hybrid shafts, obtained by combining steel shaft with CFRP and GFRP composite with the fiber orientation 90°. This is explained by the fact that, in the case of fiber orientation at 90° modulus of elasticity in the transverse direction are very small, for both CFRP and GFRP materials, compared to steel. So, in this case, the value of displacements and deformation of the shaft depends much on the contents of the steel part.

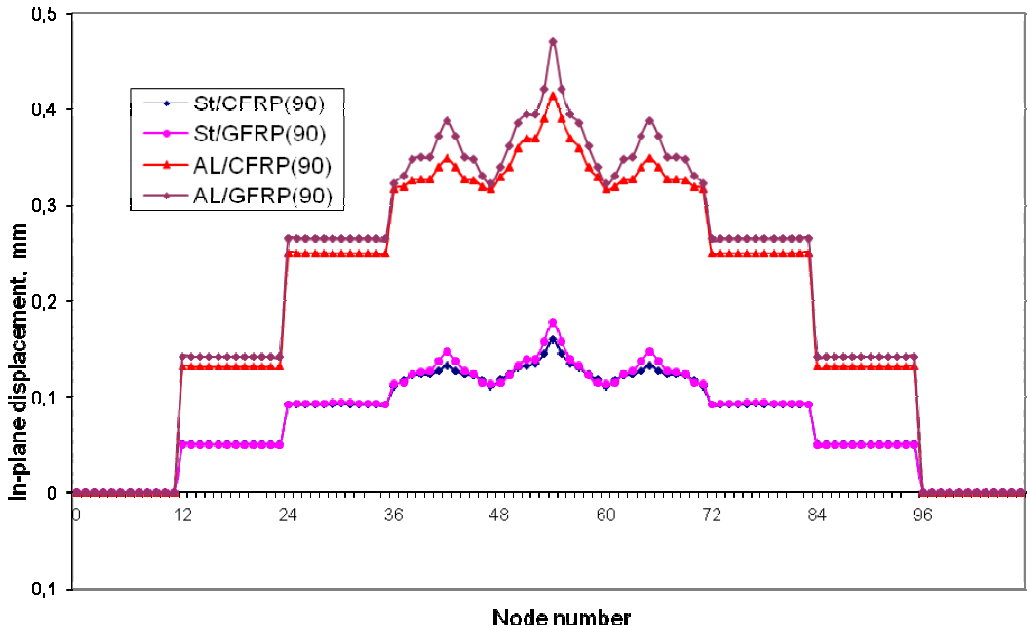


Fig. 4 Deflection and cross-section deformation hybrid shafts with 90° fibre angle

4. FUNDAMENTAL NATURAL FREQUENCY OF THE SHAFT

For the shaft, which has been subjected to static analysis, considered were also natural frequencies. It is known that the values of natural frequencies depend on the ratio E_1/ρ [7]; the ratio is almost the same for the shaft made of steel or aluminum, hence the value of natural frequencies of the shaft of steel or aluminum are almost the same as it can be seen from Table 2. However, in the case of the composites, ratio E_1/ρ varies, and depends on the orientation of the fibers, the maximum is for fibers angle of 0°, and decreases when the fiber orientation angle approaches 90°.

Thus, as it can be seen from Table 2, also natural frequencies of composite shafts (CFRP and GFRP) depend on the angle of orientation of fibers and have the highest value at angles of 0° -10°, while reducing the value of proximity to the fiber orientation angle range of 90°.

Table 2 Natural frequencies values for different types of material

Material	0°	10°	20°	30°	40°	50°	60°	70°	90°
steel	277,6								
aluminum	278,2								
CFRP	426,7	439,1	414,2	332,0	248,4	194,1	164,5	149,6	139,8
GFRP	232,4	235,8	227,1	196,5	160,7	135,9	123,2	117,1	111,7
StCFRP	320,0	316,6	306,9	292,9	278,7	268,9	264,7	264,2	265,4
StGFRP	271,5	270,3	266,9	262,5	258,3	255,4	254,2	254,2	255,0
AlCFRP	361,8	356,5	339,0	309,8	278,2	255,6	245,1	242,1	241,6
AlGFRP	262,5	260,0	253,0	243,0	233,0	225,8	222,6	222,1	222,9

Graphical display of the obtained natural frequency values, for metal and composite shafts with fiber orientation angles from 0° to 90°, is shown in Figure 5.

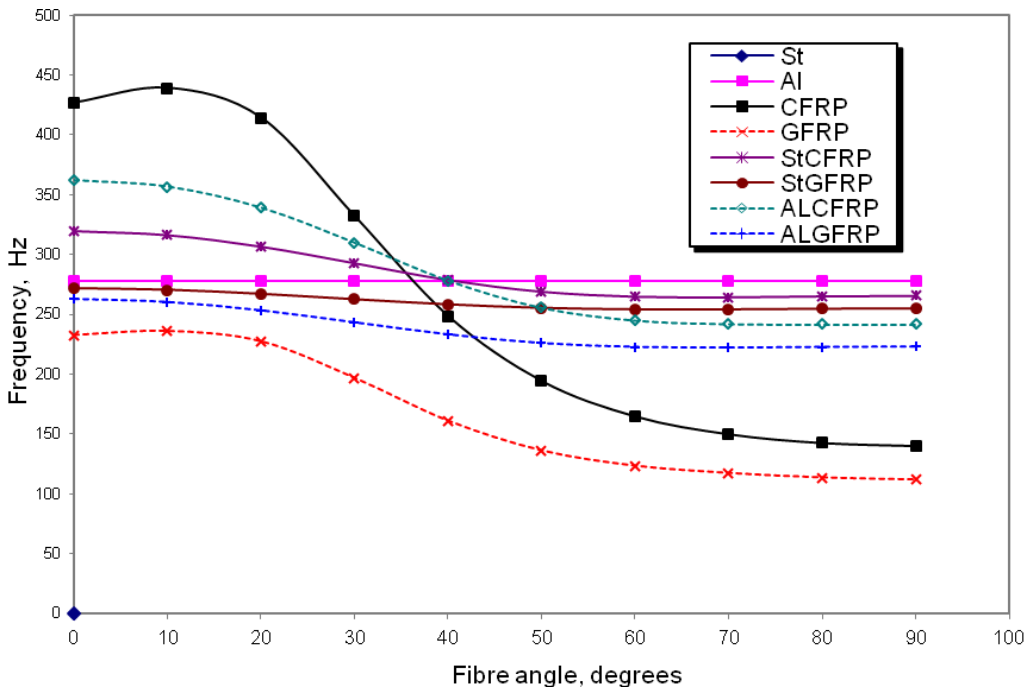


Fig. 5 Natural frequencies of shafts made of different materials

Comparing dynamic characteristics of the shaft composite (CFRP and GFRP) and the metal shaft (steel and aluminum), can be observed that the values of natural frequencies for CFRP shaft with fiber orientation angle at $37^\circ - 38^\circ$ with the same values as those of steel or aluminum shafts. If the angle of $0-37^\circ$ fiber orientation (in the case of combined returned to 40°) composite shaft is made of CFRP and the combined shaft (ST / CFRP and Al / CFRP) have higher values of frequency compared with steel or aluminum shaft.

By analysis of Figure 5 can also be concluded that the worst characteristics, in terms of the value of natural frequencies, a composite shaft made of GFRP materials have. Given the small value of the E_1/ρ ratio, shaft natural frequencies of GFRP are for all values of fiber orientation angles less than metal ones. Furthermore, from the diagram it can be concluded that in the case of combined GFRP shafts with steel or aluminum, fiber orientation angle has little influence on the value of natural frequencies.

Therefore, it can be concluded that the angle of fibers orientation has a major impact on the value of natural frequencies and the corresponding choice of the optimal fiber orientation angle can significantly affect the dynamic characteristics of the shaft.

5. CONCLUSION

Resources of classical, metal materials are running out, so the focus has been put on search for new and artificially created materials, that will be their adequate replacement.

The aim of this paper was to perform a complete analysis of the deformation state, as well as estimate of its own frequencies of composite shafts (made of CFRP and GFRP materials), and hybrid metal-composite shafts and compare their behavior with metal shafts (made of steel or aluminum).

The obtained results led to the conclusion that, in the case of pure composite shafts, along with a kind of material, fiber orientation angle also has a great influence on the behavior of the shaft. It is recommended to produce combined metal-composite shafts, characterized by lower values of deformation, good dynamic characteristics, with price as more favorable than of the pure composite shaft.

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HARDENING OF AlMgSiCu ALLOYS AS A FUNCTION OF THE THERMOMECHANICAL TREATMENT

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Summary: In the paper are given the results of researches of composition and treatment parameters effects on hardening rolled sheets of the AlMgSiCu alloys. It is found that the hardening value depends on degree of deformation, deformation programmed and copper content. It is shown that alloys subjected to less intensive deformation and those with larger copper concentration display a characteristically larger hardening effect.

Key words: thermomechanical treatment, hardening.

1. INTRODUCTION

It has long been known that it is possible to strengthen AlMgSi alloys by means of heat treatment and plastic deformation. Investigations in that direction, such as [1, 2], resulted in the discovery of very interesting alloys with high physicomechanical parameters.

Although thermomechanical treatment is widely used, there are still many questions associated with the influence of cold plastic deformation, and particularly of a deformation programme combined with alloying, on hardening of AlMgSiCu alloys which remain unanswered. One would expect a change in the cold rolling programme to affect not only hardening but also the structure and residual stresses in the material [3].

Investigation made on copper [4], steel [5] and AlMgSi alloys [3,6,7] show that the distribution of stress at the deformation centre during rolling resulting from different deformation programmes gives rise to local changes at the deformation centre.

We know [8] that the stress distribution at the deformation centre during rolling is determined by a set of geometric parameters; for instance, the pressure distribution depends on the ratio l/x_m (l is the length of the deformation centre; x_m - mean thickness of deformed specimen). The deformation is inhomogeneous at the centre and that has a strong influence on turn of the crystallites and on hardening [9, 10].

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2. EXPERIMENT

We have investigated two AlMgSiCu alloys. The first (denoted L_1) contained 0-57%, the second (L_2) 1-0,4% copper. The two alloys contained the same quantity of Mg_2Si phase . 1-5%. The aluminium used in preparation of the alloys was 99-99,5% pure.

After homogenization for a day at $520^\circ C$ and preliminary rolling with annealing (15 min, 520°) and quenching in cold water, sheets of the alloys were deformed to different degrees: 15, 30, 50, 70 and 80%. After preliminary annealing for 30 min at 520° in salt bath and quenching in water the specimens were aged for 10 min at 160° .

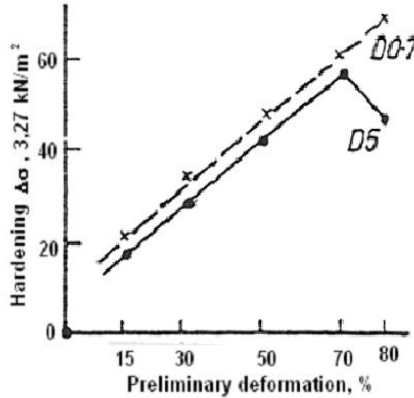


Fig. 1. Relative hardening of alloy L_1 , as a function of degree of deformation and deformation programme: \bullet - D5; \times - D0,7; \square - IA; $\varphi=40^\circ$.

The aged specimen was deformed in twee programmes. The first, with $l/x_m \geq 5$, involved a small number of passes, and will be denoted as programme D5. The second, D0-7, with $l/x_m \approx 0-7$, involved a large number of passes. In both cases the rate of deformation was constant – $0,73 \text{ sec}^{-1}$. Hardening of the specimen was examined after initial ageing (IA) and initial ageing and deformation (IA+D).

In order to determine hardening, the specimens were subjected to variable deformation by bending with a given maximum angle of bend [10].

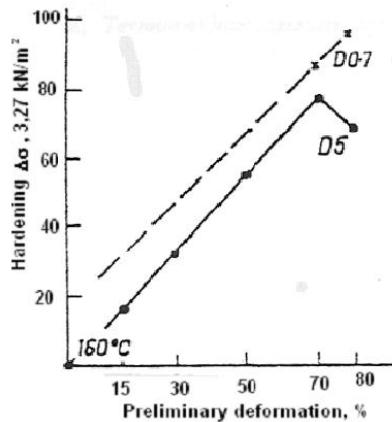


Fig. 2. Dependence of relative hardening of alloy L_2 on degree and programme of deformation: \bullet - D5; \times - 0,7; \blacksquare - IA; $\varphi=40^\circ$.

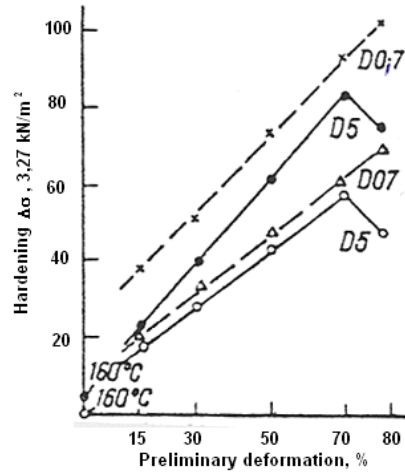


Fig. 3. Relative hardening of alloys L_1 and L_2 as function of degree and programme of deformation separately: alloy L_1 : \triangle - D 0,7; \square - IA; \bullet - D5; alloy L_2 : \blacksquare - IA; \times - D0,7; \circ - D5; $\varphi=40^\circ$.

The increment of flow stress $\Delta\sigma$ was determined relative to the flow stress for specimens after IA with angle bending $\varphi=40^\circ$. In order to eliminate the contribution of bending to hardening, the angles of residual bending φ_r were verified to be the same for the same instantaneous angle of bend φ .

3. RESULT AND DISKUSION

The results are shown in Figures 1, 2 and 3. Figures 1 and 2 shows the dependence of relative hardening of the alloys as a function of degree of deformation and programme. The dependence of hardening of the alloys on copper content and degree of deformation and programme. The dependence of hardening of the alloys on copper content of deformation and programme is shown in Figure 3.

For both alloys, maximum hardening is obtained at 15% deformation (see Fig. 3). Hardening continues to grow with further increase in degree of deformation, but at a lower rate relative to the initial increment at 15%. A difference is first seen in the curves for the IA+D specimens after 70% deformation: for the less intensive deformation programme (Fig. 3, D0,7) hardening is greater than that achieved at 70%, while for the more intensive programme (Fig. 3, D5) it is lower.

The $\Delta\sigma$ value for programmes D5 and D0,7 can be compared with the hardening value after IA+D.

It turns out that the hardening effect is greater for programme D0,7 than for D5, and greater for alloy L_2 than L_1 .

The results show that, other conditions being equal, the copper content in AlMgSi influences hardening of the alloys (see Fig. 3). The hardening value of specimens of alloy L_2 after IA and IA+D is higher than for similar specimens of alloy L_1 (see Fig. 3). We assume that copper is responsible for higher dispersion of the inclusions, increasing the number of nucleation centres [11, 12] and thereby improving corrosion resistance and the mechanical parameters of the AlMgSi alloy.

4. CONCLUSION

All the specimens had identical treatment before deformation, that is, they had identical structure, and identical thickness after rolling. We can therefore say that the observed differences in hardening of AlMgSi alloys are due to: a) difference in copper content and b) use of different deformation programmes.

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UTICAJ STEPENA DEFORMACIJE U PROCESU VUČENJA NA KVALITET ŽICE ZA ARMATURNE MREŽE

Zdravko Božičković¹, Dragoslav Dobraš², Milorad Poljašević³

Rezime: U radu je izvršeno istraživanje uticaja broja izvlačenja (stepen deformacije) žice na zateznu čvrstoću materijala žice. Armaturne mreže proizvode se zavarivanjem šipki od glatkog i rebrastog čelika. Kvalitet rebrastog čelika za armaturne mreže definisan je standardom EN 10080. Rezultati istraživanja pokazuju disperziju mehaničkih karakteristika žice u funkciji broja izvlačenja, i mogu poslužiti kao orijentacija u određivanju tehnologije izrade armaturnih mreža. (Abstract)
Ključne riječi: rebrasti čelik, čvrstoća žice, armaturna mreža.

THE INFLUENCE OF THE DEFORMATION IN THE PROCESS EXTRACTION ON QUALITY OF WIRES FOR REINFORCEMENT MESH

Abstract: The paper presents a study of the influence number of extraction (degree of deformation) wire on tensile strength wire materials. Reinforcement meshes produced by welding rods from smooth and of ribbed steel. Quality ribbed steel for reinforcement mesh is defined by standard EN 10080. The research results show the dispersion of mechanical properties as a function of the number of wire drawing, and can serve as orientation in determining the technology manufacturing of reinforcement meshes.

Keywords: ribbed steel, strength wire, reinforcement mesh.

1. UVOD

Armiranje betonskih konstrukcija i elemenata vrši se visokokvalitetnom hladno vučenom žicom prečnika ≤ 12 mm ili šipkom prečnika > 12 mm, od glatkog čelika (GA-glatka armatura), i rebrastog čelika (RA-rebrasta armatura). Armaturne mreže se dobijaju zavarivanjem hladno vučene žice propisanih mehaničkih karakteristika koja se dobije provlačenjem toplo valjane žice kroz kalibrator. Sastoje se od čeličnih šipki postavljenih u dve paralelne i normalne ravni međusobno spojene elektrootpornim zavarivanjem (podužne i poprečne šipke). Armaturne mreže su urađene od rebrastog čelika prema standardu EN 10080. Ovaj standard ne sadrži tehničke podatke za osobine čvrstoće i deformacije ili karakteristike duktilnosti. Zato je izdat set standarda: EN 10080-2, EN 10080-3, EN 10080-4 i EN 10080-5.

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Betonski čelik marke B500A/B500B prema ovom standardu nalazi se u proizvodnom programu valjaonice Metalfer Steel Mill iz Sremske Mitrovice. Proizvode se glatke hladno valjane čelične žice, 500/560, prečnika $\varnothing 4 - \varnothing 12$ mm i orebrene hladno valjane čelične žice, 500/560, prečnika $\varnothing 4 - \varnothing 12$ mm čije su mehaničke karakteristike propisane standardom:

- minimalni napon tečenja $R_{p0,2} = 500 \text{ N/mm}^2$
- minimalna zatezna čvrstoća (granica kidanja) $R_m = 560 \text{ N/mm}^2$
- minimalno relativno izduženje $A = 6 \%$.

Kontrola čelika za armiranje u građevinarstvu zahtijeva obimna ispitivanja koja nisu dovoljno prikazana u domaćoj i stranoj literaturi. Cilj rada je da se građevinski inženjeri upoznaju sa osnovnim mehaničko-tehnološkim osobinama čelika za armiranje betona, uz naglasak na postojeću zakonsku regulativu. U praksi se ispituju samo zatezne karakteristike i tehnološke probe, odnosno savijanje i povratno savijanje.

2. PROBLEM ZATEZNE ČVRSTĆE ARMATURNIH MREŽA

Tehnološki proces proizvodnje žice zasniva se, prije svega, na zahtjevima primjene žice u praksi. S toga je potrebno definisati: tolerancije oblika i mjera, mehaničke karakteristike žice, kvalitet površine i površinsku zaštitu. Žica za proizvodnju armaturnih mreža se dobija od toplovaljane žice kao ulaznog materijala. Konačne dimenzije se dobijaju procesom jednofaznog ili višefaznog provlačenja u hladnom stanju kroz profilisanu matricu od tvrdog metala. Višefaznom provlačenjem možemo postići stepen deformacije do 95% i bez potrebe za međuoperacionim žarenjem. Literatura preporučuje da se jednofaznim provlačenjem koristi stepen deformacije 15-20%. Mnogi proizvođači armaturnih mreža rade sa manjim brojem provlačenja radi smanjenog vremena izrade i manjih troškova proizvodnje. Posljedica manjeg broja izvlačenja je veliki stepen deformacije pri izvlačenju žice, neujednačena struktura materijala, povećana zatezna čvrstoća, smanjena žilavost, povećano trošenje alata, preopterećene mašine za izvlačenje i dr. U radu su prikazani rezultati ispitivanja zatezne čvrstoće žice za armaturne mreže domaćih proizvođača.

3. EKSPERIMENT

Ekperimentalna ispitivanja su rađena u tri faze:

- određivanje parametara deformabilnosti,
- ispitivanje zatezne čvrstoće žice po fazama proizvodnje i
- ispitivanje zatezne čvrstoće rebrastog čelika od tri proizvođača armaturnih mreža.

Tehnološki postupak dobijanja orebrene armaturne žice dat je na slici 1.



a) glatka žica



b) glava za orebranje



c) orebrena žica

Sl.1 Tehnološki postupak dobijanja orebrene žice

Ispitivanje zatezne čvrstoće je izvršeno na kidalici tip "TARNO C-14000", slika 2.



Sl.2 Kidalica tipa "TARNO C-14000"

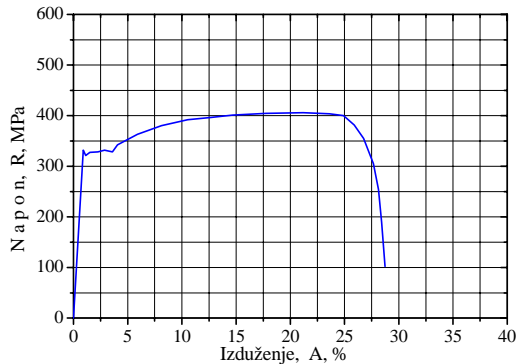
Određivanje parametara deformabilnosti

Jedna od značajnijih pojava koja se javlja u metalu pri hladnom deformisanju kao što je slučaj hladnog izvlačenja žice je očvršćavanje. Očvršćavanje metala predstavlja znatno povećanje mehaničkih karakteristika metala uz istovremeno smanjenje plastičnosti. Povećanje mehaničkih karakteristika usljed pojave očvršćavanja može u mnogim slučajevima obrade da bude poželjno, s obzirom da je moguće, od početnog materijala niskih mehaničkih karakteristika, dobiti gotov dio koji ima poboljšane mehaničke karakteristike. Zato se rade krive očvršćavanja koje daju osnovu za sva posmatranja obrade metala plastičnim deformisanjem. One predstavljaju funkcionalnu zavisnost između specifičnog deformacionog otpora K i stepena deformacije za određene uslove. Dobijaju se bliže predstave o plastičnim karakteristikama materijala. Poznavanjem tih zavisnosti moguće je pravilno dimenzionirati alat, odrediti potrebnu deformacionu silu, deformacioni rad, može se izvršiti izbor mašine za obradu deformisanjem.

Tabela 1

Kvalitet ASTM A 568/A 568M/02 SAE 1008	Gornji napon tečenja, R_{eH} , MPa	Donji napon tečenja, R_{eL} , MPa	Zatezna čvrstoća R_m , MPa	Izduženje, A, %
Epruveta 1	331	322	407	28.7
Epruveta 2	328	321	402	30.2
Epruveta 3	335	325	412	29.4

Na osnovu rezultata testa istezanja (tabela 1), urađen je dijagram napona i izduženja, sl. 3, [1] i određena kriva očvršćavanja materijala žice, sl. 4. Naime, u oblasti ravnomjernog (homogenog) deformisanja vlada jednoosno naponsko stanje i određena je zavisnosti između sile zatezanja, nominalnog i stvarnog napona (koji je istovremeno jednak deformacionom otporu i ekvivalentnom naponu).



Sl.3 Dijagram napon-izduženje

Takođe, deformacija dužine (u ovom slučaju, najveća – prva glavna deformacija) predstavlja efektivnu (ekvivalentnu) deformaciju. Na osnovu dijagrama sl.3, određeni su stvarni naponi za odgovarajuću deformaciju [3]:

$$K_0 = \sigma_v \dots K_1 = \sigma_1 \cdot (1 + \varepsilon_1) \dots K_M = \sigma_M \cdot (1 + \varepsilon_M) \quad (1)$$

Ekstrapolacija stvarne krive tečenja izvršena je funkcijom oblika:

$$K = C \cdot \varphi \quad (2)$$

Logaritamske deformacije (φ) su izračunate pomoću jednačine:

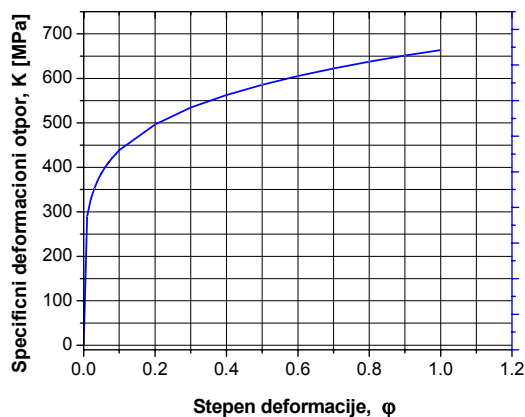
$$\varphi_0 = 0, \dots \varphi_1 = \ln(1 + \varepsilon_1) \dots \varphi_M = \ln(1 + \varepsilon_M) \quad (3)$$

C i n su konstante koje je su određene iz uslova konstantnosti zapremine i maksimuma sile na dijagramu zatezanja. Srednja vrijednost napona tečenja koja je određena ispitivanjem je $R_{eL} = 322$ MPa. Odnos napona na granici tečenja i zatezne čvrstoće (Tabela 1) iznosi 0.7912. Konstanta $C = K_M / \varphi_M^n$ je dobijena iz krive očvršćavanja i iznosi $C = 663.5$ Mpa, a eksponent krive deformacionog ojačavanja $n = \varphi_{eM} = 0,18$. Poisson's broj $\nu = 0.3$, Young's modul elastičnosti određen je eksperimentalno $E = 2.09 \cdot 10^5$ MPa.

Eksponent krive deformacionog ojačavanja predstavlja efektivnu deformaciju na granici ravnomjerne deformacije istezanja. Kriva očvršćavanja (sl. 4) predstavljena je jednačinom:

$$K = 663,5 \cdot \varphi^{0,18} \quad (4)$$

Prema vrijednosti n faktora, t.j. prema uticaju intenziteta ojačanja na deformabilnost čelika, ovaj materijal pripada grupi slabo obradivih materijala hladnim deformisanjem.



Sl.4 Kriva očvršavanja za materijal SAE 1008

Ispitivanje zatezne čvrstoće žice zavisno od stepena deformacije

Od žice prečnika 8 mm radi se rebrasta žica prečnika 5 mm višefaznim izvlačenjem. Izvodi se hladnim deformisanjem. Da bi se došlo do navedenog prečnika rade se dvije faze provlačenja kroz matricu od tvrdog metala (DIN 1547) i orebrenje. Ugao provlačenja matrice je $2\alpha=16^\circ$. Prva faza provlačenja smanjuje prečnik žice sa 8 mm na 6,4 mm. Druga faza provlačenja smanjuje prečnik na 5,2 mm. Postupkom orebrenja takođe dolazi do izvjesne redukcije tako da konačan prečnik koji se dobija proračunom prema formuli (10) iznosi 5 mm.

Stepen deformacije se računa po formuli [3]:

$$\varphi = \ln \frac{A_0}{A_1} \quad (5)$$

Stepen deformacije prvog izvlačenja:

$$\varphi_1 = \ln \frac{8^2}{6,4^2} = 0,446287 \quad (6)$$

Stepen deformacije drugog izvlačenja:

$$\varphi_2 = \ln \frac{6,4^2}{5,2^2} = 0,415278 \quad (7)$$

Ukupni stepen deformacije nakon drugog izvlačenja je:

$$\varphi_{2u} = \ln \frac{8^2}{5,2^2} = 0,81565 \quad (8)$$

Stepen deformacije orebravanja:

$$\varphi_3 = \ln \frac{5,2^2}{5,0^2} = 0,07840 \quad (9)$$

Ukupni stepen deformacije žice nakon orebravanja je:

$$\varphi_{3u} = \ln \frac{8^2}{5^2} = 0,94000 \quad (10)$$

Gdje je:

d_0 – početni prečnik

d_1 – krajnji prečnik

Od žice početnog prečnika 8 mm izvađena su tri uzorka. Takođe su urađene epruvete nakon prve i druge redukcije, kao i nakon orebrenja. Na epruvetama su određene referentne tačke na rastojanju od 100 mm, radi određivanja izduženja. Epruvete su pokidane pomoću kidalice. Rezultati eksperimenta prikazani su u tabeli 2.

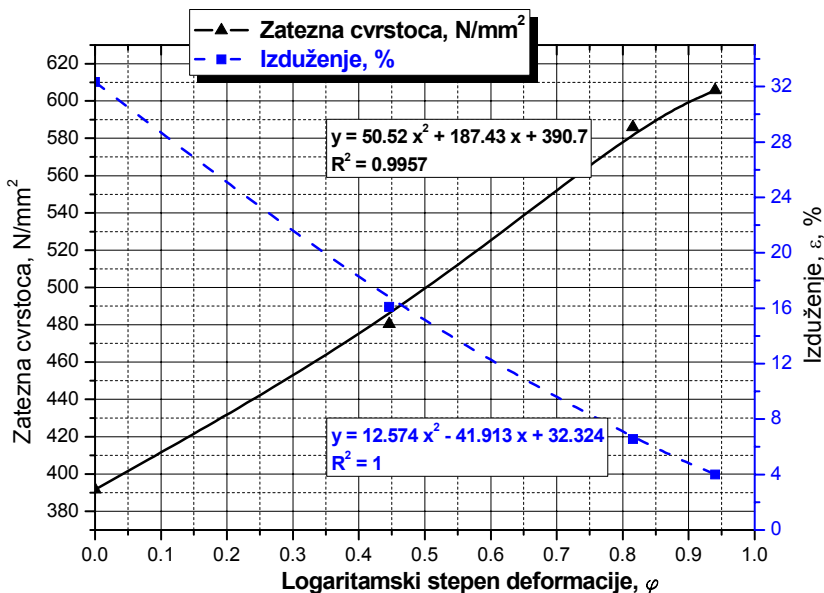
Tabela 2

Uzorak	Početni materijal			Nakon prve redukcije			Nakon druge redukcije		
	Prečnik (mm)	Zatezna čvrstoća (N/mm ²)	Izduženje (%)	Stepen deformacije φ_1	Zatezna čvrstoća (N/mm ²)	Izduženje i (%)	Ukupni stepen deformacije φ_{2u}	Zatezna čvrstoća (N/mm ²)	Izduženje (%)
1	8	395	31	0.4462	480	16	0.8156	585	5.6
2	8	392	33		478	16.5		583	6.7
3	8	388	33		483	15.8		590	7.4

Nakon orebrenja došlo je do neznatnog povećanja zatezne čvrstoće i pada izduženja. Rezultati zatezne čvrstoće i izduženja su dati u tabeli 3.

Tabela 3

Uzorak	Ukupni stepen deformacije φ_{3u}	Prekidna sila (N)	Zatezna čvrstoća (N/mm ²)	Izduženje %
1	0.9400	12.112,00	605.00	4.1
2		12.180,00	601.24	3.8
3		12.090,00	611.15	4.1



Sl.5 Kriva zatezne čvrstoće i izduženje orebrene žice

Ispitivanje zatezne čvrstoće rebrastog čelika od tri proizvođača armaturnih mreža

Za ovaj eksperiment urađeno je po pet uzorka izvađenih iz armaturnih mreža AR 5x7 od tri proizvođača. Uzorak je dužine 150 mm, sa označenim referentnim tačkama na rastojanju od 80 mm.



Sl.6 Pokidani uzorci žice

Zatezna čvrstoća računata je na osnovu prekidne sile i površine poprečnog presjeka. Kod orebrene žice prečnik se računa na osnovu mase prema formuli:

$$d = 12,74 \cdot \sqrt{m/l} \dots \dots mm \quad (11)$$

gdje je: m (gr) masa uzorka i l (mm) dužina uzorka.

Rezultati ispitivanja prikazani su u tabeli 4.

Tabela 4

	Uzorak	Prečnik (mm)	Prekidna sila (N)	Zatezna čvrstoća (N/mm ²)	Izduženje %
Proizvođač "A"	1	5,05	12.252	612,00	5,00
	2	5,00	11.932	608,00	4,90
	3	5,02	11.829	598,00	4,80
	4	4,98	11.973	615,00	4,60
	5	4,97	11.924	615,00	4,65
Proizvođač "B"	1	5,10	12.005	588,00	6,20
	2	5,03	11.440	576,00	6,45
	3	5,05	11.671	583,00	6,34
	4	5,06	11.436	569,00	6,70
	5	5,02	11.553	584,00	6,22
Proizvođač "C"	1	5,01	12.300	624,25	5,80
	2	5,00	12.210	622,16	5,23
	3	4,98	11.890	610,73	5,90
	4	5,08	12.211	606,35	6,05
	5	5,03	12.300	619,29	5,55

4. ZAKLJUČAK

Iz navedenih rezultata vidi se da je zatezna čvrstoća žice nakon dva provlačenja i faze orebravanja veća za 7,5 % od propisane standardom (560 N/mm²). Iz eksperimentalnog ispitivanja zatezne čvrstoće orebrene žice od tri proizvođača može se zaključiti da je u sva tri slučaja veća za 7 % od propisane. Obzirom da je u tehnološkom procesu izvlačenja žice stepen deformacije u prosjeku 42 % po jednom izvlačenju, potrebna su dodatna ispitivanja na žilavost orebrene žice za armaturne mreže. Ukoliko je propisana žilavost ispod dozvoljenih, potrebno je svesti stepen deformacije u granice 15-20 % ili uvesti odgovarajuću termičku obradu.

Dakle, problem je kontrole kvaliteta čelika za armiranje. Imajući u vidu zahtjeve EN 10080 serije kao i standard EN 10002-2 (Osnovni standard za ispitivanje zatezanjem), danas je mali broj laboratorija osposobljen za ispitivanje čelika za armiranje. Neophodna je i ostala regulativa, koja je bila dobro definisana u našem starom Pravilniku o tehničkim normativima za beton i armirani beton.

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MOGUĆNOSTI PRAKTIČNE PRIMENE LASERSKOG KONTURNOG SEČENJA MATERIJALA U ODRŽAVANJU MAŠINSKIH SISTEMA

Svetislav Marković¹, Dragoljub Veličković², Marijana Marković³,
Marija Popović⁴, Jelena Milić⁵, Ljubiša Milovanović⁶

Rezime: U radu je prikazana praktična primena laserskog konturnog sečenja materijala pri održavanju tehničko-materijalnih sredstava na CNC mašini LiteMaster-2212. Prednosti primene ovakvog načina izrade rezervnih delova su brojne i ogledaju se kroz nepostojanje izrade konstruktivne dokumentacije za alate i proizvodnje skupih alata za prosecanje i vulkanizaciju, brzu izmenu režima rada i smanjen broj izvršilaca na izradi delova.

Cljučne riječi: lasersko sečenje, održavanje, zaptivač

THE ABILITIES AND PRACTICAL APPLICATIONS OF LASER CONTOURING CUTTING OF MATERIALS IN THE MAINTENANCE OF MECHANICAL SYSTEMS

Abstract: *This paper presents practical application of laser contouring cutting of materials while maintaining technical and material compounds on CNC machine LiteMaster-2012. The advantages of such method of production of spare compounds are numerous since there is no need for creating constructing documentation for the tools and production of expensive tools for stamping out and vulcanization, quick change of working conditions and decreased number of people working on compounds production.*

Keywords: laser cutting, maintenance, cork

1. UVOD

Laserska obrada bazirana je na primeni visoko koncentrisane svetlosne energije dobijene indukovanim zračenjem iz optičkog kvantnog generatora koji u sudaru sa obratkom na površini vrši lokalno topljenje i isparavanje materijala. Prvi

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praktični optički generator svetlosti konstruisao je T. Neiman 1960. godine u SAD i nazvan je laser po početnim slovima engleske fraze – light amplification by stimulated emission of radiation, što znači – pojačanje svetlosti pomoću stimulisane emisije zračenja [1].

2. PRINCIP RADA I OPIS LASERA

Laser se sastoji od staklene cevi ispunjene smešom gasova: ugljen-dioksida, azota, helijuma i eventualno nekog drugog gasa. Na krajevima cevi se nalaze dva paralelna ogledala koja reflektuju laserski zrak nazad u cev i formiraju rezonator. U cevi se nalaze i elektrode na koje je priključen visoki napon [2].

Visoki napon proizvodi mnoštvo brzih elektrona u cevi koji sudarima predaju svoju energiju molekulima gasa. Molekul azota u pobuđenom vibracionom stanju ne može predati svoju energiju emisijom fotona, jer molekul azota nema dipolni moment, a njegove vibracije ne pokazuju vremensku promenu dipolnog momenta. Zbog toga su pobuđena vibraciona stanja azota dugoživaća, odnosno metastabilna. Sudarima molekul azota predaje energiju molekulima ugljen-dioksida. Energija vibracije molekula azota gotovo je jednaka energiji antisimetričnog istezanja molekula ugljendioksida (CO_2). Laserski prelaz je između prvog nivoa antisimetričnog istezanja i prvog nivoa simetričnog istezanja, ili prvog nivoa savijanja molekula CO_2 .

Laser, odnosno optički kvantni generator zrači visoko monohromatske i koherentne snopove svetlosti koji fokusirani imaju veliku gustinu energije od 10^9 do 10^{10} W/cm^2 , pa i više.

Princip obrade može se opisati na sledeći način: snop svetlosti velike gustine energije udara u površinu obratka i posle apsorpcije u materijalu dolazi do pretvaranja svetlosne energije u toplotnu tako da nastupa trenutno zagrevanje materijala do visokih lokalno koncentrisanih temperatura, više od 4000 K, koje izazivaju intenzivno topljenje i isparavanje materijala i dublje prodiranje laserskog svetlosnog snopa u materijal. U otvoru se stvara jaka struja pare i nastupa izbacivanje razrušenih čvrstih čestica, tečne faze i ostalih produkata razaranja iz zone obrade [1].

Obrada materijala je moguća samo ako se svetlosni snop fokusira na površinu sa malim koeficijentom refleksije da bi se što veća količina svetlosti pretvorila u toplotnu.

3. TIPOVI LASERA I UPOTREBA

Kao aktivna sredina lasera koristi se: čvrsto telo, tečnost ili gas. Kod dimenzione obrade materijala uglavnom se primenjuju laseri sa čvrstim i gasnim emiterom.

Laseri sa čvrstim telom prave se od kristalnog i amorfno materijala sa primesama nekih elemenata. U praksi dimenzione obrade materijala široko se koriste: sintetički rubin, staklo, itrijum-aluminijum granat i kalcijum-volframat aktivirani neodijumom (Nd). Ovi emiteri u odnosu na druga čvrsta tela daju veću izlaznu energiju i veći koeficijent iskorišćenja [1].

Po principu dejstva ovim laserima bliski su laseri sa tečnim emiterom. Kod njih je aktivna sredina tečni dielektrikum sa rastvorenim primesama.

Kod gasnih lasera kao emiteri se koriste gas, smeša gasova ili smeša gasa i pare metala sa aktivnim česticama – neutralnim atomima, jonima i molekulima gasa.

Gasni laseri sa neutralnim atomima i jonima daju vidljivo i infracrveno zračenje, a molekularni gasni laseri daju uglavnom infracrveno zračenje i oni imaju najveću snagu. Pretežno su to CO₂ laseri sa aktivnim molekulom CO₂ neprekidnog dejstva i snagom do 1000 W.

Prednosti i obrade laserom [1]:

- Laserom je moguće vršiti obradu na mestima nedostupnim drugim alatima.
- Nepotrebna izrada komplikovanih i skupih alata.
- Laserom je moguća obrada krutih materijala.

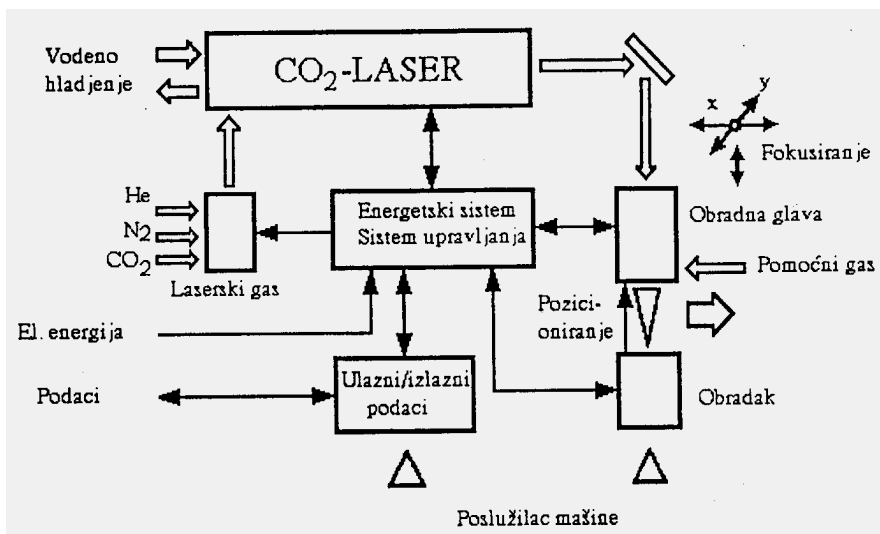
Kao aktivna sredina lasera koristi se: čvrsto telo, tečnost ili gas. Kod dimenzione obrade materijala uglavnom se primenjuju laseri sa čvrstim i gasnim emiterom.

4. PRINCIP RADA LASERSKIH MAŠINA

Laserske mašine (*slika 1*) za industrijsku primenu su počele da se izrađuju šezdesetih godina prošlog veka. Razvoj je tekao veoma brzo. Danas laserske mašine predstavljaju proizvod vrhunske tehnologije, i sastoje se od:

- lasera,
- optičkog sistema za prenos snopa laserskih zraka,
- obradne glave,
- koordinatnog radnog stola,
- sistema za napajanje energijom i
- upravljačke jedinice.

Laser stvara uniformni svetlosni snop laserskih zraka, koji može biti koncentrisan i usmeren sa velikom preciznošću. Snop laserskih zraka predstavlja alat u obradnom sistemu.



Sl.1 Principijalna šema CO₂ laserske mašine za sečenje

Optički sistem za prenos snopa laserskih zraka predstavljaju teleskopske cevi i ogledala, koja prenose snop laserskih zraka od lasera do obradne glave.

U obradnoj glavi se vrši fokusiranje snopa laserskih zraka na radni prečnik od 0,2 mm pri čemu se dobija gustina snage preko od preko 108 W/cm². Fokusirani snop laserskih zraka uz pomoć mlaza radnog gasa se koristi za obradu.

Sečenje po zadatoj konturi nastaje kretanjem snopa laserskih zraka na koordinatnom radnom stolu.

Sistem za napajanje energijom se sastoji od: sistema za napajanje laserske mašine električnom energijom, sistema za napajanje lasera smešom gasova, kada se radi o CO₂ laserima, i sistema za napajanje obradne glave radnim gasom (kiseonik - O₂, argon - Ar, azot - N₂ ili vazduh). Laser i optički sistem za prenos snopa laserskih zraka se najčešće hlade vodom.

Upravljačka jedinica je kompleksan hardver i softver sistem čiji je zadatak da procesira informacije za konturno sečenje obratka, kontroliše višeosna pomeranja, parametre lasera, parametre obrade i senzore [2].

Na kvalitet obrade laserske mašine za konturno sečenje utiču:

- karakteristike lasera,
- karakteristike optičkog sistema,
- karakteristike obradne glave i
- karakteristike koordinatnog radnog stola.

5. CNC MAŠINA LiteMaster-2212

Ova mašina je prvenstveno namenjena za krivolinijsko rezanje pločastih materijala laserom. Osnovni elementi CNC⁷ sistema su [3]:

- Računar sa CAD/CAM⁸ softverom, pomoću koga se oblikuje deo koji treba izraditi na CNC mašini,
- Medij za prenos podataka od računara sa CAD/CAM softverom do upravljačkog računara CNC mašine. To može biti USB⁹ memorija, mrežni link itd.
- Upravljački računar koji ima instalirani upravljački softver koji vrši servisiranje koda i prosleđivanje signala upravljačkoj jedinici. Na ovaj način se vrši kontrola procesa obrade.



Sl.2 CNC mašina LiteMaster-2212

⁷ CNC - Computerized Numerical Control Machine, računarska numerički upravljana mašina.

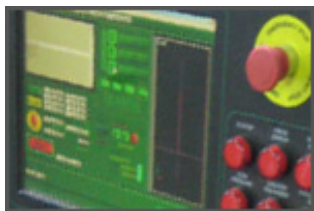
⁸ CAD/CAM – sistem projektovanja pomoću računara (CAD) i povezan sa proizvodnjom (CAM).

⁹ USB - Universal Serial Bus u slobodnom prevodu univerzala serijska magistrala. USB memorija je ustvari „USB flesh memorija“, ali se skraćeno zove USB memorija.

- Upravljačka jedinica koja sadrži interfejs za obradu podataka, servo drajvere za pogon osa kao i kontroler za ostale elemente sistema.
- CNC mašina za lasersko sečenje.

Tabela 1. Tehničke karakteristike CNC mašine LiteMaster-2212 [3]

Spoljni gabariti	1650x2600x1243 mm
Masa	900 kg
Radni hodovi alata (X, Y, Z)	1250x2200x100 mm
Maksimalna brzina kretanja alata	10000 mm/min



Upravljačka jedinica najnovije generacije predstavlja integraciju savremenih tehničko-tehnoloških dostignuća. Sadrži sledeće elemente:

- Interfejs karticu koja prima podeatke od upravljačkog računara, obrađuje ih i prosleđuje ka izvršnim elementima
- Drajvera za AC¹⁰ servo motore koji vrše pozicioniranje X, Y, Z osa.
- Kontroler za obradnu glavu.
- Pogon osa X i Y ostvaruje se pomoću zupčaste letve, dok se pogon Z ose ostvaruje pomoću kugličnog navojnog vretena i navrtke sa recirkulirajućim nizom kuglica visokog kvaliteta.
- Upotrebom ovakvog sistema pogona omogućeno je pozicioniranje osa bez zazora, čime se postiže visok kvalitet obrade i dug servisni interval.
- Upravljački softver vrši kompletnu kontrolu procesa i upravlja svim funkcijama mašine.
- Radi na Windows XP platformi i omogućava brzo i jednostavno rukovanje, sa potpunom vizuelnom interpretacijom.
- Podržava standardne G i M komande, što ga čini kompatibilnim sa svim poznatim softverskim paketima za mašinsko modeliranje i CNC programiranje.
- Takođe sadrži integrisane module za generisanje programa za sve standardne forme.
- Laseri serije LaserCut opremljeni su savremenom upravljačkom jedinicom baziranom na AC servo tehnologiji koja obezbeđuje precizno pozicioniranje i rad pogonskih motora bez buke.
- CO₂ Laserske cevi snage od 40 W do 120 W opremljene su sistemom za vodeno hlađenje čime je omogućen kontinualan rad i dug vek trajanja.
- Kompletna upravljačka jedinica smeštena je u samu

¹⁰ AC (Alternating Current) servo motor - električni motor koji koristi naizmeničnu struju.



mašinu čime je postignuta kompaktnost i zaštita elektronskih komponenti [3].

6. PRIMENA LASERSKOG KONTURNOG SEČENJA U ODRŽAVANJU

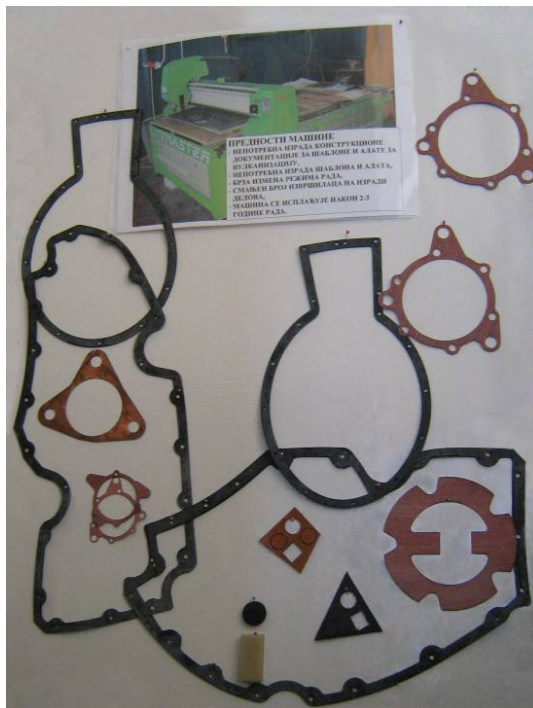
Konturno lasersko sečenje materijala našlo je praktičnu primenu u našim preduzećima.

Prilikom održavanja mašinskih sistema, počevši od sitnih popravki do generalnog remonta, kao najvišeg stepena održavanja kako iz vojnog tako i iz civilnog programa, vrši se proizvodnja i regeneracija rezervnih delova i sklopova.

Kao posledica prestanka proizvodnje kod brojnih koperanata, teškoća prilikom uvoza i problema sa zakonskom regulativom (male i velike nabavke) javljaju se veliki problemi u nabavci rezervnih delova i otežavaju i produžuju rokove u održavanju mašinskih sistema.

Ako se sagledaju napred navedene teškoće, onda se može istaći pun značaj primene mašine za konturno sečenje laserom u izradi rezervnih delova.

Kako se ovde radi o proizvodnji malih serija, može se reći o pojedinačnoj proizvodnji, primenom laserskog sečenja izrađuju se podmetači i zaptivači različitog oblika. Prednost ovakvog načina proizvodnje ogleda se u sledećem [2]:

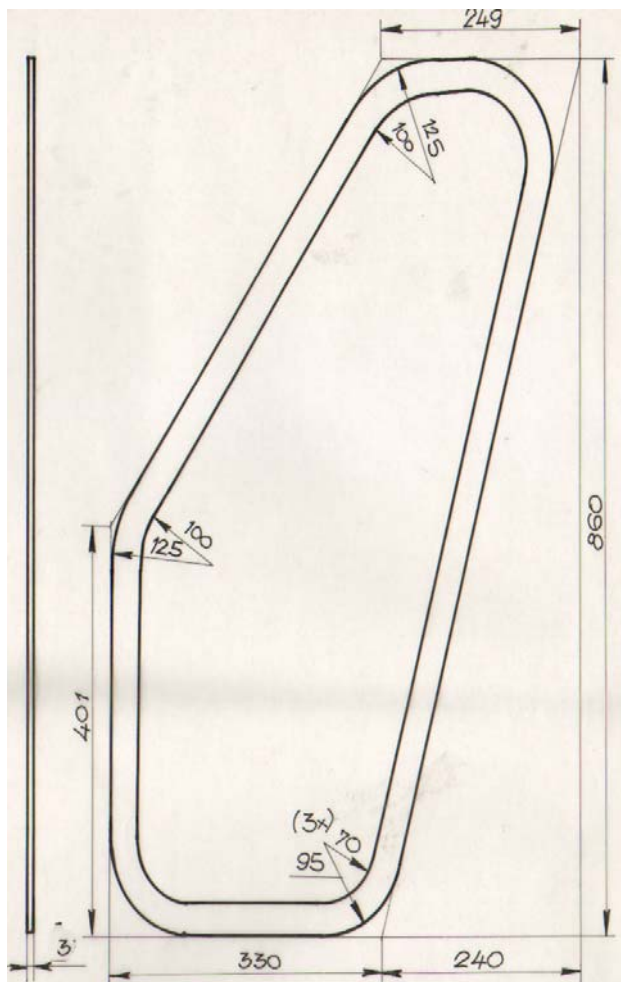


Sl.3 Zaptivke izrađene laserskim sečenjem na CNC mašini LiteMaster-2212

- nepotrebna izrada konstrukcione dokumentacije za alate za prosecanje i vulkanizaciju,
- nepotrebna izrada skupih alata za prosecanje i vulkanizaciju,
- brza izmena režima rada (softverska izmena režima, u zavisnosti od materijala koji je predmet sečenja),
- smanjen broj izvršilaca na izradi delova.

Navedene prednosti imaju za posledicu smanjenje cene i rokova održavanja mašinskih sistema. Proračuni pokazuju da je isplativost mašine za konturno sečenje laserom, u ovom obimu proizvodnje (održavanja) dve godine.

Prednost primene mašine za konturno sečenje laserom u izradi rezervnih delova može se u potpunosti sagledati u primeru izrade gumenog zaptivača prikazanog na slici 4.



Sl.4 Crtež gumenog zaptivača

Za izradu datog zaptivača (za sredstvo inostrane proizvodnje) a zbog nemogućnosti nabavke rezervnih delova potrebno je bilo izraditi alat za vulkanizaciju, slika 5.



Sl.5 Izgled alata za vulkanizaciju

Za izradu datog alata potrebno je oko 60 kg materijala Č4732. Pored toga, za izradu konstrukcione dokumentacije alata, sečenje materijala, obradu glodanjem i brušenjem, bravarske radove, termičku obradu i galvansku zaštitu neophodno je 98 NČ¹¹. Takođe za vulkanizaciju svakoga dela utroši se 1,2 NČ.

Kako su analize pokazale potreba za ovim zaptivačem je 5 komada na godišnjem nivou. Na osnovu napred navedenog, kada se zna kolika je cena 1 NČ i kolika je cena materijala, može se zaključiti koliko je visoka cena izrade jednog zaptivača.

Primenom mašine za konturno sečenje laserom, isti zaptivač bio bi urađen zajedno sa dizajniranjem u odgovarajućem CAD programu za 2 NČ. Pored drastičnog smanjenja cene izrade jednog zaptivača u startu skraćuje se i vreme održavanja kompletnog pripadajućeg mašinskog sistema.

7. ZAKLJUČAK

Laserska mašina za konturno sečenje predstavlja proizvod vrhunske tehnologije. Sačinjavaju je najsavremeniji sistemi, komponente i primenjena znanja iz mehanike, fizike, optike i elektronike. Primena laserske mašine u održavanju tehničkih sredstava je neosporna, ali visoki investicioni troškovi zahtevaju maksimalnu uposlenost iste, pa je potrebno sprovesti odgovarajuće mere da se upotreba laserske mašine održi na što je moguće višem nivou. To podrazumeva da mašinom upravlja obučena i stručna radna snaga, da se poštuju postupci održavanja same mašine, kako bi pouzdanost sistema ostala na visokom nivou, a mašina maksimalno koristila u procesu održavanja tehničkih sredstava.

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¹¹ NČ – norma čas.

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PRIMJENA NELOKALNE TEORIJE ELASTIČNOSTI U ANALIZI IZVIJANJA DVOSTRUKIH ORTOTROPNIH NANOPLOČA

Nebojša Radić¹, Dejan Jeremić²

Rezime: U ovom radu je izvršena analitička studija izvijanja dvostrukih ortotropnih nanoploča primjenom nelokalne teorije elastičnosti. Dvije nanoploče su međusobno spojene sa jednim unutrašnjim elastičnim medijom i okružene sa spoljašnjim elastičnim okruženjem. Detaljno su razmotrena sva tri karakteristična tipa izvijanja. Glavne jednačine su izvedene na osnovu nelokalne teorije i izrazi za kritičnu silu izvijanja su prikazani u eksplicitnom obliku za slučaj kada su sve četiri strane nanoploča simply-supported. Uticaj small scale coefficient, krutosti spoljašnjeg i unutrašnjeg elastičnog medijuma i aspect ratio na vrijednost nondimensional buckling load su detaljno razjašnjene u ovom radu.

Ključne riječi: Nanostrukture; Izvijanje; Analitičko modeliranje; Dvostruke ortotropne nanoploče

BUCKLING ANALYSIS OF DOUBLE-ORTHOTROPIC NANOPATE USING NONLOCAL ELASTICITY THEORY

Abstract: Presented in this paper is analysis of buckling of double-orthotropic nanoplates based on nonlocal elasticity theory. It is assumed that two nanoplates are bonded by an internal elastic medium and surrounded by external elastic foundation. Three characteristic types of buckling are considered. Governing equations are derived based on nonlocal theory, while the expressions for the buckling load are given in explicit form for a nanoplate with all edges simply supported. Explained in detail is the influence of small scale coefficient, aspect ratio, and stiffness of internal elastic media and external elastic foundation, on the nondimensional buckling load.

Keywords: Nano-structures; Buckling; Nonlocal elasticity; Double-layered orthotropic nanoplate

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1. UVOD

Od otkrića nanocijevi nanostrukturni elementi privlače veliku pažnju naučnika zbog njihovih izvanrednih mehaničkih, hemijskih i električnih osobina u poređenju sa konvencionalnim strukturnim materijalima. U zadnjih nekoliko godina nanostrukturni elementi kao što su nanogrede, nanomembrane i nanoploče se veoma često koriste kao komponente u nanoelektromehaničkim uređajima. Zbog svojih izvanrednih mehaničkih i električnih osobina ovi nanoelementi imaju perspektivu raznovrsne primjene u nanotehnološkoj industriji uključujući i skladiztenje i konverziju energije, senzore deformacije, mase i pritiska, solarne ćelije. U narednim godinama se očekuje njihova sve veća primjena u svemirskim letjelicama, biomedicini, bioelektrotehnici, superbrzoj mikroelektronici, itd. Osnovni nedostatak primjene nanoploča ili listova grafena je u njihovoj još uvijek teškoj proizvodnji. Budući da veća potencijalnih primjena nanoploča zavisi od razumijevanja njihovog mehaničkog ponašanja, mehanička analiza nanoploča je od primarnog interesa u narednom periodu. Eksperimentalna istraživanja na nanonivou su vrlo teška, a molekularne dinamike simulacije su veoma skupe. Problemi izvijanja nanoploča su razmatrani u [2],[3],[4],[5],[6].

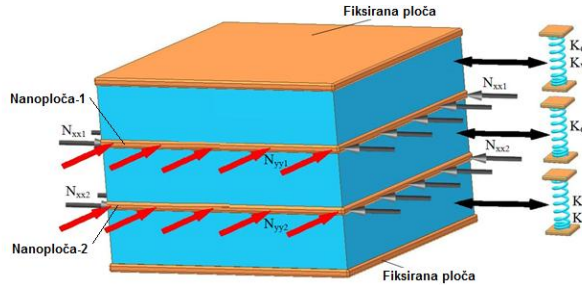
U ovom radu je elastični medij na koji se oslanja jednoslojna nanoploča modeliran kao osnova Winklerovog tipa koja je aproksimirana sa serijom usko raspoređenih međusobno nezavisnih elastičnih opruga. Uticaj elastičnog medija na ponašanje nanoploče je uzet u obzir preko krutosti opruga. Realniji i tačniji način modeliranja elastičnog medija može se postići ako se uticaj osnove na nanoploču prikazuje preko dva parametra. Ovakav tip modeliranja osnove se zove Pasternakov tip modeliranja elastičnog medija. Prvi parametar u Pasternakovom modelu reprezentuje normalni pritisak dok drugi parametar uzima u obzir uticaj smičnog napona izmeđ u elastičnog medija i nanoploče. Pasternakov model fizički realnije uzima u obzir uticaj elastičnog medija na ponašanje nanostrukture i zbog toga je primjenjen u ovom radu.

Veliki tehnološki napredak u konceptu jednostrukih nanogreda i nanoploča su kompleksne nanogrede i kompleksne nanoploče. Najprostiji primjeri kompleksnih nanosistema su dvostruki nanogredni sistemi i dvostruki sistemi nanoploča. Oskora se dvostruki nanogredni sistemi i dvostruki sistemi nanoploča (DNPS) koriste u nanoelektromehaničkim sistemima [7,8]. Pored toga DNPS se koriste kao izolatori zvuka i vibracija. DNPS su dvije nanoploče su vezane elastičnim medijumom kao što je polimer smola. Potrebno je napomenuti da su DNPS razlikuju od dvoslojnih (double layered) sistema kao što je dvo-zidni (double walled) grafen sistemi [9,10]. Ovi dvo-zidni nanoentiteti su vezani sa konstantnom van der Waals-ovom silom, dok se DNPS mogu vezati sa vezivnim sredstvom različite krutosti. DNPS su važni i mogu se naći u nanokompozitnim strukturama gdje je veliki broj grafen listova (graphene sheet) disperzovan u polimer matrici. Primjene DNPS zahtijevaju razumijevanje njihovih mehaničkih osobina. Tako je izvijanje i vibracije DNPS su veoma važni u predviđanju njihovih vrsta.

Razumijevanje izvijanja i ponašanja (buckling behaviour) i vibracionih karakteristika DNPS je značajno. U poređenju sa jednodimenzionalnim nanostrukturama kao što su nanogrede i nanoztapovi veoma je mali broj objavljenih studija u kojima se proučava mehaničko ponašanje nanoploča. Istraživanje DNPS je uglavnom bilo usmjereno na vibracije, a manje na izvijanje. Nedavno su Murmu i Pradhan [11], i Pradhan i Murmu [12] sproveli studiju dvoosnog izvijanja jednoslojnih

(single-layered) nanoplo a. Murmu i Adhikari [13], i Simsek [14] su objavili studiju izvijanja dvostrukih nanogrednih sistema.

2. GLAVNE JEDNAČINE ZA DVOSTRUKE ORTOTROPNE PLOČE



Sl. 1 Dvostruka ortotropna nanoploča ugrađena u elastični medij

Posmatramo dvostruku ortotropnu nanoplo u koja je prikazana na Sl. 1. Dvije nanoplo e su obilje0ene kao nanoplo a-1 i nanoplo a-2. Ove dvije plo e su me usobno vezane sa jednom elasti nom sredinom. Ova veza dvije plo e je matemati ki modelirana sa sistemom vertikalnih jednakih opruga ija je krutost k_0 . Sa spoljnje strane dvije ortotropne nanoplo e su okru0ene sa spoljnjom elasti nom sredinom . Spoljnja sredina je matemati ki modelirana sa Pasternak-osnovnim tipom koji je ekvivalentan Winklerovom k_w i smi u em k_G modulu matrice polimera. U ovoj studiji su koriztene razli ite vrijednosti za k_0 , k_w i k_G za razli ite matrice polimera. Pretpostavljeno je da svaka nanoplo a ima istu du0inu L_x i zirinu L_y , masu po jedinici du0ine i savojnu krutost. U opztem slu aju te vrijednosti mogu biti razli ite. Savojna pomjeranja nanoplo e-1 i nanoplo e-2 su $w_1(x, y, t)$ i $w_2(x, y, t)$ respektivno. Mi emo pretpostaviti da je nanoplo a-1 dvoosno pritisnuta sa silama N_{xx1} i N_{yy1} u pravcu osa x i y respektivno (Sl.1). Tako e na nanoplo u-2 djeluju dvije biaksijalne sile N_{xx2} i N_{yy2} u x i y pravcu respektivno.

Sada emo definisati odnos kompresije (compression ratio) koji jednak koli niku sila u pravcu ose y i x

$$\delta = \frac{N_{yy}}{N_{xx}} \quad (1)$$

U daljoj analizi uvest emo promjenjivu w koja predstavlja relativno pomjeranje dvije nanoplo e [15]

$$w = w_1 - w_2 \quad (2)$$

Uproštene glavne jedna ine imaju oblik

$$D_{11} \frac{\partial^4 w}{\partial x^4} + 2(D_{12} + 2D_{66}) \frac{\partial^4 w}{\partial x^2 \partial y^2} + D_{22} \frac{\partial^4 w}{\partial y^4} + (1 + \delta) N_{xx} \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} \right) + 2k_0 w - k_G \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} \right) - (e_0 a)^2 \nabla^2 \left[(1 + \delta) N_{xx} \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} \right) + 2k_0 w + k_w w - k_G \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} \right) \right] = 0 \quad (3)$$

$$D_{11} \frac{\partial^4 w_2}{\partial x^4} + 2(D_{12} + 2D_{66}) \frac{\partial^4 w_2}{\partial x^2 \partial y^2} + D_{22} \frac{\partial^4 w_2}{\partial y^4} + (1 + \delta) N_{xx} \left(\frac{\partial^2 w_2}{\partial x^2} + \frac{\partial^2 w_2}{\partial y^2} \right) - k_0 w + k_w w_2 - k_G \left(\frac{\partial^2 w_2}{\partial x^2} + \frac{\partial^2 w_2}{\partial y^2} \right) - (e_0 a)^2 \nabla^2 \left[(1 + \delta) N_{xx} \left(\frac{\partial^2 w_2}{\partial x^2} + \frac{\partial^2 w_2}{\partial y^2} \right) - k_0 w + k_w w_2 - k_G \left(\frac{\partial^2 w_2}{\partial x^2} + \frac{\partial^2 w_2}{\partial y^2} \right) \right] = 0 \quad (4)$$

Pri emu su savojne krutosti nanoplo e-1 i nanoplo e-2 jednake

$$D_{11} = \frac{E_1 h^3}{12(1 - \nu_{12} \nu_{21})}, \quad D_{22} = \frac{E_2 h^3}{12(1 - \nu_{12} \nu_{21})}, \quad D_{12} = \frac{\nu_{12} E_2 h^3}{12(1 - \nu_{12} \nu_{21})}, \\ D_{66} = \frac{G_{12} h^3}{12} \quad (5)$$

U ovom radu emo pretpostaviti da su obadvije nanoplo e jednako optere ene u pravcu osa x i y tako da je

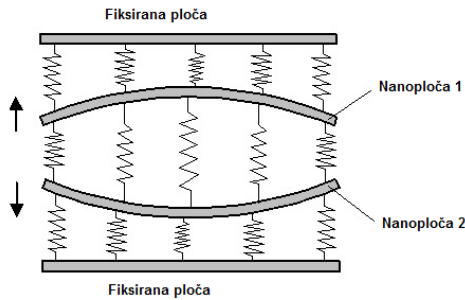
$$N_{xx1} = N_{xx2} = N_{xx}, \quad N_{yy1} = N_{yy2} = N_{yy}$$

(6)

3. TAČNO RJEŠENJE ANALIZE IZVIJANJA

U ovom poglavlju emo razmotriti tri razli ita slu aja nelokalnog dvoosnog izvijanja DNPS. Prou i emo slu ajeve kada se dvije nanoplo e izvijaju asinhrono (out-of-phase), sinhrono (in-phase) i kad je jedna nanoplo a fiksna.

3.1. Asinhrono (out-of-phase) izvijanje



Sl. 2 Asinhroni tip izvijanja

U ovom slučaju obadvije nanoploče se izviti out-of-phase (asinhrono) i

$$w_1(x, y, t) - w_2(x, y, t) \neq 0 \text{ kao što je prikazano na Sl.2.}$$

Ovdje ćemo razmatrati slučaj kada su svi krajevi nanoploča zglobno oslonjeni. Da bismo izrazili kritično opterećenje u ovom slučaju, možemo koristiti jednačinu (3). Ova jednačina (3) zajedno sa nelokalnim konturnim uslovima može se riješiti primjenom Navier metode pretpostavljajući rješenje u sljedećem obliku

$$w = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} W_{mn} \sin(\alpha x) \sin(\beta y) \quad (7)$$

U gornjoj jednačini je

$$\alpha = \frac{m\pi}{L_x} \text{ i } \beta = \frac{n\pi}{L_y} \quad (8)$$

Pri čemu su m i n brojevi talasa.

Zbog uprošćenja analize koristimo sljedeće nedimenzionalne veličine

$$\dot{N}_{cr} = \frac{N_{xx} L_x^2}{D_{11}}, \quad R = \frac{L_x}{L_y}, \quad \mu = \frac{e_0 a}{L_x}, \quad S_1 = \frac{2(D_{12} + 2D_{66})}{D_{11}}, \quad S_2 = \frac{D_{22}}{D_{11}},$$

$$K_W = \frac{k_w L_x^4}{D_{11}}, \quad K_0 = \frac{k_0 L_x^4}{D_{11}}, \quad K_G = \frac{k_G L_x^2}{D_{11}}$$

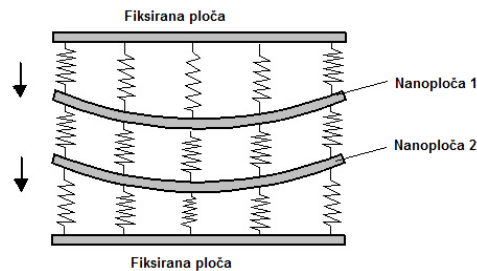
(9)

Ako zamijenimo jedna inu (7) u jedna inu (3) dobi emo vrijednost nedimenzionalne kriti ne sile izvijanja dvostrukih ortotropnih nanoplo a za asinhroni oblik izvijanja.

$$\dot{N}_{cr}^{\zeta} = \frac{(\alpha^4 + S_1 R^2 \alpha^2 \beta^2 + S_2 R^4 \beta^4) + [1 + \mu^2 (\alpha^2 + R^2 \beta^2)] [K_W + 2K_0 + K_G (\alpha^2 + R^2 \beta^2)]}{\mu^2 [\alpha^4 + (\delta + 1) R^2 \alpha^2 \beta^2 + \delta R^4 \beta^4] + \alpha^2 + \delta R^2 \beta^2}$$

(10)

3.2 Sinhrono (in-phase) izvijanje



Sl. 3 Sinhroni tip izvijanja

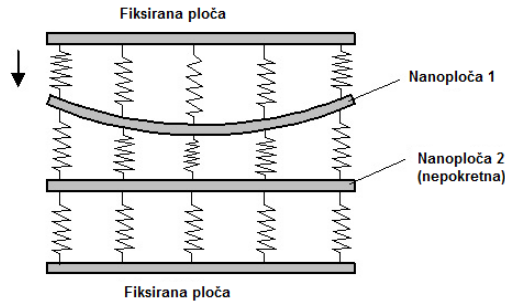
U ovom slu aju dvije nanoplo e se izvijaju sinhrono kao zto je to prikazano na Sl.3 tako da je relativno pomjeranje $(w_1(x, y, t) - w_2(x, y, t) = 0)$. Obadvije nanoplo e se izvijaju u istom smjeru. Za analizu ovog slu aja izvijanja potrebno je koristiti jedna inu (12). Slijede i proceduru kao u slu aju asinhronog izvijanja mo0emo odrediti nedimenzionalnu kriti nu silu izvijanja

$$\dot{N}_{cr}^{\zeta} = \frac{(\alpha^4 + S_1 R^2 \alpha^2 \beta^2 + S_2 R^4 \beta^4) + [1 + \mu^2 (\alpha^2 + R^2 \beta^2)] [K_W + K_G (\alpha^2 + R^2 \beta^2)]}{\mu^2 [\alpha^4 + (\delta + 1) R^2 \alpha^2 \beta^2 + \delta R^4 \beta^4] + \alpha^2 + \delta R^2 \beta^2}$$

(11)

Na osnovu gornjeg izraza mo0e se zaklju iti da sinhronog izvijanja dvostrukih ortotropnih nanoplo a interakcija izme u dvije nanoplo e ne uti e na vrijednost kriti ne sile. Dobijena vrijednost kriti ne sile je ista kao u slu aju izvijanja jedne nanoplo e.

3.3 Jedna nanoploča je nepokretna



Sl. 4 Izvijanje u slučaju da je nanoploča nepokretna

U ovom slučaju se izvija samo nanoploča 1 dok je druga nanoploča 2 nepokretna kao što je prikazano na Sl. 4. Za ovaj slučaj izvijanja glavna jednačina ima sljedeći oblik

$$\begin{aligned}
 & D_{11} \frac{\partial^4 w}{\partial x^4} + 2(D_{12} + 2D_{66}) \frac{\partial^4 w}{\partial x^2 \partial y^2} + D_{22} \frac{\partial^4 w}{\partial y^4} + (1 + \delta) N_{xx} \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} \right) + k_0 w + k_w w \\
 & - k_G \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} \right) - (e_0 a)^2 \nabla^2 \left[(1 + \delta) N_{xx} \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} \right) + k_0 w + k_w w - k_G \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} \right) \right] = 0
 \end{aligned}
 \tag{12}$$

Slično kao u prethodna dva slučaja dobije se vrijednost kritične sile izvijanja

$$\begin{aligned}
 \dot{N}_{cr} = \frac{(\alpha^4 + S_1 R^2 \alpha^2 \beta^2 + S_2 R^4 \beta^4) + [1 + \mu^2 (\alpha^2 + R^2 \beta^2)] [K_w + K_0 + K_G (\alpha^2 + R^2 \beta^2)]}{\mu^2 [\alpha^4 + (\delta + 1) R^2 \alpha^2 \beta^2 + \delta R^4 \beta^4] + \alpha^2 + \delta R^2 \beta^2}
 \end{aligned}
 \tag{13}$$

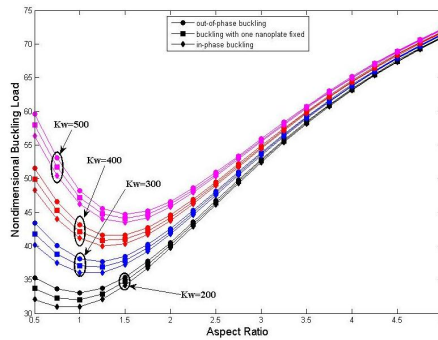
Na osnovu jednačina (10), (11) i (13) može se zaključiti da uticaj interakcije između dvije ploče zavisi od tipa izvijanja.

4. REZULTATI I DISKUSIJA

U ovom poglavlju će se na osnovu jednačina (10), (11) i (13) izvršiti analiza uticaja efekta malih dužina ili nelokalnog efekta na nedimenzionalnu kritičnu opterećenje. Osobine nanoploče u DNPS su uzete kao u slučaju ortotropnih jednoslojnih graphene ploče [16]. Young-ovi moduli ortotropnih nanoploče su $E_1 = 1765 \text{ GPa}$, $E_2 = 1588 \text{ GPa}$, i Poisson-ovi odnosi $\nu_{12} = 0.3$, $\nu_{21} = 0.27$. Debljina graphene ploče je $h = 0.34 \text{ nm}$. Odnos dužine L_x i širine L_y nanoploče označiti sa $R = L_x / L_y$. Koeficijent dužine ($\mu = e_0 a / L_x$) će se uzeti u opsegu 0-1.0. U [17] su uzete vrijednosti za koeficijent dužine između 0 i 0.8 pri čemu je

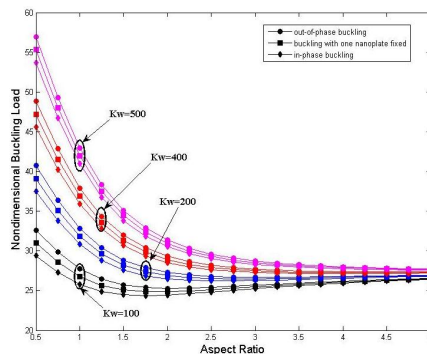
vrzena analiza nanogreda. Za ilustraciju uticaja efekta malih dužina na izvijanje, definisano je odnosa opterećenja.

$$\text{Odnos opterećenja} = \frac{\text{bezdimeziono kritično opterećenje izračunato koristeći nelokalnu teoriju}}{\text{bezdimeziono kritično opterećenje izračunato koristeći lokalnu teoriju}}$$



Sl. 5 Efekt odnosa dužine na bezdimeziono kritično opterećenje za različite vrijednosti Winkler-ovog modula za koeficijent dužine $\mu = 0.1$

Na Sl. 5 je prikazana zavisnost izme u odnosa dužine i bezdimezionog kriti nog optere enja za vrijednosti $K_W = 200, 300, 400$ i 500 respektivno i $K_0 = 20, K_G = 5$. Uzeto je da je $e_0a = 2\text{ nm}$ i $L_x = 20\text{ nm}$ tako da je vrijednost koeficijent dužine $\mu = e_0a / L_x = 0.1$. Može se primjetiti da nakon dostizanja odre ene minimalne vrijednosti bezdimezionog kriti nog optere enja za vrijednost odnosa dužina $1 < R < 1.5$ sa daljim pove anjem odnosa dužine vrijednost bezdimezionog kriti nog optere enja raste. Pored toga može se vidjeti da se sa pove anjem odnosa dužine vrijednosti bezdimezionog kriti nog optere enja postaju vrlo bliske za sve vrijednosti K_W i za sva tri karakteristi na slu aja izvijanja.



Sl. 6 Efekt odnosa dužine na bezdimeziono kritično opterećenje za različite vrijednosti Winkler-ovog modula za koeficijent dužine $\mu = 0.2$

Na Sl. 6 je za razliku od Sl.5 uzeto da je $e_0a = 2nm$ i $L_x = 10nm$ tako da je vrijednost koeficijenta dužine $\mu = e_0a/L_x = 0.2$. Sve ostale vrijednosti su iste. Za razliku od Sl. 5 može se vidjeti da ne dolazi do povećanja vrijednosti bezdimenzionog kritičnog opterećenja sa povećanjem vrijednosti odnosa dužine. Sa smanjenjem vrijednosti $L_x = 20nm$ na vrijednost $L_x = 10nm$ i sa povećanjem odnosa dužine smanjuje se i vrijednost dužine L_y tako da se povećava uticaj efekta male dužine ili nelokalni efekt. Vrijednost bezdimenzionog kritičnog opterećenja pri većim vrijednostima odnosa dužina je približno konstantna i ne dolazi do njenog povećanja kao u slučaju na Sl.5.

5. ZAKLJUČAK

U ovom radu je na osnovu nelokalne teorije prikazan uticaj efekta malih dužina na bezdimenziono kritično opterećenje dvoosno pritisnute dvostruke ortotropne nanoploče ugrađene u elastični medij. Posmatrana su tri karakteristična slučaja izvijanja: asinhrono (out-of-phase) izvijanje, sinhrono (in-phase) izvijanje i izvijanje kada je jedna nanoploča nepokretna. Posmatrane su nanoploče koje su na svojim krajevima zglobno oslonjene tako da je pomoću analitičkog metoda dobijena vrijednost bezdimenzionog kritičnog opterećenja u eksplicitnoj zatvorenoj formi za sva tri karakteristična slučaja. Razmatrani su efekti malih (nano) dužina, Winklerovog i smičućeg modula spoljnjeg elastičnog medija, krutosti elastičnog medija kojim su spojene dvije nanoploče, veće broja modova i odnos dužina na bezdimenziono kritično opterećenje. U radu je pokazano da efekti malih (nano) dužina i u ovom slučaju imaju značajan uticaj na ponazanje pri izvijanju i ne mogu se zanemariti.

Pokazano je da se sa povećanjem Winklerovog modula i smičućeg modula povećava vrijednost bezdimenzionog kritičnog opterećenja za sva tri karakteristična slučaja izvijanja. Sa povećanjem Winklerovog i smičućeg modula povećava se i vrijednost odnosa dužina. Na osnovu toga može se zaključiti da spoljnjiji elastični medij značajno utiče na smanjenje efekta malih dužina na bezdimenziono kritično opterećenje. Sa povećanjem parametara krutosti krive koje predstavljaju tri karakteristična slučaja izvijanja se međusobno približavaju. Krutost elastičnog medija koji spaja dvije nanoploče utiče na povećanje bezdimenzionog kritičnog opterećenja, osim u slučaju sinhronog (in-phase) izvijanja koji ne zavisi od vrijednosti K_0 .

Nelokalni efekti imaju veću uticajnu veličinu i modove izvojanja. Krutost spoljnjeg elastičnog medija (Winklerov modul) utiče na ponazanje većih modova izvijanja nanoploče. Pri određenoj vrijednosti koeficijenta dužine vrijednost bezdimenzionog kritičnog opterećenja za veću modove postaje manja od vrijednosti za prvi mod. Ta vrijednost koeficijenta dužine se smanjuje sa povećanjem vrijednosti Winklerovog modula. Kod dvostrukih ortotropnih nanoploča male dužine povećava se uticaj nelokalnih efekata tako da i pri povećanju odnosa dužina imamo situaciju da se bezdimenziono kritično opterećenje ne povećava.

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DYNAMIC RESPONSE SIMULATION OF PLANETARY GEAR BY NEWMARK METHOD

Ljupco Trajcevski¹, Tale Geramitchioski²

Summary: In this paper, a planetary gear is modeled where the Newmark numeric method is used to find solution of the given model equations. The planetary gear modeling also includes the varying time of the gear mesh stiffness which is considered as a main source of the observed vibrations that exists in the system. The main purpose of this paper is to create a link between the mathematical model and the actual characteristics of a particular planetary gearbox. The mathematical model is applied on the planetary gearbox type EM1010 mark "BREVINI"-Italy..

Key words: Planetary gear, Dynamic response simulation, Newmark method

1. INTRODUCTION

The planetary gear is the most used transmission set in the heavy industry, such as in the naval and the aeronautic application where various transmissions of high torque are produced. The dynamical behaviour modelling of the planetary gear is widely treated in the literature [1, 2], where the computation of the dynamic response is unable to be calculated by using analytical methods. For that purpose, the classical perturbation methods [3] can be used to solve the problem. Generally for the solution of this problem, different procedures are used to determine the response time in a numerical integration schemes such as the central-difference, the Runge –Kutta and the well-known Newmark's Method [4] which is mostly used to compute the dynamic response of the planetary gear applied to the gearbox type EM1010 mark "Brevini".

2. EQUATION OF MOTION OF THE PLANETARY GEAR

Treating a problem with plane vibration by using one-stage planetary gear train with N planets is presented in Fig.1. The sun (s), the ring (r), the carrier (c), and the planets (p) are considered as rigid bodies. Bearings are modelled by a linear springs. The gear-mesh is modelled by linear springs acting on the lines of an action. Each component has three degrees of freedom: two linear movements " u_i ", " v_j " and one rotation " w_j " with $w_j = r_j \cdot \theta_j$ ($j=c, r, s, 1...N$); where "r" is the base radius. The displacements of the " δ_{sp} " and " δ_{rp} " along with the lines of the action are expressed as shown (6).

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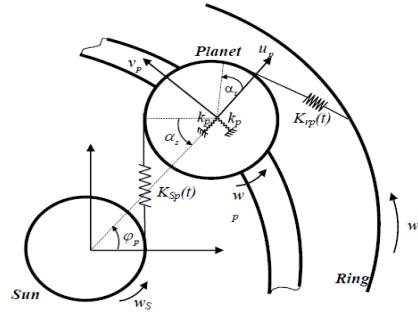


Fig.1 Planetary gearbox model

Presentation of the global equation to the motion in a matrix form:

$$M \ddot{q} + \Omega_c G \dot{q} + [K_b + K_m - \Omega_c^2 K_\Omega] q = T(t) + F(t)$$

The gear-mesh stiffness matrix has a time varying characteristic. The maximum value represents the gear-mesh stiffness of two pair in contact while the minimal value represents single pair gear-mesh stiffness. It can be divided into a mean matrix and a time varying matrix:

$$K(t) = K + K(t).$$

3. DYNAMIC RESPONSE SIMULATION

Studying the planetary gearbox type EM1010 mark “BREVINI”-Italy (Figure 2). The material and the geometrical characteristics of the planetary reducer are provided by the manufacturer and are listed in Table 1.

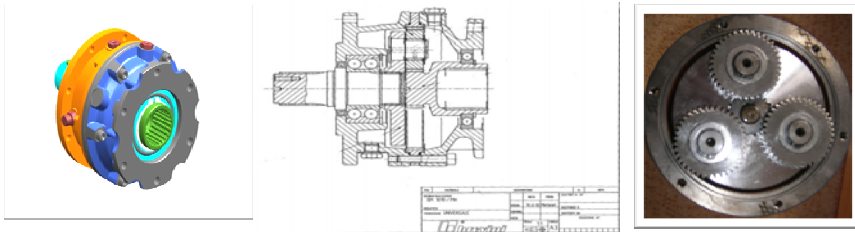


Fig. 2. Planetary gearbox EM1010 “Brevini” – Italy

Table 1. Characteristics of the planetary gears

	Sun	Ring	Planet	Carrier
Material	20MoCr4 UNI8620	20MnCr5 UNI8550	16MnCr5 UNI8550	C40 UNI7874
Mass	0,91 kg	0,76 kg	0,27 kg	1,5 kg
Number of tooth	16	95	38	
Pressure angle	20°	20°	20°	
Module	1,5	1,5	1,5	
Inertial mass	0,000544 kgm ²		0,000134 kgm ²	0,003218 kgm ²

Calculation of gearmesh stiffness is necessary to know geometric features gear pair or profile of the teeth. Geometric features for planetary reducer obtained using the software package KISSsoft - Hirnware10-2004, (6).

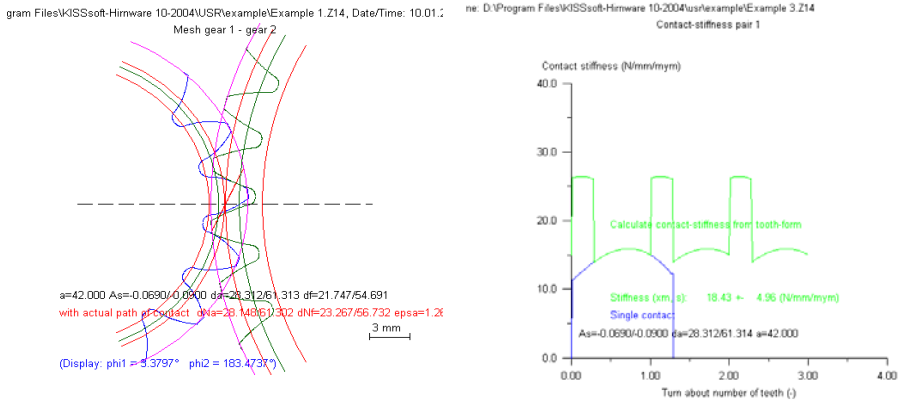


Fig. 3. Gearmesh stiffness for pair sun-planet

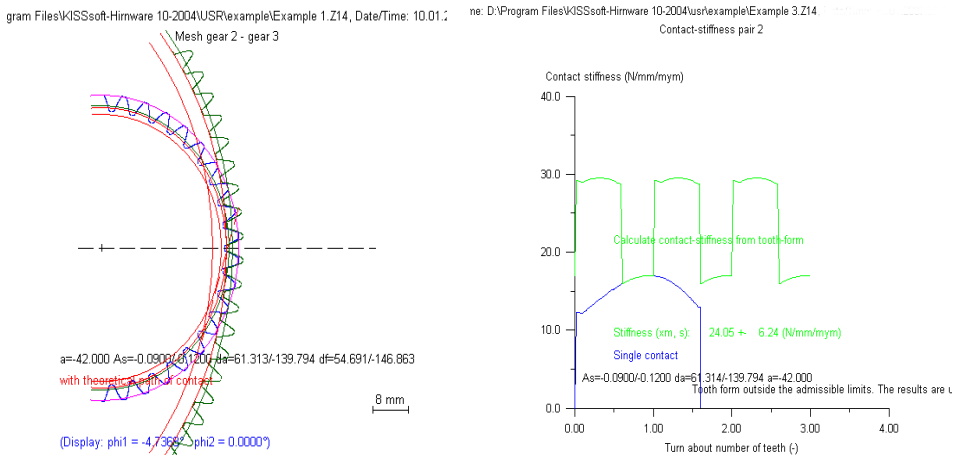


Fig 4. Gearmesh stiffness for pair planet- ring

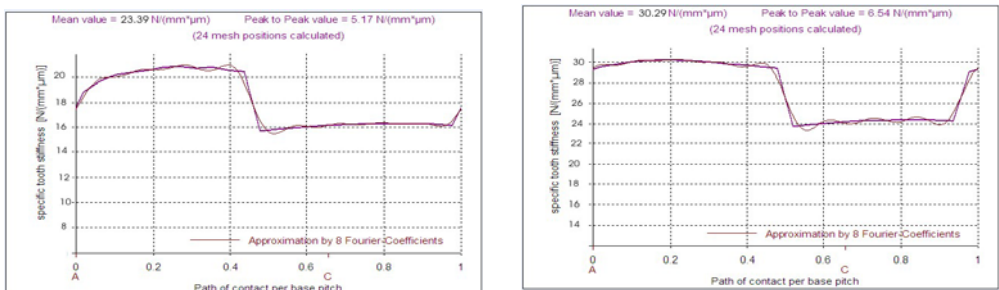


Fig. 5 Gearmesh stiffness along the line of contact for pair sun-planet and pair planet-ring

The gear-mesh calculations for the pair sun-planet (Fig.3) and the planet-ring (Fig.4) depending on the number of teeth in the grip are obtained by using the same software and the results are given below. For the determination of the coefficients K_0 , K_1 , K_2 , and K_3 to be entered into the equation for variable stiffness it is used the software package MDESIGN LVR-Software owned Swiss company KISSOFT-AG. This software package provides output of 8 (eight) coefficients developed in Fourier row that are corresponding with the gear-mesh stiffness. In this paper are taken only the first three coefficients of these calculations. The graphic change gear-mesh stiffness along with the line of the contact with the approximation Fourier coefficients are given in Fig.5.

The values of the coefficients for a pair of sun-planet:

$$K_0 = 18.43 \cdot 10^8; K_1 = 0.304 \cdot 10^8; K_2 = 0.185 \cdot 10^8; K_3 = 0.05 \cdot 10^8; (N / m)$$

with phase angles

$$\gamma_1 = 1.02; \gamma_2 = -0.72; \gamma_3 = -0.93 \text{ (rad)},$$

and values for a pair of planet-bell:

$$K_0 = 24.05 \cdot 10^8; K_1 = 0.134 \cdot 10^8; K_2 = 0.108 \cdot 10^8; K_3 = 0.02 \cdot 10^8; (N / m)$$

with phase angles

$$\gamma_1 = 1.47; \gamma_2 = -0.37; \gamma_3 = -0.52 \text{ (rad)}.$$

It should be emphasized that the coefficients are taken up to the third coefficient for further calculation in a numerical analysis. The third coefficient is four times less than zero, which means that the remaining coefficients (up to eight) define the value after the fourth decimal point. Because it is a great stiffness, the value after the decimal point does not affect the size of the force in the displacement system. Also our simulation is limited by taking into the account of the first three values. This explanation applies to the number of coefficients which are taken into a consideration when determining the static transmission error. The calculations of the determined coefficients e_0 , e_1 and e_2 to be incorporated into a basic equation are obtained from the same software package. This software package provides with output of 8 (eight) coefficients developed in the Fourier row of the corresponding static of the transmission error. The total transmission error, including the displacement shaft of the bearings is shown in the Fig. 6.

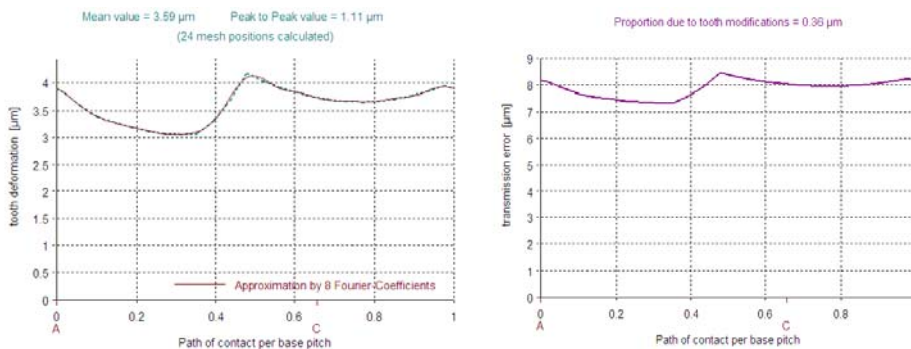


Fig.6 Total static transmission error for pair sun-planet and planet-ring

The values of the coefficient s of the static transmission errors for pair sun-planet is: $\alpha_1 = \pi/3$; $\alpha_2 = \pi/4$; $e_1 = 0.0036\text{mm}$; $e_2 = 0.0011\text{mm}$, and for pair planet-ring is: $\alpha_1 = \pi/3$; $\alpha_2 = \pi/4$; $e_1 = 0.008\text{mm}$; $e_2 = 0.0036\text{mm}$.

Getting the basic dynamic features of the system development can be obtained by using the original software package MATLAB. The software program is vtb4_1.m. This program, before carrying out the calculation of their own values, reads the corresponding matrices for mass, stiffness and gyroscopic effect with reference to the

file values. By solving these matrices of the Newmark method that has $(3n + 9)$ degrees of freedom ($n = 3$ number of planets), the following free system values are given:

omega1 = 9765.9027 rad/s	Freq1 = 1555.1 Hz
omega2 = 17699.6443 rad/s	Freq2 = 2818.4 Hz
omega3 = 18408.5539 rad/s	Freq3 = 2931.3 Hz
omega4 = 12664.5488 rad/s	Freq4 = 2016.6 Hz
omega5 = 12664.5488 rad/s	Freq5 = 2016.6 Hz
omega6 = 22258.4717 rad/s	Freq6 = 3544.3 Hz
omega7 = 22232.5025 rad/s	Freq7 = 3540.2 Hz
omega8 = 22232.5025 rad/s	Freq8 = 3540.2 Hz
omega9 = 23094.0108 rad/s	Freq9 = 3677.4 Hz
omega10 = 24450.5408 rad/s	Freq10 = 3893.4 Hz
omega11 = 28463.9563 rad/s	Freq11 = 4532.5 Hz
omega12 = 31496.4177 rad/s	Freq12 = 5015.4 Hz
omega13 = 44788.8609 rad/s	Freq13 = 7132 Hz
omega14 = 47720.021 rad/s	Freq14 = 7598.7 Hz
omega15 = 47720.021 rad/s	Freq15 = 7598.7 Hz
omega16 = 56847.73 rad/s	Freq16 = 9052.2 Hz
omega17 = 58156.2452 rad/s	Freq17 = 9260.5 Hz
omega18 = 64921.6299 rad/s	Freq18 = 10338 Hz

Outputs may show that a certain results are overlapping of a certain values in the system: the fourth and the fifth frequency with same 2016.6Hz frequency; seventh and eighth frequency of 3540.2Hz; fourteen and fifteen frequency of 7598.7Hz. These overlapping frequencies occur due to an equal distance between planets, as well as an equal stiffness of all the bearings and the planetary reducer. Therefore the defined geometry planetary reducer is using software KISSsoft - Hirnware10-2004 display of 3D modeling for the planetary reducer given at Fig.7:

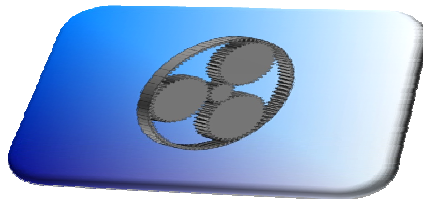


Fig 7. 3D model of planetary gearbox

Using the MDESIGN LVR-Software it can be performed advanced calculations during gear-mesh gear along with the line of the contact. The loading is given in Figure 8:

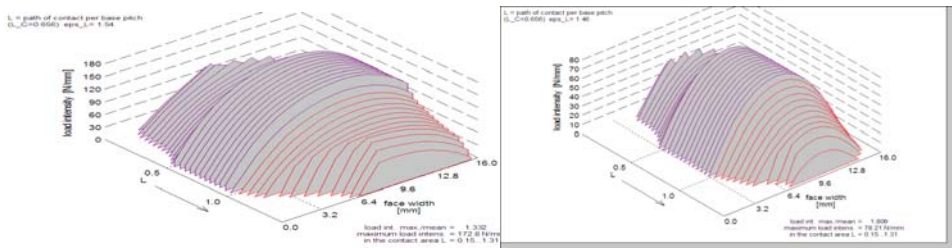


Fig. 8 Load of the loading for pair sun-planet and planet – ring

All data provided by the software package KISSsoft - Hirnware10-2004 and MDESIGN LVR-Software is implemented in the program newmarkmodel.m, which uses numerical method to solve the Newmark method. Before using the program for solving the mathematical model, it is important to define the interval step ie with purpose to determine the pace of the integration of differential equations:

$$(\omega_s - \omega_c)N_s = -(\omega_p - \omega_c)N_p = -(\omega_R - \omega_c)N_R$$

$$T_{cycle} = \left| \frac{2\pi}{(\omega_s - \omega_c)N_s} \right| = \left| \frac{2\pi}{(\omega_p - \omega_c)N_p} \right| = \left| \frac{2\pi}{(\omega_R - \omega_c)N_R} \right|$$

$$T_{cycle} = \left| \frac{60}{(RPM_s - RPM_c)N_s} \right| = \left| \frac{60}{(RPM_p - RPM_c)N_p} \right| = \left| \frac{60}{(RPM_R - RPM_c)N_R} \right|$$

$$\Delta T = \frac{T_{cycle}}{N_{steps}}$$

$$T_{cycle} = \left| \frac{60}{(1380 - 198.9) \cdot 16} \right| = 0.003175 \quad \Delta t = \frac{T_{cycle}}{N_{step}} = 3.175e - 5$$

$$K_m(t) = K_0 + \sum_{n=1}^l K_n \cos(n\omega_{nt} + \gamma_n) = K_0 + K_1 \cos(\omega_{nt} + \gamma_1) + K_2 \cos(2\omega_{nt} + \gamma_2) + K_3 \cos(3\omega_{nt} + \gamma_3)$$

$$= 18.43 \cdot 10^8 + 0.304 \cdot 10^8 \cos(629.9\pi + 1.02) + 0.185 \cdot 10^8 \cos(2 * 629.9\pi - 0.72) +$$

$$0.05 \cdot 10^8 \cos(3 * 629.9\pi - 0.93)$$

$$K_m(t) = K_0 + \sum_{n=1}^l K_n \cos(n\omega_{nt} + \gamma_n) = K_0 + K_1 \cos(\omega_{nt} + \gamma_1) + K_2 \cos(2\omega_{nt} + \gamma_2) + K_3 \cos(3\omega_{nt} + \gamma_3)$$

$$= 24.05 \cdot 10^8 + 0.134 \cdot 10^8 \cos(629.9\pi + 1.47) + 0.108 \cdot 10^8 \cos(2 * 629.9\pi - 0.37) +$$

$$0.02 \cdot 10^8 \cos(3 * 629.9\pi - 0.52)$$

$$e(t) = \sum_{i=1}^s e_i \cos(i\omega_1 t + \alpha_i) = e_1 \cos(\omega_1 t + \alpha_1) + e_2 \cos(2\omega_1 t + \alpha_2) =$$

$$0.0036 \cos(46\pi t + \pi/3) + 0.0011 \cos(2 * 46\pi t + \pi/4)$$

$$e(t) = \sum_{i=1}^s e_i \cos(i\omega_1 t + \alpha_i) = e_1 \cos(\omega_1 t + \alpha_1) + e_2 \cos(2\omega_1 t + \alpha_2) =$$

$$0.008 \cos(46\pi t + \pi/3) + 0.0036 \cos(2 * 46\pi t + \pi/4)$$

Before running the program, Newmarkmodel2.m receives several output sizes (time, speed and acceleration). The program defines the input sizes: input speed of 1492 rev. / min. ie $\omega_1 = 49.73\pi$ rad or (24.87Hz), and gear-mesh frequency of FM = 340.5Hz or ($\omega_m = 681\pi$ rad). The input external point is 0 Nm, while the system input

applies a moment of $750 / (1492 \cdot \pi/30) = 4.8\text{Nm}$. Also it is required to be defined the static displacement of the tooth of the gear-mesh. In this case it is used the above input value of $q_0 = 550 / 21.24e8 = 2.59 \cdot 10^{-7} \text{ m}$, so that the defined input data model diagram with his speed range (FFT transformation) generalize a coordinate “y” (a coordinate in the direction of the axis accelerometer) that is given in Fig. 9:

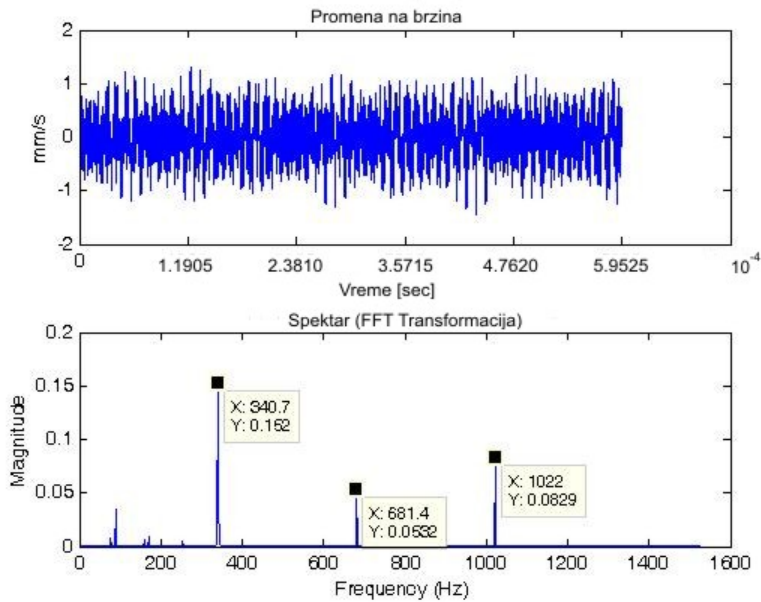


Fig.9 Change of speed and his spectral (FFT) from numerical simulation 1492 rev/min and power of 750 W

Display of the phase diagram is given in fig.10

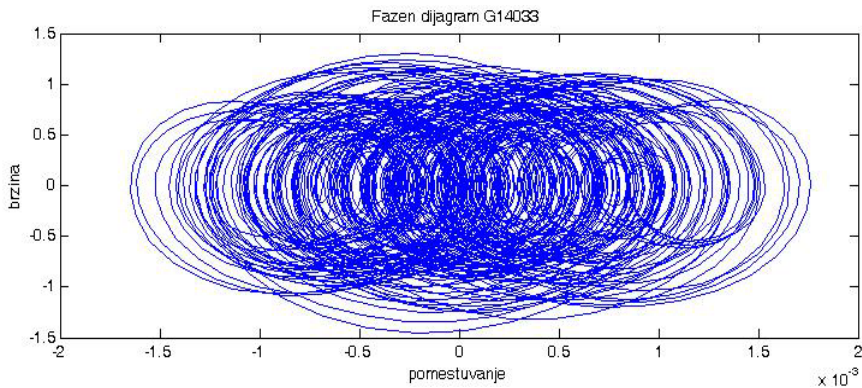


Fig.10 Phase diagram

From this diagram it can be concluded that by using a very small load and a very little throttle there is a chaos that occurs as a result of the sub-harmonic resonance input data from the numerical model.

4. CONCLUSION

Exposed procedure is defined dynamic model of behavior the planetary gearbox. This model allows testing the dynamic behavior when it changing the parameters of influence, especially the influence of the stiffness of the gearmesh. It also provides a basis for verification of measured values of vibration in working conditions, which opens space for easier detection of possible defects in planetary reducer. It greatly facilitates the work of the constructor because very often occurs doubt about the origin of the increasing levels of vibration and defining generators due manifested defect. Used Newmark method provides for a fairly high accuracy in modeling reductor improve defect detection.

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COMPUTER SIMULATION A VIBRATION SIGNAL FOR THE GEAR FAULT DIAGNOSTICS

Tale Geramitchioski¹, Ljupco Trajcevski² Vangelce Mitrevski³

Summary: *The fact that the Wigner-Ville Distribution (WVD) can represent the energy of a gear vibration signal was used for the gear diagnostics. A novel method for gear damage detection using a new gear fault detection parameter based on the WVD and is called NP4 detection parameter. This parameter is calculated from a time-domain power signal derived from the WVD. The novelty of the NP4 parameter is in the application of the previously defined statistical parameter called kurtosis and its interpretation for gear fault detection. The sensitivity of this gear fault detection parameter to the gear damage is demonstrated on the numerical simulation example. Also, in this paper is developed software in Matlab for solved the Wigner-Ville Distribution and NP4 detection parameter.*

Key words: *WVD, NP4, FFT, fault detection, gear, kurtosis, vibration signal, power signal*

1. INTRODUCTION

The primary goal of the signal processing for machine health monitoring is to aid the fault detection and classification. Various signal processing techniques have been developed and applied for gear fault detection and diagnosis. Nevertheless the researchers are continuously looking for “better” techniques for gear fault detection and new signal processing techniques for machine health monitoring are still appearing in the literature.

The signal averaging or time synchronous averaging technique is the most commonly used time domain method ([7], [8],[9]). In this method the gear vibration signal is synchronously sampled with the rotation of the gear. The demodulation methods were developed to detect local gear defects such as fatigue cracks, pits and spalls ([9],[10]). After being synchronously averaged, the gear vibration signal consists of the gearmesh frequency and its several harmonics. The demodulation methods assume that a gear tooth fault will produce amplitude and phase modulations of the dominant gearmesh frequency and its harmonics.

In the early 1930's Wigner introduced the probability function of the simultaneous values of the coordinates and the moment in the study on the

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thermodynamics of quantum mechanical system [11]. In the late 1940's Ville demonstrated the potential applications of the Wigner probability function in signal processing. The early research demonstrated that a direct application of the WVD to the signal analysis is not advantageous ([12]). The WVD is a non-linear transform (a quadratic type), and therefore generates interference terms between signal components ([13]). Many researchers on the WVD for gear diagnostics introduced the techniques (windowing function) to increase the WVD resolution and improve its gear fault detection capabilities ([14]). Wang and McFadden pioneered in the introduction of the image processing techniques to interpret the WVD patterns of the faulty gear. The higher-order spectral analysis has yet to be fully developed for the gear fault diagnostic. There are few studies reported in the literature concerning the application of the higher-order spectral analysis techniques (biocoherence, hypercoherence) for gear diagnostics ([15]).

2. WIGNER – VILLE DISTRIBUTION

The Wigner-Ville Distribution (WVD) is a general time-frequency analysis technique that provides good resolution along both time and frequency scales in comparison with other joint time-frequency transforms such as short time Fourier Transform (STFT) and wavelet transforms. However, the direct application of the WVD to the analysis of the vibration signals is not as straightforward as it may seem. The extensive studies in signal processing have been made to address the problems associated with the computation of the WVD. To avoid the aliasing the problem arising in the computation of the WVD, the original real signal is transformed into a complex analytic signal. Another major observed in the application of the WVD is due to its non-linear behavior. The non-linearity of the WVD causes the interference between different signal components. As a result, the appearance of the interference terms in the WVD greatly complicates its interpretation.

The WVD can be written as

$$W_{xx}(t, f) = \int_{-\infty}^{+\infty} x(t + \tau/2)x^*(t - \tau/2)e^{-j2\pi f\tau} d\tau, \quad (1)$$

where $W_{xx}(t,f)$ is the Wigner-Ville distribution of a complex continuous time analytic signal $x(t)$, t is a time variable and f is a frequency variable. In order to suppress the interference terms in the WVD, a weighting function is added to calculation of the WVD kernel. In the continuous case, the WVD with the added weighting function $\mu(\tau)$ is

$$W_{xx}(t, f) = \int_{-\infty}^{+\infty} x(t + \tau/2)x^*(t - \tau/2)\mu(\tau)e^{-j2\pi f\tau} d\tau, \quad (2)$$

$$\mu(\tau) = h\left(\frac{\tau}{2}\right)h^*\left(-\frac{\tau}{2}\right) \quad (3)$$

$$h(\tau) = C \exp(-\sigma^2 \tau^2) \quad (4)$$

where C and σ are real positive constants. Although process may decrease the resolution of the distribution, it reduces the repetition of the WVD in the time domain, and, thus makes the interpretation of the WVD easier.

Other important signal characteristics that can be defined from the WVD include the instantaneous energy of the signal, or signal power

$$P(t) = \int |W_{xx}(t, f)| df. \quad (5)$$

To utilize the sensitivity of the WVD to signal changes let us define a parameter NP4 as a normalized kurtosis of signal power P(t) given by Equation (6) as

$$NP4 = \frac{1}{N} \sum_{i=1}^N \left(\frac{P(t_i) - \bar{P}}{\sigma} \right)^4 - 3, \tag{6}$$

where σ is the standard deviation of P(t). NP4 is a non-dimensional parameter. The parameter NP4 depends only on the shape of the power distribution P(t). Rescaling of the original vibration signal x(t) by multiplying it by a constant does not affect the value of NP4. The same statement is true for any scaling of the signal power P(t). Multiplication of the signal power by a constant does not change the value of the parameter NP4. In short, the parameter NP4 is invariant to scale transformation. The scale invariance property of this fault detection parameter greatly simplifies its practical utility as can be seen later on numerical examples. Most of the rotating machinery components including gearboxes produce complex vibration signal. Some of these vibration components might indicate faulty conditions if they are viewed on the appropriate signal energy scale without being attenuated by the signal components with a higher energy content.

The primary goal of the parameter NP4 is to detect a gear tooth damage. It is expected that NP4 can provide a warning before the multiple gear teeth become damaged. This strategy can be refined by calculating the residual signal of higher order, setting the thresholds other than 0 and -1, etc.

3. NUMERICAL SIMULATION EXAMPLE

This numerical simulation is used to generate a vibration signal that consist of 1024 points, equally spaced between 0 and 360 degrees, according to the formula [8-9]:

$$\begin{aligned}
 x(\theta) &= 2 \cos(2\pi 64\theta / 360) & 0 \leq \theta \leq 360 & \quad f1 \\
 &+ 3 \cos(2\pi 16(\theta - \theta_1) / 360) \exp(-120(\theta - \theta_1)^2 / 360^2) & -50 \leq \theta - \theta_1 \leq 50, \theta_1 = 210 & \quad f2 \\
 &+ 3 \cos(2\pi 26(\theta - \theta_1) / 360) \exp(-100(\theta - \theta_1)^2 / 360^2) & -50 \leq \theta - \theta_1 \leq 50, \theta_1 = 210 & \quad f3 \\
 &+ 2 \cos(2\pi 110(\theta - \theta_2) / 360) \exp(-65(\theta - \theta_2) / 360) & 0 \leq \theta - \theta_2 \leq 100, \theta_2 = 160 & \quad f4 \\
 &+ 4 \cos(2\pi 96(\theta - \theta_3) / 360) \exp(-2000(\theta - \theta_3)^2 / 360^2) & -10 \leq \theta - \theta_3 \leq 10, \theta_3 = 70 & \quad f5 \\
 &+ 4 \cos(2\pi 96(\theta - \theta_4) / 360) \exp(-2000(\theta - \theta_4)^2 / 360^2) & -10 \leq \theta - \theta_4 \leq 10, \theta_4 = 100 & \quad f6
 \end{aligned}$$

- In this signal, the major dominate frequency component is f1 which is synchronized with the shaft rotation speed of gearbox.
- 2nd and 3rd components (f2+f3) are similar to the vibration signal associated with looseness or unbalance.
- 4th component f4 is similar to the vibration signal of damage tooth
- 5th and 6th components (f5+f6) are similar to the vibration signal of wear or poor lubrication.

The characteristics of different types of faults are given in Table 1.

Table 1 *The characteristics of different types of faults*

	f1	f2+f3	f4	f5+f6	Note
CASE 1	*				Normal reference signal
CASE 2	*		*		Damaged tooth
CASE 3	*	*			Looseness/unbalance
CASE 4	*	*	*	*	Mixed all fault signal

* means this kind of signal exist in this case

CASE 1

First case is simple example to study the WVD. WVD in Eq.(1) is a real-valued function of time and frequency, i.e. the WVD can be viewed as an image or a matrix.

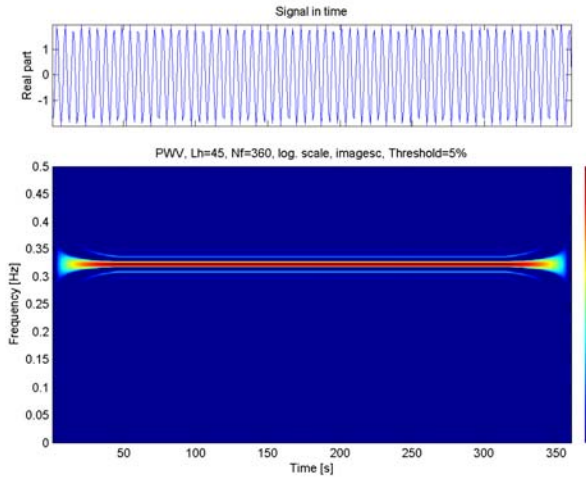


Fig. 1 (a) *WVD in a real valued function of a time*

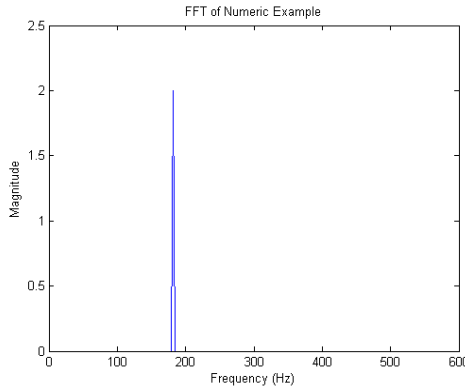


Fig. 1 (b) *WVD in a real valued function of a frequency*

The values of constants for the weighting function Eq.(4) is kept $C=1.0$ and $\sigma^2=10^{-4}$ for this case and all following cases. The increase of the value σ^2 would produce a crest with a wider shape on the WVD plot. The non-zero values around main frequency component at the WVD plot were mainly due to the data windowing.

The real time signal, FFT,WVD image is shown in figure 1 (a) and (b). On figure 1(a) the real time signal is show for one revolution of rotating machinery and is display from 0 to 360 degrees. Along with the normalized signal, the WVD image and its color scale, one other important characteristics of signal can be shown. i.e. FFT of signal. The FFT of the signal is better suited for the presentation of the signal energy density spectrum than the value calculated from the WVD using Equation (2). The horizontal line shown in a figure 1(a) of the WVD image is telling as that no energy change i.e. this signal is a normal .

Kurtosis of the signal is -1.5 and used Eq. (6) $NP4(0) = -1.507$ and $NP4(1) = -1.5092$. Using a value for NP4 we have conclusion do not set a fault of the gear.

CASE 2

In this case the numerical simulation example is similar to the vibration signal of a gear with damaged tooth. The real time signal, FFT, WVD image is shown in figure 2. From WVD image is shown that the vibration energy was distributed between 160° and 270°. The growth of the energy is the first symptom for a fault alarm for a gear tooth damage.

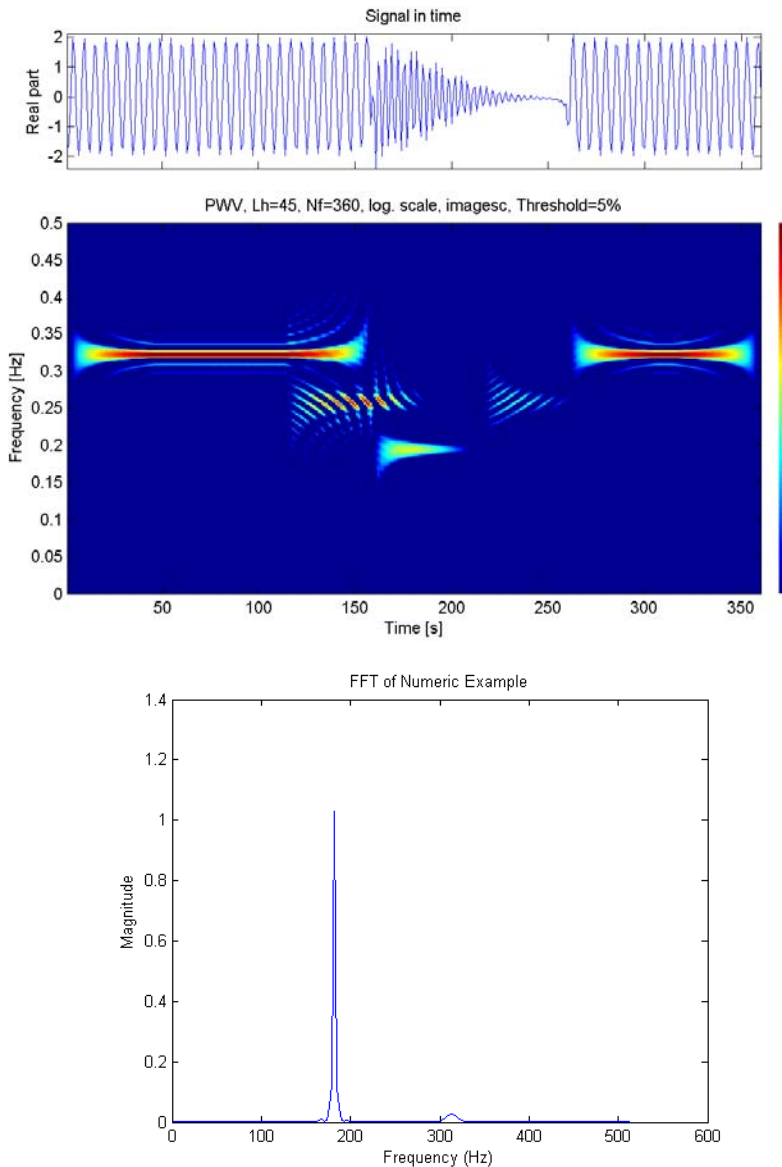


Fig. 2. WVD in a real valued function of a time and frequency in case of one damaged tooth

Kurtosis of the signal is -1.1762 and used Eq. (6) $NP4(0) = 1.8238$ and $NP4(1) = 0.4502$. From the figure 2 we have a confirm for a fault of gear tooth because we have dissipation of energy.

CASE 3

In this case the numerical simulation example is similar to the vibration signal of a gear with looseness and unbalance. The real time signal, FFT, WVD image is shown in figure 3. From WVD image is shown that the vibration energy was distributed between 60° and 110°.

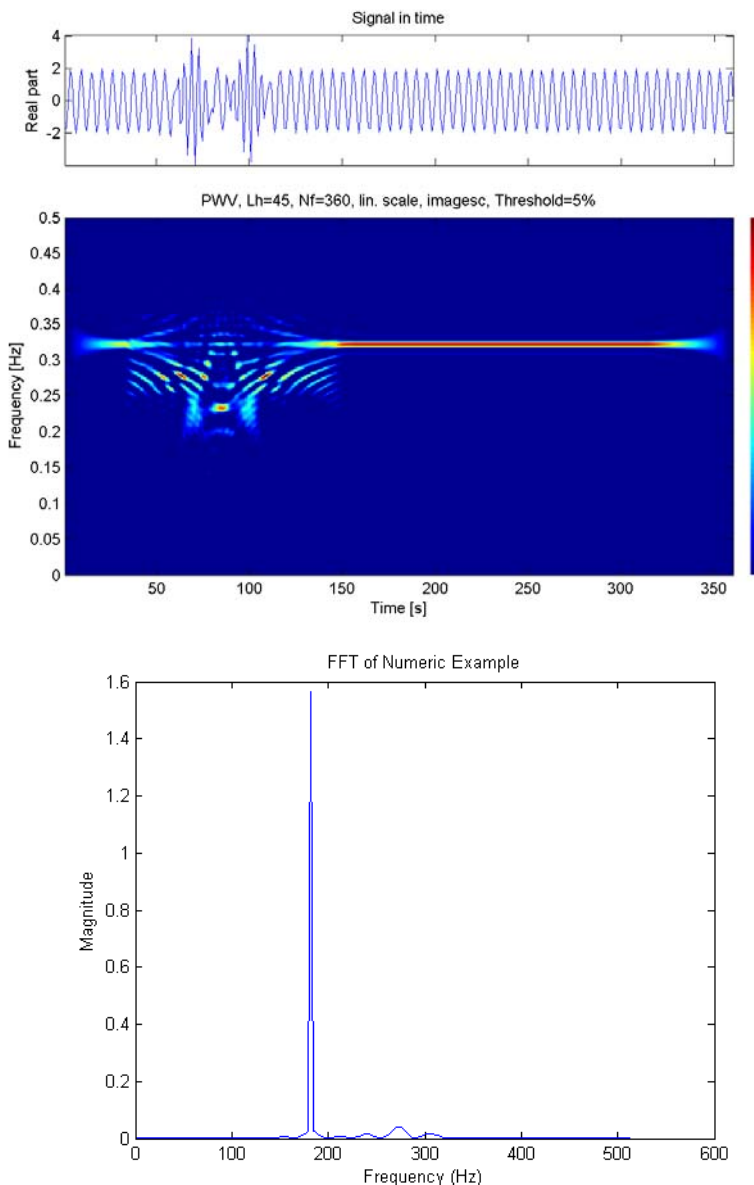


Fig. 3. WVD in a real valued function of a time and frequency in case of looseness and unbalans

The growth of the energy is the first symptom for a fault alarm for a gear tooth damage. Kurtosis of the signal is -1.007 and used Eq. (6) $NP4(0) = -0.28$ and $NP4(1) = 0.694$. Because one of the NP4 parameter is positive we have possible gear tooth damage and from fig.3 we have dissipation of energy signal.

CASE 4

In this case the numerical simulation example is similar to the vibration signal of a gear with looseness, unbalance, wear, poor lubrication and damage gear. The real time signal, FFT, WVD image is show in figure 3. From WVD image is shown that the vibration energy was distributed between 60° - 110° and 160° - 270° .

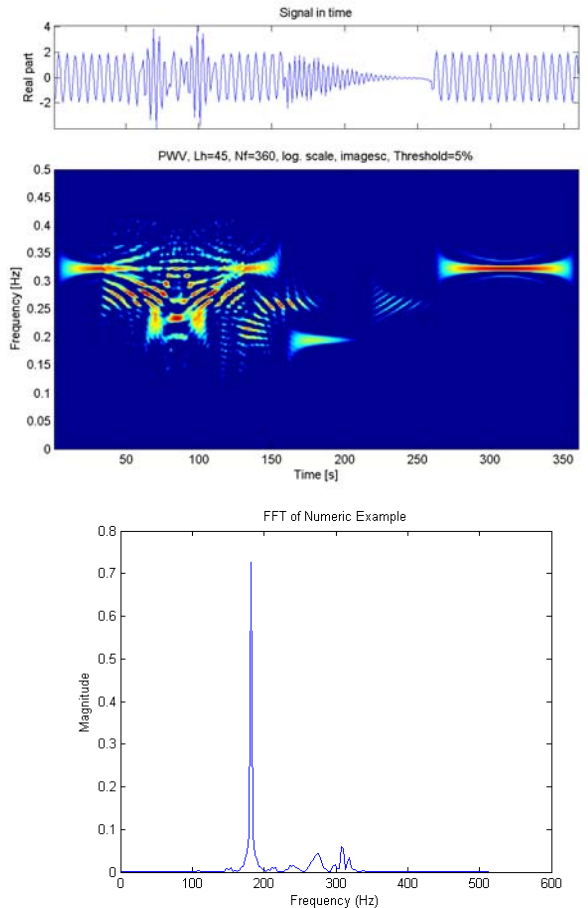


Figure 4. *WVD in a real valued function of a time and frequency in case of looseness, unbalans, wear, poor lubrication and damaged gear*

The growth of the energy is the first symptom for a fault alarm for a gear tooth damage. Kurtosis of the signal is -0.4352 and used Eq. (6) $NP4(0) = 0.9428$ and $NP4(1) = 5.364$. Because both NP4 parameter is positive we have confirmed gear tooth damage and from fig.4 we have dissipation of energy signal.

4. CONCLUSION

The simulation example demonstrates that the time-frequency localization methods such as WVD can be applied in condition monitoring of rotating machines such as gearbox. It follows from the simulated examples that the parameter NP4 could be a viable tool in detecting single gear tooth faults. Unlike the fault detection parameters NA4 and NB4 with trending capabilities, NP4 was constructed as an event parameter, which simplifies its calculation. Also the NP4 parameter utilizes the time-frequency information about signal energy given by the WVD, while figures of merit

and NA4, NB4 use only time domain information. The variance was calculated for the original vibration signal and the 1st order residual vibration signal. The developed method, algorithms and software package in MATLAB are integrated into a general health monitoring procedure for a gear transmission.

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PREGLED VIBRODIJAGNOSTIČKIH METODA ZA PRAĆENJE STANJA ZUPČANIKA PLANETARNIH REDUKTORA

Rusmir Bajrić¹, Ninoslav Zuber², Denijal Sprečić³

Rezime: Praćenje stanja rotirajuće opreme kroz analizu vibracija je dobro poznata metoda koja je kvalitetno dokumentovana za određene tipove mašina ili mašinskih elemenata kao što su zupčanici reduktora sa fiksnim osama rotacije vratila. Međutim, postoje sistemi gdje implementacija tehnika analize vibracija nije pokazala dobre rezultate. Planetarni reduktori pripadaju takvoj vrsti sistema. Analiza vibracija planetarnih reduktora je poprilično ograničena u usporedbi s klasičnim reduktorima gdje su ose rotacije vratila reduktora fiksne. Za razliku od reduktora sa fiksnim osama, planetarne reduktore karakteriše jedinstveno ponašanje, što onemogućuje primjenu metoda za identifikaciju oštećenja koje se često primjenjuju kod reduktora sa fiksnim osama. Ovaj rad predstavlja prikaz određenih metode koje su razvijene za praćenje stanja zupčanika planetarnih reduktora baziranih na analizi vibracija te prezentira tehnike koje imaju svoju praktičnu primjenu.

Ključne riječi: planetarni reduktor, analiza vibracija, teorija obrade signala vibracija

REVIEW OF VIBRODIAGNOSTIC METHODS FOR PLANETARY GEARBOX GEARS CONDITION MONITORING

Abstract: Condition monitoring through vibration analysis is well known and has been documented for different types of machines or machine parts such as gears of fixed-axis gearboxes. However, there are some systems where the application of vibration analyses has not given the same good results. Planetary gearboxes belong to this group of systems. Vibration analysis of planetary gearboxes is quite limited compared with those of fixed-axis gearboxes. Different from fixed-axis gearboxes, planetary gearboxes exhibit unique behaviours which invalidate fault diagnosis methods that work well for fixed-axis gearboxes. This paper explores a range of methods which have been developed to deal with planetary gearbox gears condition monitoring based on vibration analysis, and introduces the techniques by considering various practical applications.

Keywords: planetary gearbox, vibration analysis, vibration signal theory processing

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1. UVOD

Osnovni razlog u nedostatku jasnih načina identifikacije i procjene stepena oštećenja zupčanika planetarnih reduktora kroz analizu mehaničkih vibracija je u složenosti vibracionog signala nastalih u njihovom radu kao i same lokacije prikupljanja signala vibracija. Planetarni reduktor je takve kinematske strukture u kome se svaki planetarni zupčanik istovremeno uzupčava s centralnim i vanjskim zupčanikom. Zbog toga broj uzupčavanja je dva puta veći u odnosu na broj planetarnih zupčanika, s tim da je polovina od tih uzupčavanja unutrašnja a druga polovina vanjska. Ako se uzme u obzir da su planetarni reduktori najčešće konstruisani kao višestepeni, time se usložnjava signal vibracija na osnovu kojeg je potrebno utvrđivati stanje pojedinih zupčanika planetarnog reduktora. Kada govorimo o planetarnom reduktoru, kod istog u zavisnosti od geometrije zupčanika, mogu postojati fazne razlike između uzupčavanja zupčanika. Ove fazne razlike su takođe prisutne i kod nastanka svakog slijedećeg uzupčavanja. Navedeno predstavlja ključni element za razumijevanje nastanka vibracija pri radu planetarnog reduktora. Drugi osnovni element predstavlja uticaj pozicije mjerenja na planetarnom reduktoru. Tipičan primjer i najčešći slučaj mjerenja vibracija je pomoću senzora koji se postavlja na vanjskom dijelu planetarnog reduktora. U toku rada nosač planetarnih zupčanika koncentrično rotira zajedno s centralnim zupčanikom, te obzirom na činjenicu da su planetarni zupčanici montirani na nosač, time isti rotiraju i oko svoje vlastite ose tako da se istovremeno smjenjuju i oko centralnog zupčanika. Znači, dodirne tačke između zupčanika u toku procesa uzupčavanja, što u stvari i predstavlja lokaciju izvora vibracija, se isto tako smjenjuju oko centralnog i vanjskog zupčanika. S druge strane, u toku akvizicije signala mehaničkih vibracija mjerni senzor je najčešće nepomičan, tako da se udaljenost između senzora i mjesta izvora vibracija neprekidno mijenja. Ovaj fenomen se izražava kao amplitudna modulacija vibracija nastalih u procesu uzupčavanja svakog planetarnog zupčanika sa centralnim i vanjskim zupčanikom, što se dešava sa svakom rotacijom nosača planetarnih zupčanika ako se obrtni moment prenosi preko nosača planetara. Amplitudne modulacije ovako nastalih vibracija na svakom od planetarnih zupčanika su vremenski pomjerene u odnosu na relativni ugao između planetarnih zupčanika. Navedene pojave koje se javljaju pri radu planetarnog reduktora direktno zavise od njihove konstrukcione izvedbe, što direktno utiče na sadržaj vibracionog spektra. Prema tome, vibracije mjerene na različitim konstrukcionim izvedbama planetarnog reduktora mogu imati različit sadržaj vibracionog signala. Iz tog razloga kao i uzimanjem u obzir činjenicu da su planetarni reduktori sastavni elementi važnih postrojenja, prikaz kao i praktična primjena metoda vibrodijagnostičke analize predstavlja značajan korak pri efikasnom praćenju stanja zupčanika i procjene stepena oštećenja zupčanika planetarnih reduktora kroz analizu mehaničkih vibracija.

2. PREGLED TEHNIKA ZA PRAĆENJE STANJA ZUPČANIKA PLANETARNIH REDUKTORA

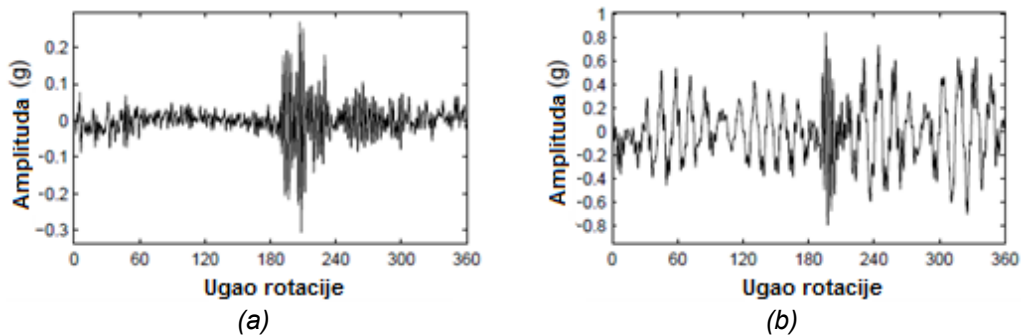
Kontinualno vremenska Furierova analiza

Kod većine reduktora prilikom mjerenja vibracija s ciljem utvrđivanja stanja zupčanika spektar vibracija je simetričan i centričan oko frekvencija uzupčavanja. Kod planetarnih reduktora spektar je najčešće asimetričan te se dominantne frekvencije komponenata ne pojavljuju oko frekvencija uzupčavanja. Ovo predstavlja značajno

saznanje jer neke od popularnih metoda koje se koriste za praćenje stanja i otkrivanje oštećenja zupčanika upravo se baziraju na frekvencijama uzupčavanja i jačini bočnih pojaseva kao indikatora nekog oblika oštećenja. McFadden i Smith su prvi koji su uočili ovaj efekat koji nastaje iz razloga promjene faznog ugla generatora vibracija, odnosno planetarnog zupčanika kada su u pitanju planetarni reduktori. Isti autori su koristili sumator faze ali nisu mogli predvidjeti relativnu amplitudu dominantnih komponenta. Drugi autor koristeći kontinualno vremensku Furierova analizu objašnjava izvore asimetrije spektra vibracija kod planetarnih reduktora. Važnost istraživanja ovog autora se prvenstveno ogleda u primjeni prilikom procjene stanja uz pomoć vibracija iz razloga što se demonstrira nastanak asimetrija, koja nastaje prirodno i nije nužno izvor problema odnosno alarma lošeg elementa unutar planetarnog reduktora.

Tehnike bazirane na vremenski sinhronom osrednjavanju signala vibracija

Vibrodijagnostika zupčanika se proučava dugi niz godina, Stewart je čak 1970. godine predložio niz značajnih ali kompliciranih dijagnostičkih alata koji su postali mjerila za opremu vibrodijagnostike a naročito za planetarne reduktore. Zbog značajnosti bočnih pojaseva oko frekvencija uzupčavanja prilikom indentifikacije stanja zupčanika, kada su u pitanju reduktori sa fiksnim osama Inalpolat i Kahraman su pojasnili mehanizam kreiranja jednostavnog matematičkog modela koji dovodi do modulacija bočnih pojaseva planetarnih zupčanika. Model se sastoji od ključnih elemenata kao što su: broj planetarnih zupčanika, uglovi pozicije planetarnih zupčanika, odnos faza planetarnih zupčanika definisanih preko uglova pozicije i broja zubi zupčanika. Model koji su autori prikazali je analizirao nekoliko oblika planetarnih reduktora i time pokazali da se isti mogu klasificirati u pet različitih grupa baziranih na ponašanju bočnih pojaseva koristeći informacije o frekvencijama i amplitudama. Prezentirana je metodologija za razvoj modulacije bočnih pojaseva za slučaj mjerenja ubrzanja vanjskog zupčanika. Na kraju, autori predlažu opšte principe nastajanja modulacija bočnih pojaseva kada su u pitanju planetarni reduktori. Veliki broj tehnika se temelje na vremenski sinhronom osrednjavanju signala vibracija za svaki stepen prenosa iz kojih su izdvojeni određeni spektari vibracija značajnih za analizu. Vjerojatno najuticajni od predloženih alata je bio FM4, definisan kao Kurtosis od 'ostatka' signal dobivenog uklanjanjem dijela signala koji je gotovo uvijek prisutan, odnosno uklanjanjem oblika signala nastalih uzupčavanjem, koji su skloni da ometaju lokalne varijacije u signalu. Odnosno, obrađivao se rezidualni signal dobiven oduzimanjem iz spektra poznatih harmonika frekvencije uzupčavanja te povratka na signal u vremenskom domenu. Kasnije je uočeno da se na ovaj način zadržavaju veliki efekti modualcije prvog i drugog harmonika brzine rotacije koja naravno nije u vezi s lokalnim oštećenjima te se predložilo uklanjanje jednog ili oba para bočnih pojaseva oko svakog harmonika frekvencija uzupčavanja kako bi se dobio rezidualni signal. U skorije vrijeme od strane Wang i Wong iz Australiske organizacije za odbranu i tehnologiju je predložen fleksibilniji način uklanjanja oblika signala uzupčavanja koristeći linearno predviđanje. Slika 1 prikazuje poboljšanja omogućena korištenjem linearnog predviđanja u odnosu na tradicionalni metod. Peter McFadden sa Univerziteta u Oxforu je predstavio nekoliko poboljšanja baziranih na tehnici vremenko sinhronog osrednjavanja.



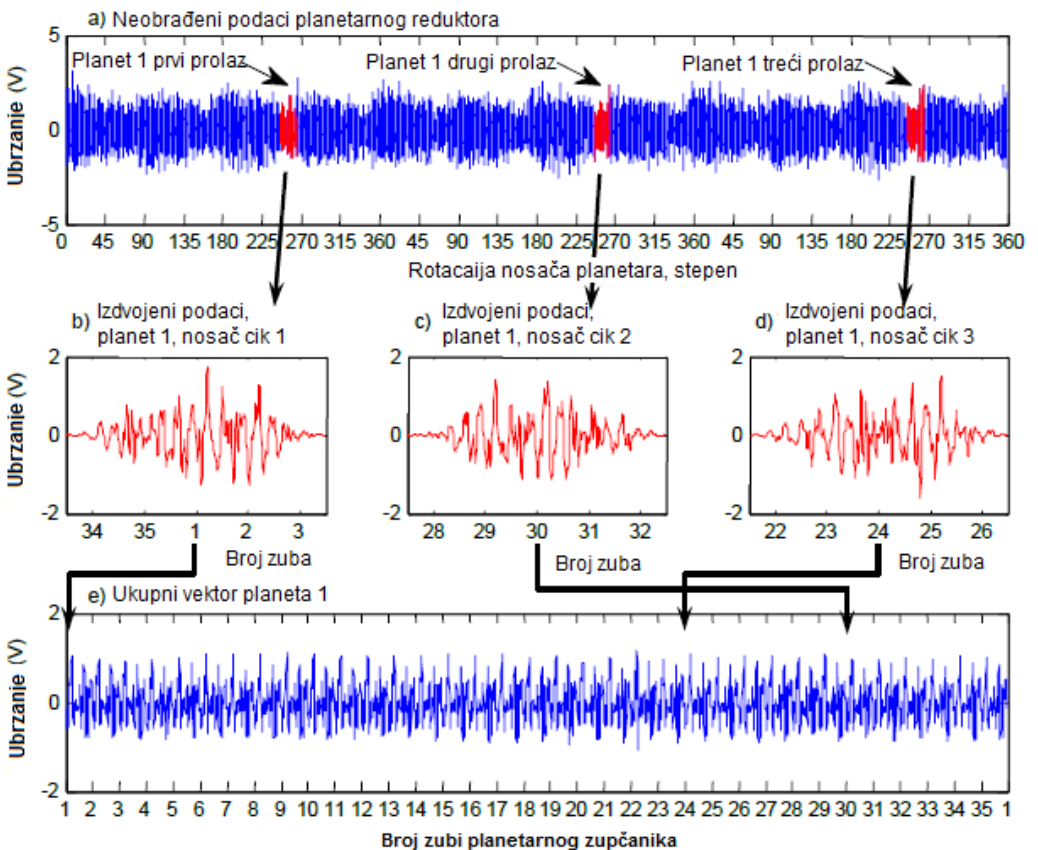
Sl. 1 Usporedba rezidualnog signala koristeći različite metode (a) linearno predviđanje (kurtosis 11.14); (b) obrađivani spektrum (kurtosis 3.03)

Značajan napredak se desio razvojem metode za dobijanje vremensko sinhronog osrednjelog signala za planetarne i centralni zupčanik planetarnog reduktora. Za senzore montirane na vanjski dio kućišta, najčešće u blizini vanjskog zupčanika, signal je značajno opterećen signalom koji generiše planetarni zupčanik koji se nalazi u neposrednoj blizini mjerne tačke u procesu mjerenja. McFadden je predložio da se ova pojava iskoristi tako što će se primjeniti funkcija prozora na ovaj relativno kratak dio signala koji se odnosi na prolazak pored senzora samo jednog zuba zupčanika. Sledeći puta će isti planetarni zupčanik proći pored senzora, odnosno drugi zub planetarnog zupčanika kao i centralnog zupčanika će se uzubiti.

Međutim, zbog kinematike sistema nepoznato je koji je to zub zupčanika. Ovim se omogućava da se prikupljeni signal dodjeljuje svakom zubu i svakom zupčaniku. Nakon dovoljnog broja prolazaka ne samo da će svaki zub planetarnog i centralnog zupčanika biti u blizini senzora, nego će se to dešavati nekoliko puta tako da će osrednjavanje na ovaj način omogućiti vremensko sinhrono osrednjavanje signala za svaki zub zupčanika te njihovim sastavljanjem moguće je obuhvatiti cijeli zupčanik. Za navedeno proučavanje McFadden koristi pravougaoni prozor koji tačno odgovara periodu jednog uzupčavanja, međutim u kasnijim istraživanjima autor preporučuje Hanning prozor kojeg on naziva Tukey prozor koji primjenjuje dvostruku dužinu perioda uzupčavanja. Autor navodi da se ovim dobiva mala uočljiva razlika vremenskog zapisa ali se značajno poboljšava izgled frekventnog spektra. Bitno je navesti da je frekvencija uzupčavanja ista za svaki par jednostepenog planetarnog reduktora. Kako bi se prevazišla navedena ograničenja, Samuel i dr. proširuju ovu tehniku na taj način što koriste više senzora koji su montirani na vanjski dio planetarnog reduktora pod pretpostavkom da su signali vibracija izmjereni na ovaj način slični.

Međutim, u istom radu je zaključeno da ova pretpostavka nije održiva te se nepreporučuje korištenje više senzora. Jedna od prednosti ovog metoda je smanjenje vremena potrebnog za vremenski sinhrono osrednjavanje. Samuel, Conroy i Pines ističu da postoje problemi u vezi tačnosti kada je u pitanju tehnika osrednjavanja signala. Isti autori ističu da je ključni element poboljšanja učinka procesa obrade vibracija velika brzina uzorkovanja u toku same digitalizacije. Predložena minimalna brzina uzorkovanja je 26.8 uzoraka po periodu uzupčavanja zuba. Drugi faktor koji utiče na tehniku osrednjavanja signala je interpolacija. Nakon provedenog osrednjavanja signala, isti se ne računa u vremenskom obliku nego u obliku promjene ugla rotacije zupčanika koji rotira. Zbog toga, pri određenoj frekvenciji uzorkovanja, funkcija brzine rotacije zupčanika je zavisna od broja uzoraka po rotaciji. Kako bi se

signal osrednjavao po promjeni ugla, mjesta za prikupljanje podataka moraju postojati na identičnim uglovnim razmacima. Izmjereni signal se mora transformirati iz vremenskog domena u domen uglova, pri čemu je potrebno redefinisati frekvenciju uzorkovanja kao funkciju ugla. Ukoliko je brzina rotacije zupčanika promjenljiva u vremenu, frekvencija uzorkovanja u domeni uglova neće odgovarati. Vremenski sinhrono osrednjavanje može direktno biti primijenjeno i na planetarne reduktore, međutim autori naglašavaju činjenicu da mogu nastati dodatne komplikacije prilikom primjene ove metode. Konstatovano je da dva faktora komplikuju primjenu vremenski sinhronog osrednjavanja kod planetarnih reduktora. Prvi, jeste činjenica da se senzor jedino praktično može montirati na vanjski dio kućišta reduktora, a drugi jeste činjenica da osa rotacije planetarnih zupčanika nije fiksna, nego je više relativna u odnosu na kućište i senzor koji se nalazi na kućištu. Vibracije centralnog zupčanika se prenose preko planetarnih zupčanika prije nego se iste mogu detektovati uz pomoć senzora. Ove komplikacije je potrebno riješiti prije nego se primijeni vremenski sinhrono osrednjavanje signala dobivenog iz planetarnog reduktora. David G. Lewicki i ostali djelimično modificiraju tehniku koju je razvio McFadden a dijagram ove metode je prikazan na Slici 2.



Sl. 2. Tehnika razdvajanja signala vibracija planetarnih zupčanika

Tehnika bazirane na sintetičkom modelu vibracija

Kao alternativni pristup praćenju stanja planetarnih reduktora Keller je predložio modifikaciju mnogih standardnih matrica primjenom na planetarnim sistemima. Ove modifikacije se odnose na redefinisane rezidualnog signala nakon što se uklone složene komponente frekvencija uzupčavanja i njihovi bočni pojasevi. Predložene metode su neefikasne kod malih razmaka bočnih pojaseva kao što je slučaj kod planetarnih reduktora sa malim brojem planetarnih zupčanika ili neravnomjerno raspoređenim planetarnim zupčanicima. U ovakvim slučajevima rezidualnom signalu će se ukloniti suviše frekventnih komponenti. Mosher radeći sa sintetičkim podacima, razvija sintetički model. Algoritam razdvajanja signala u pogledu tačnosti se može testirati poređenjem idealnog signala i modeliranog signala oštećenja. Autor navodi da je tačnost algoritma nemoguće testirati s podacima dobivenih u realnim uslovima iz razloga što su komponente signala realnog sistema nepoznate. Signali sintetičkih vibracija su dobiveni uz pomoć kinematskog modela. Jednostavno, model se sastoji od amplitudno modelisanih periodičnih signala uzupčavanja dok se kompleksnost signala dobija dodavanjem poremećajnog signala. Autor potvrđuje iregularnost rezultata te da su potrebna dodatna istraživanja i ovom pravcu.

Tehnike bazirane na vremensko-frekventnoj analizi

McFadden objašnjava WVD (Wigner-Ville Distribuciju) kao kvalitetan alat za prikaz signala vibracija u vremensko-frekventnom domenu. WVD je korištena da se usporedi nekoliko različitih signala. WVD osrednjenog vremenskog domena je u stanju otkriti oštećenje zupčanika, međutim autor dolazi do zaključka da WVD ne mora nužno biti optimalna tehnika za otkrivanje oštećenja zupčanika jer ista nastoji da prikaže više frekvencija u spektru nego ostale tehnike što za posljedicu ima težu identifikaciju. Bartelmus i Zimroz naglašavaju važnost promjene vanjskog opterećenja pri utvrđivanju stanja planetarnih reduktora. Autori navode da najvažnije faktore pri identifikaciji oštećenja planetarnih reduktora predstavljaju smetnje koje se dešavaju pri kretanju nosača planetarnih zupčanika a čije se karakteristike objašnjavaju preko tehnika STFT i WVD, prezentirane preko mape frekvencija. Navedeno je da su dva dominantna razloga koja imaju uticaja na modulaciju signala vibracija, i i ω ; promjenljivo opterećenje i rotacija nosača planetara. Autori primjenom ovih metoda navode da nisu uočena lokalna oštećenja u obliku napuknuća ili loma zuba zupčanika ili oštećenja elemenata ležajeva u toku istraživanja. Iz njihovog rada se može zaključiti da se predlaže novi pristup u ocjeni stanja planetarnih reduktora. Autori predlažu korištenja korjenite analize uzroka nastanka vibracija a sve u cilju utvrđivanja stanja planetarnih reduktora.

3. PRAĆENJE STANJA BAZIRANO NA INDIKATORIMA STANJA

Samuel i Pines su proveli istraživanja koristeći devet indikatora stanja kako bi pokušali utvrditi stanje zupčanika planetarnih reduktora. Korišteni indikatori stanja su: RMS, crest factor, energy ratio, FM0, kurtosis, energy operator, FM4, M6A and M8A. Svi navedeni indikatori stanja su ranije razvijeni za jednostepene planetarne reduktore te su korišteni kako bi se izdvoio vektor vibracija željenog centralnog, planetarnog ili vanjskog zupčanika. Navedeni indikatori su dobiveni direktno iz osrednjenog signala specifičnog zuba zupčanika. Prije izračunavanja indikatora stanja uklonjene su iz signala frekvencije uzupčavanja centralnog, vanjskog i specifičnog zuba zupčanika.

Indikator stanja M8A se pokazao kao najbolji prilikom istraživanja. Autori ističu da se standardni indikatori stanja mogu koristiti uz preddefinisane alarme što zahtijeva mnogo podataka i duži vremenski period nadgledanja u kome napreduje oštećenje unutar reduktora. Standardni indikatori su prilagođeni epicikličnim reduktorima na način opisan od strane McFadden i Smith. Postoje i drugi indikatori stanja koji su najčešće patentna rješenja proizvođača opreme za nadgledanje i ocjenu stanja rotirajućih mašina, koji su prvenstveno vezani za vojnu industriju i industriju vjetroturbina. Keller i Grabill istražuju mogućnost korištenja indikatora stanja kako bi otkrili pukotinu u nosaču planetarnih zupčanika unutar glavnog reduktora helikoptera.

Indikator, Dynamic Energy Index (DEI), razvijen od strane GE Energy's Bently Nevada je jedan od specifičnih indikatora stanja. DEI je razvijen kako bi se omogućila relativno jednostavna karakterizacija energije spectra vibracija kroz pet nivoa na frekventnoj skali koji približno odgovaraju frekvencijama oštećenja ležaja, frekvencijama uzupčavanja zupčanika za više stepeni te strukturnim frekvencijama. Dynamic Energy Index (DEI) je specifično kreiran za mašine sa promjenljivim brojem obrtaja.

Indeks asimetričnosti (Skewness) je isto tako statistički parametar dobiven koristeći vremenski zapis vibracija. Indeks asimetričnosti prikazuje simetriju tačaka vremenskog zapisa oko prirodne ose.

Kumulativni impuls je skup mjerenja koja otkrivaju i prate prolaz čestica krhotine kroz planetarni reduktor. Kako se stvara oštećenje unutar planetarnog reduktora stvarat će se i metalne krhotine nastale od sastavnih elemenata reduktora. Najčešće ove metalne krhotine će u procesu uzupčavanja stvarati dodatna oštećenja. Ove metalne krhotine kada se nađu između zubi u toku izupčavanja će dodatno stvarati impulse vibracija. Ovako nastali impulsi vibracija se prenose na cijeli planetarni reduktor sve do vanjskog zupčanika. Kao rezultat nastaje impuls vibracija koji je u vezi sa prirodnom frekvencijom kućišta reduktora. Ovako nastao karakterističan impuls, odnosno signal odziva, se detektuje i prati kroz indikator nazvan kumulativni indeks. Najčešće se ovaj indikator prati on-line, pri čemu se utvrđuje amplituda odziva, računa se broj impulsa u toku jednog sata te se na osnovu svega navedenog utvrđuje stanje planetarnog reduktora. Kumulativni impuls se prikazuje kroz tri promjenljive: broj kumulativnih impulsa, energije kumulativnog impulsa te stope rasta kumulativnog impulsa.

4. ZAKLJUČAK

Praćenje stanja zupčanika planetarnih reduktora analizom vibracija koristeći klasične metode je neefikasno, prvenstveno iz razloga kinematske složenosti planetarnog reduktora, odnosno složenosti nastanka vibracija. Uspjeh identifikacije oštećenja zupčanika planetarnog reduktora prvenstveno zavisi od primjenjene tehnike procesiranja signala vibracija snimljenog na njegovom kućištu. Radom su prikazane dosadašnje vibrodijagnostičke metode koje su pružile više ili manje pouzdane rezultate prilikom utvrđivanja oštećenja i praćenja stanja zupčanika planetarnih reduktora. Uočljivo je da ne postoji univerzalna metoda koja će omogućiti preciznu lokaciju više oblika oštećenja od momenta njihovog nastanka do havarijskog stanja.

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PREGLED VIBRODIJAGNOSTIČKIH METODA ZA PRAĆENJE STANJA KOTRLJAJNIH LEŽAJEVA

Ninoslav Zuber¹, Rusmir Bajrić²

Rezime: Radom je dat prikaz različitih mehanizama nastanka oštećenja kotrljajnih ležajeva, njihov razvoj u toku eksploatacije ležaja kao i pregled univerzalnih metoda za praćenje stanja ležajeva na bazi analize snimljenih vibracija sa kućišta ležajeva u vremenskom i frekventnom domenu.

Ključne riječi: vibracije, kotrljajni ležaj, frekventni spektar, vremenski zapis, envelopna analiza

REVIEW OF VIBRODIAGNOSTIC METHODS FOR ROLLER ELEMENTS BEARING CONDITION MONITORING

Abstract: This paper addresses a review of existing roller element bearing's defects generation and their development during the bearing operation. A brief review of existing universal vibration signals processing methods for bearing's defect monitoring and analysis in time and frequency domain is presented.

Keywords: vibration, roller elements bearing, frequency spectrum, time waveform, envelope analysis

1. UVOD

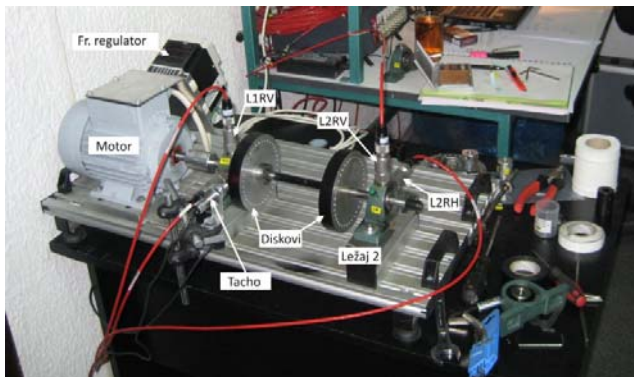
Kotrljajni ležajevi su jedni od najčešće ugrađivanih komponenti rotirajućih mašina i, mada neopravdano, smatraju se najčešćim "krivcima" za neplanske zastoje i havarije istih. Isto tako, mada neutemeljeno, vibrodijagnostičke metode, se najviše vezuju za dijagnostiku stanja kotrljajnih ležajeva, iako su ležajevi samo jedan od velikog broja tipova komponenti mašina čije je oštećenje moguće identifikovati metodama vibrodijagnostičke analize. Pomenuti neplanski zastoji i havarije direktno utiču na smanjenje produktivnosti pogona, dodatne troškove održavanja a u ekstremnim situacijama čak mogu dovesti i do gubitka ljudskih života. Iz tog razloga kao i uzimanjem u obzir činjenice da svega 10% ležajeva doživi svoj projektovani radni vek, razvoj metoda vibrodijagnostičke analize i primena specijalnih metoda analize – procesiranja signala, kao i njihovo poređenje predstavlja veoma značajnu oblast vibrodijagnostike.

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2. EKSPERIMENTALNA POSTAVKA

Ekperimentalni deo ovog rada je izveden na probnom stolu koji je prikazan slikom 1. Probni sto se sastoji od asinhronog frekventno regulisanog motora snage 0.37kW čije je izlazno vratilo preko elastične spojnice povezano sa vratilom koje nosi dva rotirajuća diska. Rotor je oslonjen preko dva kotrljajna ležaja tipa UC201. Četiri IEPE akcelometra tipa AC102-1A (proizvođač: CTC, US) su preko usadnih zavrtnjeva montirani u horizontalnom i vertikalnom radijalnom pravcu na kućištima ležajeva. Za snimanje i kontrolu broja obrtaja korišćen je laserski optički merni pretvarač (proizvođač: Monarch Instruments, US) sa reflektujućom markicom koja je montirana na jedan od rotirajućih diskova.



Sl. 1. Probni sto korišćen u eksperimentu

Za simultanu višekanalnu akviziciju korišćen je 16-kanalni akvizicioni sistem OneproD MVX sa pratećim softverom za akviziciju i analizu XPR300 (proizvođač: 01dB-Metravib, AREVA, Francuska). Osim mehaničkih vibracija snimani su i nivoi zvučnog pritiska korišćenjem prenosivog analizatora buke Blue Solo i pratećeg softvera za analizu dbTrait (proizvođač: 01dB-Metravib, AREVA, Francuska).

Za potrebe eksperimenta ležajevi su kontrolisano oštećivani. Oštećenja koja su uvođena na ležajeve, obuhvaćena ovim radom su: ležaj u ispravnom stanju (oznaka "OK"), ležaj sa oštećenjem na spoljnoj stazi u neopterećenoj zoni (oznaka "OU"), ležaj sa oštećenjem na spoljnoj stazi u opterećenoj zoni (oznaka "OL"), ležaj sa malim oštećenjem na unutrašnjoj stazi (oznaka "I"), ležaj sa većim oštećenjem na unutrašnjoj stazi (oznaka "II"), ležaj sa manjim zazorima (oznaka "Z1") i ležaj sa povećanim zazorima (oznaka "Z3"). Sva snimanja su izvedena pri brzini obrtanja od 22 Hz. Koristeći poznate obrasce i dimenzione parametre ležaja, dobijaju se sledeće karakteristične frekvencije oštećenja komponenti kotrljajnog ležaja (napomena - karakteristične komponente su prikazane kao umnošci osnovnog harmonijskog reda): $BPFI^3 = 4.9$, $BPFO^4 = 3.1$, $BS^5 = 2.1$, $FT^6 = 0.39$.

³ Frekvencija oštećenja na unutrašnjoj stazi

⁴ Frekvencija oštećenja na spoljnoj stazi

⁵ Frekvencija oštećenja kotrljajnog tela

⁶ Frekvencija oštećenja kaveza

3. MEHANIZMI NASTANKA OŠTEĆENJA U LEŽAJEVIMA

Pojava prevremenog oštećenja kotrljajnih ležajeva može nastati usled velikog broja faktora, pri čemu su najčešći: zamorni lom, habanje, plastična deformacija komponenti ležaja, korozija, efekat brinelling-a, loše podmazivanje, nepravilna montaža, neadekvatan izbor. Često se gore pomenuti uzroci preklapaju a nije redak slučaj i da jedan tip uzroka inicira oštećenje a da kasnije drugi mehanizam stradanja izazove potpuno uništenje ležaja.

- Zamorni lom. Kotrljajni ležaj koji je izložen projektovanom dinamičkom opterećenju će stradati usled zamornog loma nakon projektovanog broja radnih časova. Zamorni lom počinje pojavljivanjem mikropukotine najčešće ispod površine unutrašnje staze ležaja. Kako je opterećenje i dalje prisutno, pukotina se širi ka površini i dovodi do odvajanja materijala na stazi. Ukoliko se tako oštećen ležaj i dalje ostavi u radu, usled povećanih napreznja u blizini pukotine, dolazi do povećavanja iste tj. do još intenzivnijeg ljuspanja. Na ovaj način oštećena staza dovodi do poremećaja u kretanju kotrljajnih tela preko tog dela staze, što dovodi do pojave periodičnih udarnih komponenti u vibracionom signalu. Ukoliko se ležaj i dalje ostavi u radu, dolazi do poremećaja kretanja u tolikoj meri da je u nefiltriranom vremenskom signalu vibracije nemoguće razlikovati pojedinačne impulse. Sledeća faza oštećenja se manifestuje pojavom oštećenja na kotrljajnim telima a nakon toga i na ostalim delovima staza. Na kraju, rad ovakvog ležaja dovodi do povećanog trenja između komponenti ležaja što kao posledicu ima i stradanje kaveza kotrljajnog ležaja i definitivne havarije istog.
- Habanje je sledeći tipični mehanizam pojave oštećenja na kotrljajnim ležajevima. Najčešće se javlja kao posledica prisustva prljavštine odnosno stranih tela unutar samog ležaja, što je posledica neadekvatnog zaptivanja ili pak kontaminiranog sredstva za podmazivanje. Intenzivno habanje dovodi do poremećaja unutrašnje geometrije elemenata ležaja što dovodi do povećanih zazora. U tim uslovima osim obrtnog kretanja kotrljajnih tela prisutno je i znatno klizanje, što ukoliko se dozvoli, može dovesti do havarije ležaja. Zavisno od toga koji su elementi ležaja pohabani, sadržaj frekventnog spektra može biti različit. Ukoliko su geometrije unutrašnje ili spoljašnje staze poremećene usled habanja, frekventni spektar će sadržavati familiju harmonika karakterističnu za periodične – neperiodične udarce u vremenskom zapisu. Osim toga, frekventni spektar će pokazati i prisustvo širokopojasnog šuma. Ukoliko je pak došlo do poremećaja geometrije kotrljajnog tela (ili više njih) tada će frekventni spektar sadržavati i komponente modulacije kaveza.
- Plastična deformacija. Plastična deformacija na delovima kontaktnih površina elemenata ležaja nastaje kao posledica preopterećenja i najčešće se javlja u vidu „useka“ na kotrljajnim stazama.
- Korozija u ležaju nastaje kad voda ili kiseline kojima je ulje za podmazivanje kontaminirano dospe u unutrašnjost ležaja. To se najčešće javlja usled oštećenih zaptivnih elemenata ili pak usled kondenzacije koja može nastati kao posledica naglog hlađenja ležaja u prisustvu velike vlage u vazduhu. Korozija se manifestuje kao rđa na stazama ležaja koja dovodi do veoma neujednačenog i bučnog rada ležaja. Čestice rđe koje se ljuspaju sa staza dalje dovode do abrazije elemenata ležaja odnosno do njegovog habanja.

- Pod efektom brinelling-a se podrazumeva oštećenje koje se manifestuje velikim brojem ekvidistantno raspoređenih useka na stazi ležaja, što generalno može nastati na tri različita načina: usled statičkog preopterećenja što kao posedicu ima pojavu plastične deformacije na stazama, usled konstantne izloženosti stacionarnog dela ležaja vibracijama susednih mašina – u praksi nije redak slučaj da prevremeno strada spoljna staza ležaja rezervne pumpe (koja nema ni jedan radni čas iza sebe...) koje je u neposrednoj blizini radne pumpe i usled električnog pražnjenja u samom ležaju ukoliko preko njega dolazi do prolaska električne struje. U sva tri slučaja staza ležaja će posedovati veći broj ekvidistantno raspoređenih useka što dovodi do veoma bučnog rada.
- Neadekvatno podmazivanje je veoma čest uzročnik prevremenog oštećivanja ležajeva. Ukoliko je odabrano neadekvatno sredstvo za podmazivanje ili ukoliko je ležaj nepodmazan dolazi do pregrevanja ležaja usled direktnog kontakta elemenata ležaja - kontakti su u formi mikrozavara koji se momentalno formiraju i nakon toga se otkidaju kad dođe do kretanja u ležaju. Postoje tri kritična mesta po pitanju podmazivanja ležaja i to: kontakt staza-kotrljajno telo, kontakt kotrljajno telo – kavez i kontakt kavez – staza.
- Neadekvatna montaža odnosno instalacija ležaja podrazumeva preopterećivanje ležaja u radijalnom ili aksijalnom pravcu, uvođenje nesaosnosti u isti ili pak njegovo oštećivanje usled navlačenja na osovinu bez primene posebnih alata. Uvedeno radijalno preopterećenje ležaja obično dovodi do njegovog bučnijeg rada i do veće razlike temperatura između unutrašnje i spoljne staze ležaja. Usled toga dolazi do povećanih kontaktnih napona i do progresivnog razvoja zamornog loma kome prethodi intenzivno habanje usled poremećene geometrije komponenti ležajeva. Neadekvatna montaža odnosno unošenje dodatnog preopterećenja u ležaj u velikoj meri umanjuje šanse kotrljajnog ležaja da doživi svoj projektovani radni vek sa obzirom da je procenjeno L10 vreme (zagarantovano vreme u radu minimalno 90% ležaja iz odabrane populacije ležaja) definisano kao

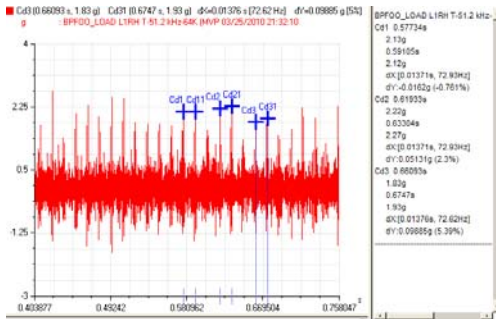
$$L_{10} \approx \frac{1}{\Delta RPM} \times \left[\frac{1}{\Delta LOAD} \right]^3 \quad (1)$$

gde je ΔRPM promena radnog broja obrtaja dok je $\Delta LOAD$ dinamička promena opterećenja.

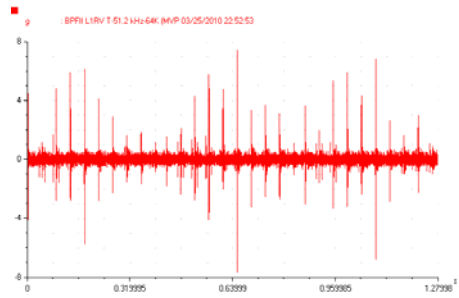
4. TEHNIKE ANALIZE VIBRACIJA ZA IDENTIFIKACIJU OŠTEĆENIH KOTRLJAJNIH LEŽAJEVA

Svaki put kad kotrljajno telo pređe preko useka na stazi, dolaziće do privremenog trenutnog smanjenja naprezanja u ležaju, dok ukoliko kotrljajno telo pređe preko metalnog uključka na stazi koji je nastao ljušpanjem komponenti, doći će do naglog porasta naprezanja u ležaju. Ove tranzijentne sile rezultiraju u naglim promenama ubrzanja komponenti unutar ležaja i kompleksnim oscilatornim kontaktima između komponenti ležaja. Najčešće primenjivane tehnike signalne analize primenjene za identifikaciju oštećenja kotrljajnih ležajeva su: tehnike analize u vremenskom domenu, tehnike analize u frekventnom domenu, metode envelopiranja – demodulacije i tehnike vremensko – frekventne transformacije.

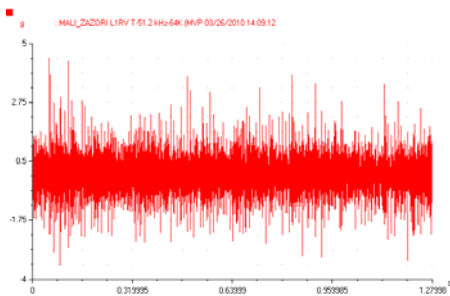
Tehnike analize u vremenskom domenu se fokusiraju na ekstrakciji statističkih pokazatelja sirovog ili filtriranog vremenskog signala u cilju kvantifikacije fenomena udarnog impulsa koji je prisutan u slučajevima oštećenih ležajeva. U obilju različitih statističkih parametara najčešće se primenjuju: koren srednje kvadratne vrednosti - RMS (eng. Root mean square), vršna vrednost – peak, standardna devijacija signala – StDev, peak faktor – PF, Kurtosis parametar – Kurt i tzv. defekt faktor.



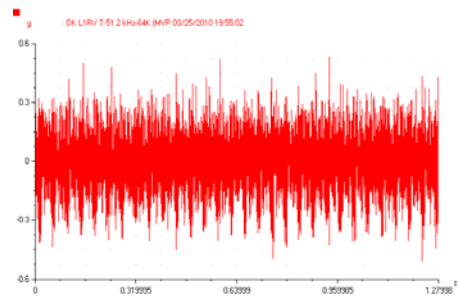
Sl. 2. Vremenski zapis ležaja sa oštećenjem na spoljnoj stazi – snimak sa korišćenog probnog stola



Sl. 3. Vremenski zapis ležaja sa oštećenjem na unutrašnjoj stazi – snimak sa korišćenog probnog stola



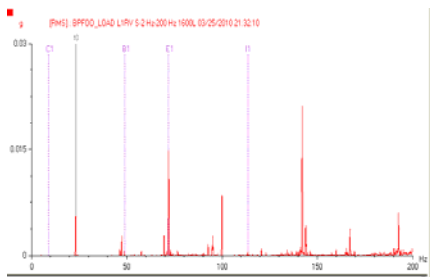
Sl. 4. Vremenski zapis ležaja sa manjim zazorima – snimak sa korišćenog probnog stola



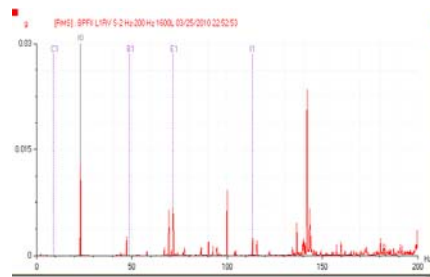
Sl. 5. Vremenski zapis ispravnog ležaja – snimak sa korišćenog probnog stola

Tehnike analize u frekventnom domenu se zasnivaju na predstavljanju vibracionog signala u frekventnom domenu primenom algoritma brze Fourier-ove transformacije – FFT. Osnovne prednosti analize signala u frekventnom domenu su identifikacija periodičnosti u vremenskom signalu i dekompozicija na diskretne frekventne komponente koje se najčešće ne mogu uočiti u sirovom vremenskom zapisu. Iz tih je razloga analiza u frekventnom domenu dominantna signalna analiza koja se primenjuje u vibrodijagnostici. Ujedno automatizovanom ekstrakcijom pojedinih diskretnih komponenti frekventnog spektra ili pak energijskih sadržaja u pojedinim frekventnim opsezima i njihovim daljim tretiranjem kao skalara, frekventna analiza može biti primenjena i za potrebe monitoringa nivoa degradacije ležaja. Na dole prikazanim slikama su dati frekventni spektri vremenskih signala snimljeni na probnom

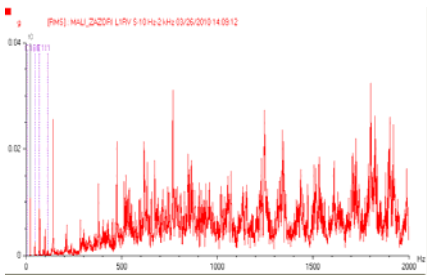
stolu korišćenom u eksperimentalnom delu ovog rada, koji su prikazani u prethodnom poglavlju. Osnovu analize u frekventnom domenu predstavlja poznavanje očekivanih frekventnih komponenti koje se dobijaju na osnovu kinematskih parametara ispitivanog sistema – brojevi obrtaja, prenosni odnosi, brojevi zubaca na zupčanicima, broj štapova u rotoru elektromotora, broj elemenata na radnom kolu pumpe, tip i proizvođač kotrljajnih ležaja na mašini. Proizvođačem i tipom ležaja su definisani i osnovni parametri za izračunavanje karakterističnih frekvencija ležaja koje je potrebno identifikovati u spektru. Na dole prikazanim spektrima frekvencije korišćenog ležaja su označene markerima: C1 koji odgovara FTF (kavez), B1 koji odgovara BS (kotrljajno telo), E1 koji odgovara BPFO (spoljna staza) i I1 koji odgovara BPFI (unutrašnja staza), gde fo predstavlja marker osnovne frekvencije (broja obrtaja).



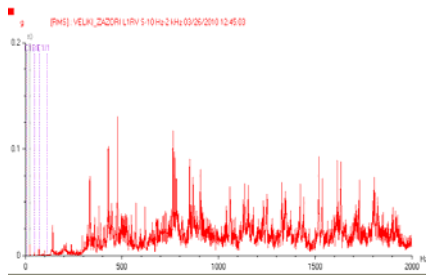
Sl. 6. FFT zapisa sa ležaja sa oštećenjem na spoljnoj stazi



Sl. 7. FFT zapisa sa ležaja sa oštećenjem na unutrašnjoj stazi



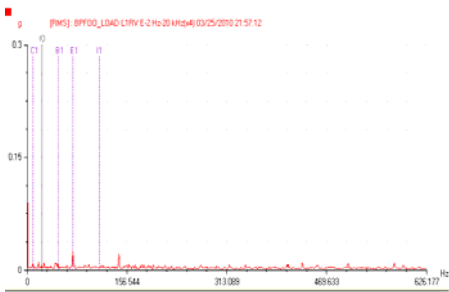
Sl. 8. FFT zapisa sa ležaja sa manjim zazorima



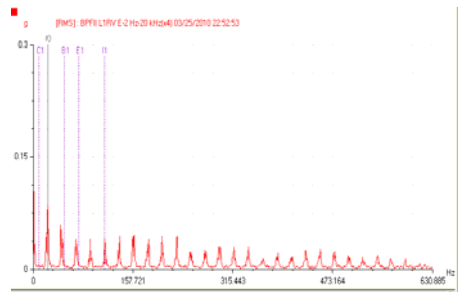
Sl. 9. FFT zapisa sa ležaja sa većim zazorima

Metoda demodulacije odnosno envelopiranja je napredna tehnika procesiranja signala koja je svoju najširu primenu našla baš za potrebe pouzdane dijagnostike oštećenja kotrljajnih ležajeva u najranijim fazama pojave i razvoja oštećenja. Svaki put kad kotrljajno telo pređe preko oštećenja na jednoj od kotrljajnih staza, dolazi do pojave visokofrekventnog impulsnog signala veoma kratkog trajanja. Kao takav, sa obzirom da je trajanje impulsa veoma kratko u poređenju sa frekvencijom pojave impulsa, ukoliko poseduje dovoljan nivo energije, impuls pobuđuje više sopstvenih frekvencija mehaničkih komponenti u blizini. Pobuđivanje sopstvenih frekvencija će, u opštem slučaju, biti periodično, pri čemu perioda pojavljivanja impulsnih komponenti odgovara karakterističnoj

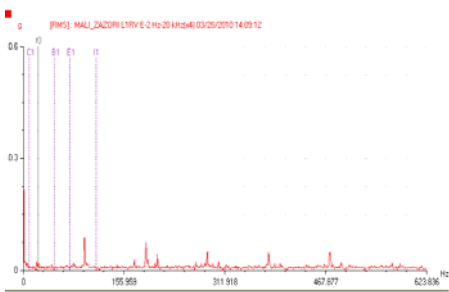
frekvenciji oštećene komponente ležaja. Kao rezultat takve pobude, komponente sopstvenih frekvencija će biti modulirane frekvencijom pojavljivanja impulsnih komponenti u vremenskom signalu. Envelopna analiza je tehnika ekstrakcije informacije o pomenutoj periodičnoj pobudi odnosno modulaciji sopstvene frekvencije. Klasična metoda dobijanja envelope podrazumeva pojasno filtriranje vremenskog signala oko sopstvene frekvencije kućišta ležaja (koja u opštem slučaju najčešće nije poznata) nakon čega se isti usmerava odnosno ispravlja. Prvi postupak u tehnici demodulacije jeste primena visokopojasnog filtra čiji je zadatak eliminacija pomenutih niskofrekventnih komponenti visoke amplitude. Odsečna frekvencija visokopojasnog filtra za potrebe dijagnostike ležajeva i za uobičajne brojeve obrtaja je obično iznad 2 kHz. Kao rezultat visokopojasnog filtriranja dobija se vremenski zapis koji ne sadrži pomenute niskofrekventne komponente. Nakon toga sledi postupak demodulacije koji vrši „translaciju“ bočnih pojaseva sa desne strane sopstvene frekvencije u zonu niskih frekvencija. Nakon demodulacije sledi još jedno filtriranje, sada niskopojasno filtriranje radi eliminacije ostalih komponenti modulacije koje mogu poticati od drugih komponenti u sistemu, a ne od kotrljajnih ležajeva. Najčešće se kao odsečna karakteristika niskopojasnog filtra uzima frekvencija koja je 15-20 puta veća u odnosu na osnovnu frekvenciju (broj obrtaja). Kao rezultat niskopojasnog filtriranja dobija se tzv. spekter envelopnog ubrzanja sa izraženim frekventnim komponentama koje potču od periodičnih udaraca odnosno od oštećene komponente kotrljajnog ležaja.



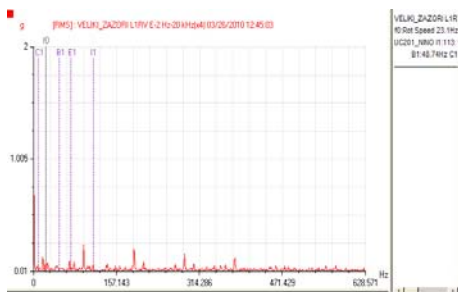
Sl. 10. Envelopni spekter ležaja sa oštećenjem na spoljnoj stazi – snimak sa korišćenog probnog stola



Sl. 11. Envelopni spekter ležaja sa oštećenjem na unutrašnjoj stazi – snimak sa korišćenog probnog stola



Sl. 12. Envelopni spekter ležaja sa manjim zazorima – snimak sa korišćenog probnog stola



Sl. 13. Envelopni spekter ležaja sa većim zazorima – snimak sa korišćenog probnog stola

Tehnike vremensko – frekventnih transformacija su našle svoju primenu u vibrodijagnostici kotrljajnih ležajeva zbog nestacionarne prirode udarnih signala. Kao rezultat, tehnike vremensko – frekventne analize daju prikaz signala simultano u oba domena (vreme i frekvencija) kako bi bilo moguće analizirati svu nestacionarnost opisanog fenomena. Najčešće su u primenu: kratkotrajna uskopojasna Fourier-ova transformacija – STFT (eng. Short time frequency transform), Wagner – Ville distribucija (WVD) i talasna analiza – WA (eng. Wavelet analysis).

U odnosu na standardni FFT, STFT se razlikuje po upotrebi vremenskog prozora, tj. analizirajućeg otvora željenih karakteristika u oba domena (vremenskom i frekventnom). Pomeranje funkcije prozora po vremenskoj osi daje vremensku zavisnost promene frekventnog sadržaja vremenskog signala. Za određenu frekvenciju, vremenski prozor w se kontinualno pomera od početka do kraja vremenskog bloka signala i vrši Fourier-ovu transformaciju za svaki položaj w . Na taj način u odnosu na klasični FFT rezultat transformacije je uvećan za dimenziju signala tj. transformacija je dvodimenzijska (u vremenu i frekvenciji).

5. EVOLUCIJA KOMPONENTI FREKVENTNOG SPEKTRA SA RAZVOJEM OŠTEĆENJA U LEŽAJU

U cilju razvoja pouzdanih metoda vibrodijagnostičke analize kotrljajnih ležajeva, kao i u ostalim oblastima vibrodijagnostičkog pristupa, potrebno je temeljno poznavanje korelacije između mehanizama koji dovode do oštećivanja ležajeva i sadržaja vibracionog signala. U praksi je najočekivaniji slučaj razvoja oštećenja usled habanja koje je inicirano zamornom pukotinom na jednoj od četiri komponente kotrljajnog ležaja.

Inicijalna faza razvoja oštećenja ležaja počinje pojavom zamorne pukotine neposredno ispod površine oštećene komponente ili pak na njoj površini, uz napomenu da se radi o malom intenzitetu oštećenja. Komponente snimljenog vibracionog signala koje potiču od ležaja su posledica pomenutih neznatnih udaraca (odnosno udarnih talasa) i trenja koje se javlja usled narušenog mehanizma podmaizivanja. Pomenute komponente se javljaju u visokofrekventnom domenu (preko 20 kHz u najranijoj fazi).

Analiza pouzdanosti metoda u detekciji oštećenja u ovoj fazi otkaza daje sledeće zaključke:

- Visokofrekventne metode (SPM, SpikeEnergy, PeakVue7) – dovoljno su pouzdane u ovoj fazi i skalarni parametri kao rezultat njihove primene će imati tendenciju rasta sa razvojem oštećenja.
- Envelopiranje/demodulacija – envelope ubrzanja će, pod pretpostavkom da su odsečne frekvencije filtra dobro definisane, i pored lošeg odnosa signal/šum detektovati oštećenu komponentu ležaja.
- Frekventni spektar – frekventni spektar brzine vibracije neće detektovati oštećenje, usled činjenice da se radi o visokofrekventnim komponentama, dok frekventni spektar ubrzanja može dati blage indicije o postojećem oštećenju.
- Vremenski zapis – generalno, za klasične rotirajuće mašine, nije koristan za ovu fazu oštećenja.

⁷ Pomenute metode se ne smatraju univerzalnim pošto zahtevaju korišćenje opreme pojedinih proizvođača, te samim tim nisu ni posebno obrađene ovim radom.

U drugoj fazi razvoja oštećenja, pukotine na oštećenim komponentama postaju veće usled čega periodični impulsi poseduju dovoljan nivo energije za pobudu sopstvenih frekvencija okolne strukture, ležaja i samog senzora. U ovoj fazi envelope treba jasno da pokaže karakteristične frekvencije oštećene komponente ležaja.

- Analiza pouzdanosti metoda u detekciji oštećenja u ovoj fazi otkaza daje sledeće zaključke:
- Visokofrekventne metode – i dalje će pokazivati tendenciju rasta sa razvojem oštećenja.
- Envelopiranje/demodulacija – envelope ubrzanja će veoma jasno ukazivati na oštećenu komponentu ležaja.
- Frekventni spektar – frekventni spektar brzine vibracije neće detektovati oštećenje, usled činjenice da se radi o visokofrekventnim komponentama, dok će frekventni spektar ubrzanja dati jasnu identifikaciju oštećenja.
- Vremenski zapis – njegova pouzdanost kod ove faze je ista kao i kod prethodne.

Treću fazu oštećivanja ležaja odlikuje veći intenzitet udarnih komponenti i njihovo češće pojavljivanje u vremenskom signalu. U ovoj fazi je moguće da dođe i do „zaribavanja“ kotrljajnog ležaja. Faza se karakteriše intenzivnom modulacijom pobuđenih sopstvenih frekvencija karakterističnim frekvencijama oštećene komponente. Generalno, nivo visokopojasnog šuma u frekventnom spektru i envelope će biti povećan a modulacija će se jasno videti kako u frekventnom spektru tako i u vremenskom zapisu.

Analiza pouzdanosti metoda u detekciji oštećenja u ovoj fazi otkaza daje sledeće zaključke:

- Visokofrekventne metode – i dalje će pokazivati tendenciju rasta sa razvojem oštećenja.
- Envelopiranje/demodulacija – envelope ubrzanja će veoma jasno ukazivati na oštećenu komponentu ležaja uz povišen nivo šuma na širokom frekventnom opsegu.
- Frekventni spektar – frekventni spektar brzine i ubrzanja vibracije će dati jasnu identifikaciju oštećenja.
- Vremenski zapis – veoma koristan kod analize oštećenja u ovoj fazi sa obzirom da se periodični udarci i modulacija jasno vide.

Osnovne korektivne mere koje se generalno preporučuju pri detekciji ove faze su momentalna zamena ležaja odnosno, ukoliko to nije moguće njegovo snimanje na nedeljnoj bazi.

Ukoliko se ležaj ne promeni u prethodnoj fazi, oštećenja sa inicijalno oštećene komponente dovode do razvoja oštećenja i u ostalim komponentama ležaja. Usled glačanja ivica useka može doći do smanjenja nivoa sumarnog ubrzanja u visokofrekventnim delovima spektra.

Usled odvajanja materijala sa elemenata ležaja i povećanja zazora u istom dolazi do poremećene geometrije usled čega dolazi do: povećanih nivoa generisane buke, do promene karakterističnih frekvencija ležaja i povećanog nivoa šuma u celom vibracionom signalu.

- Analiza pouzdanosti metoda u detekciji oštećenja u ovoj fazi otkaza daje sledeće zaključke:
- Visokofrekventne metode – veoma nepouzdana kod ove metode usled snižavanja nivoa ubrzanja u visokofrekventnim opsezima.

- Envelopiranje/demodulacija – envelope ubrzanja će veoma jasno ukazivati na oštećenu komponentu ležaja uz povišen nivo šuma na širokom frekventnom opsegu.
- Frekventni spektar – frekventni spektar brzine i ubrzanja vibracije će dati jasnu identifikaciju oštećenja.
- Vremenski zapis – veoma koristan kod analize oštećenja u ovoj fazi sa obzirom da se periodični udarci i modulacija jasno vide.

Osnovna korektivna mera koja se generalno preporučuje pri detekciji ove faze je obavezna i momentalna zamena ležaja.

6. ZAKLJUČAK

Analiza mehaničke vibracije je dokazano najpouzdaniji metod za identifikaciju oštećenja rotirajuće opreme. Uspeh jednoznačne identifikacije oštećenog ležaja u najvećoj meri zavisi od primenjene tehnike procesiranja vibracionog signala snimljenog na kućištu ležaja. Radom je prikazano da ne postoji univerzalna metoda procesiranja signala koja može da isprati lokalizovano i distribuirano oštećenje ležaja od momenta njegovog nastanka do havarije samog ležaja.

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DIJAGNOSTIKA STANJA ELEKTROMOTORA POMOĆU SPEKTRALNE ANALIZE STRUJA

Saša Nikolić¹

Rezime: *Asinhroni motori su najviše korišteni električni pogonski sistemi. Smatra se da industrijski razvijenim zemljama udio elektromotornih pogona sa asinhronim motorima u ukupnoj potrošnji električne energije dostiže i do 50%. Mnogi bitni i skupi industrijski procesi zasnivaju se na elektromotornim pogonima. Svaki neplanirani zastoj procesa proizvodnje prouzrokuje ogromne troškove. Zato je veoma važno da se greške i nedostaci uoče na vrijeme u fazi u kojoj još nije došlo do nepovratnog oštećenja, kako bi se mogao planirati zastoj postrojenja i otkloniti kvar u najpogodnijem trenutku. Ovim se izbjegava šteta od neplaniranog prekida procesa, kao i smanjuju troškovi remonta elektromotora. Metoda koja omogućava dijagnostiku stanja elektromotora i održavanje po stanju zasniva se na spektralnoj analizi struja elektromotora (eng. Motor Current Signature Analysis – MCSA). Svi standardni defekti elektromotora imaju svoj zapis u strujnom spektru. Ovi zapisi su uočljivi u ranoj fazi nastanka defekta i omogućavaju blagovremenu intervenciju prije nego defekt dovede do skupih ili nepopravljivih šteta.*

Ključne riječi: *dijagnostika stanja elektromotora, spektar struja, održavanje po stanju*

MOTOR CURRENT SIGNATURE ANALYSIS TO DETECT FAULT OF INDUCTION MOTOR

Abstract: *Induction motors are the most widely used electric propulsion systems. It is considered that in the industrialized countries the share of electric drive with induction motors in total electricity consumption reaches up to 50%. Many important and expensive industrial processes are based on electrical drives. Any unscheduled downtime of the production process causes enormous costs. It is therefore very important to detect errors and defects during the stage that has not been irreversible damage to the plant could delay the plan to repair the defect at the right time. This avoids costs from unplanned interruption of process, and reduce the costs of overhaul of electric motors. The method allows the diagnosis of the state of electric motors and maintenance by the state based on the spectral analysis of electric currents (Eng. Motor Current Signature Analysis¹ - MCSA). All common motors defect have a record in the power spectrum. These records are found in the early stages of defect formation and facilitate timely intervention before the defect leads to expensive or irreparable damage.*

Keywords: *diagnostics of electric motors, power spectrum, maintenance by the state*

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1. UVOD

Zbog postizanja konkurentnosti na tržištu, prisutan je stalni pritisak da se smanje troškovi održavanja i spriječe neplanirani zastoji u proizvodnji, koji dovode do gubitka proizvodnje, povećanih troškova održavanja, odnosno do finansijskih gubitaka.

Posljednjih godina se koriste online strategije održavanja po stanju. Međutim i kod ovakvog održavanja, operator je taj koji donosi konačnu odluku kad će zaustaviti postrojenje i uvesti ga u remont. Takođe, ovi online monitoring sistemi se uglavnom baziraju na praćenju mehaničkih parametara, odnosno vibracija i analizi spektra vibracija. Kad su u pitanju čisto mehanički sistemi, ovaj pristup daje dobre rezultate. Međutim, kad se radi o velikim sistemima koji sadrže i elektromotor, ovakav pristup nije dovoljan. Naime, može se dogoditi da se mjerenjem vibracija ustanovi neki defekt sistema i pogrešno procijeni uzrok. Tipičan primjer je pojava drugog harmonika u spektru vibracija koji nema mehanički uzrok. Sa druge strane, tačno je da se električni defekti manifestuju kroz pojavu određenih harmonika u spektru vibracija, ali se njihova pojava uglavnom na taj način može otkriti tek kad oštećenje dostigne ozbiljne razmjere.

Suštinska stvar kod spektralne analize struja elektromotora je da svaki kvar elektromotora moduliše fluks motora, stvarajući rotacione komponente fluksa koji dalje proizvode karakteristične strujne komponente. Uočavanjem i izdvajanjem ovih strujnih komponenti, može se detektovati defekt elektromotora kao što je oštećena šipka rotora, međuzavojni spoj namotaja statora ili ekscentricitet rotora. [1]

Defekti koje je moguće detektovati preko komponenti u struji elektromotora su:

- Oštećenje rotorskih šipki;
- Nesaosnost/debalans;
- Labavost osnove;
- Statički ekscentricitet;
- Dinamički ekscentricitet;
- Oštećenje jezgra;
- Labavost klinova;
- Međuzavojni spoj;
- Oštećenje ležajeva;

Spektralna analiza struje motora može detektovati ove defekte u veoma ranoj fazi, sprečavajući dalje sekundarno oštećenje i potpuni otkaz elektromotora.

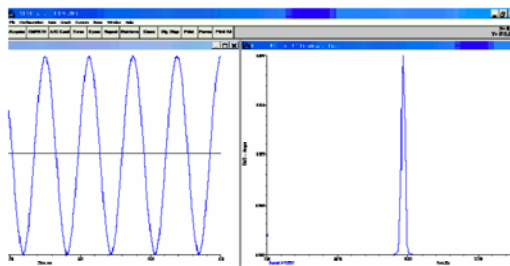
Oštećenje rotorske šipke će se odraziti na vibracioni spektar motora, ali pošto se vibracije tradicionalno mjere na ležajevima i pošto za svaki elektromotor postoji različita mehanička krutost između elektromagnetnih sila izazvanih pucanjem rotorske šipke i mjesta gdje se mjere vibracije, to dodatno usložnjava pokušaj da se kvantitativno definiše nivo oštećenja preko vibracione analize. Vibracije nastale od oštećenja rotorskih šipki je sekundarni efekat i često oštećenje dostigne ozbiljan nivo prije nego što je moguće da se detektuje u spektru vibracija.

Zbog svega ovoga, spektralna analiza struja motora i online monitoring mogu da posluže za kvalitetno praćenje stanja elektromotora i održavanje prema stanju. Ovakav sistem paralelno sa online monitoringom vibracija može da potpuno spriječi neplanirane zastoje elektromotora i time troškove održavanja svede na minimum.

2. TEORIJSKA OSNOVA

Strujni signal elektromotora je u idealnom slučaju prava sinusoida sa učestanosti 50Hz, koja naravno zavisi od učestanosti napojne mreže. Grafički, strujni signal može da se predstavi u vremenskom i u frekventnom domenu.

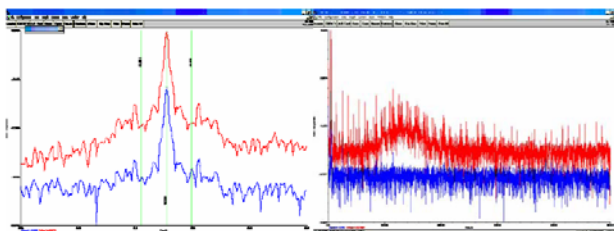
Ovi dijagrami su prikazani na slici 1.



Slika 1. Idealni sinusni signal u vremenskom i frekventnom domenu

Tokom rada motora, u strujnom spektru će se pojaviti više komponenti, odnosno harmonika. Spektar struje će se sastojati od više pikova uključujući komponentu na mrežnoj frekvenciji i njene harmonike. Ovo je poznato kao *Strujni Potpis Motora* (eng. *Motors Current Signature*). Analiza ovih harmonika posle pojačavanja i obrade signala omogućava detektovanje raznih kvarova elektromotora.

Na slici 2. Je prikazan tipičan nisko i visoko frekventni spektar struje i napona ispravnog elektromotora.



Slika 2. Niskofrekventni i visokofrekventni spektar struje i napona ispravnog elektromotora

Određeni harmonici su uvijek prisutni u mrežnom naponu, kao posledica harmonijskog zagađenja mreže. Međutim ovi harmonici su zanemarljivi. Nasuprot tome, drugi harmonici se generišu usled različitih električnih i mehaničkih defekata. Sve greške izazivaju promjenu u unutrašnjoj raspodjeli fluksa, koje dalje generišu harmonike u struji motora.

Treba napomenuti da se u spektru javljaju i međuharmonici, koji se ne mogu detektovati standardnim analizatorima spektra.

Kako se harmonici karakteristični za određene defekte pojavljuju u strujnom spektru a ne i u naponskom, onda se upoređivanjem strujnog i naponskog spektra mogu izdvojiti harmonici koji su posledica defekta a ne zagađenja napajanja.

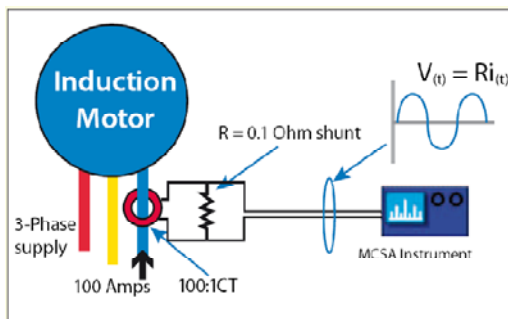
3. ANALIZA STRUJNOG SPEKTRA I DETEKCIJA DEFEKATA

3.1. Potrebna instrumentacija

Osnovni instrumentacioni sistem za mjerenje strujnog spektra sastoji se od:

- Strujnog transformatora CT za mjerenje signala
- Otpornog šanta koji se postavlja na izlaz CT
- Analizatora spektra

Na slici 3. je šematski prikaz osnovne mjerne postavke. [5]



Slika 3. Osnovni instrumentacioni sistem za analizu strujnog spektra

Zavisno od realne situacije u postrojenju, strujni transformator može biti tipa *clip-on* i montira se na jednu fazu motora ili ako u postrojenju već ima ugrađen strujni mjerni transformator, što je obično slučaj kod velikih motora, onda se koristi strujna sonda koja se postavlja na sekundar postojećeg strujnog mjernog transformatora. Napominje se da je dovoljan samo jedan strujni transformator, za analizu spektra samo jedne faze motora. Osnovni razlog za ovo je da svaki defekt proizvodi rotacionu komponentu fluksa koja presijeca sve tri fazna namotaja motora i u njima indukuje odgovarajuću komponentu struje koja reprezentuje pojavu defekta. Za uspješnu spektralnu analizu dovoljni su standardni komercijalni strujni transformatori.

4. PREGLED NAJČEŠĆIH DEFEKATA

4.1. Oštećenje rotorskih šipki

Ovo je jedan u praksi veoma čest tip defekta elektromotora. Ovaj kvar se najčešće javlja usled prevelikog broja direktnih uključenja motora ili previše čestih startova motora. Poznato je da prilikom direktnog starta struja motora dostiže vrijednost pet i više puta veću od nominalne. Ovo izaziva velika termalna i mehanička naprezanja. Direktni start velikih motora je uobičajen u velikim industrijskim postrojenjima, posebno elektranama, jer tamo postoji nezavistan izvor napajanja pa direktni starti ne utiče na druge potrošače. Takođe, kavezni rotor trpi velika naprezanja i prilikom pogona pulsirajućeg mehaničkog opterećenja, kao što su kompresori. Oštećenje rotorske šipke je veoma važno uočiti na vrijeme, dok ne dođe do podizanja šipke iz žlijeba koje obavezno dovodi do velikog ili čak nepopravljivog oštećenja kompletnog motora. Ovaj defekat dovodi do indukovanja komponente u faznoj struji elektromotora koja je data sledećim izrazom.

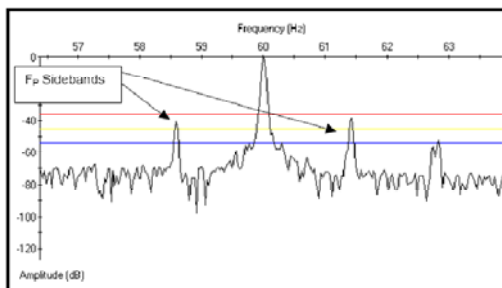
$$f_{sb} = f_1(1 \mp 2s) [Hz] \quad (1)$$

Gdje je f_1 frekvencija napajanja, a s je normalizovano klizanje motora i iznosi

$$s = (N_s - N_r)/N_s \quad (2)$$

N_s je brzina obrtnog magnetnog polja, a N_r je stvarna brzina obrtanja rotora.

Na slici 4. je prikazan primjer strujnog spektra motora sa oštećenom šipkom u rotoru.



Slika 4. Primjer spektra struje motora sa oštećenjem rotora

Dubljom analizom spektra moguće je procijeniti stepen oštećenja rotora, kao i broj oštećenih šipki.

4.2. Dijagnoza ekscentričnosti vazdušnog zazora

Idealan elektromotor ima ravnomjeran vazdušni zazor između rotora i statora. U praksi to najčešće nije slučaj. Ekscentričnost vazdušnog zazora može poticati kako od grešaka u izradi motora i fabričkih tolerancija, tako i od posledica eksploatacije, grešaka pri montaži i slično. Od fabričkih defekata, čest je slučaj ovalnog rotora ili statora, dok se kao posledica grešaka pri montaži, posebno kod velikih motora kod kojih ležajevi nisu postavljeni u poklopcima motora, najčešće javlja nesaosnost rotora i statora.

Razlikuju se statički i dinamički ekscentricitet. Kod statičkog ekscentriciteta minimalni vazdušni zazor se nalazi uvijek na istom mjestu na obodu statora. Nasuprot tome, kod dinamičkog ekscentriciteta, tačka minimalnog vazdušnog zazora se kreće tokom obrtanja rotora.

Komponente u strujnom spektru koje izaziva ekscentričnost vazdušnog zazora su date sledećom jednačinom.

$$f_{sb} = f_1 \left(\frac{R(1-s)}{p} \mp n \right) \mp f_1(1-s)/p \quad (3)$$

Gdje je:

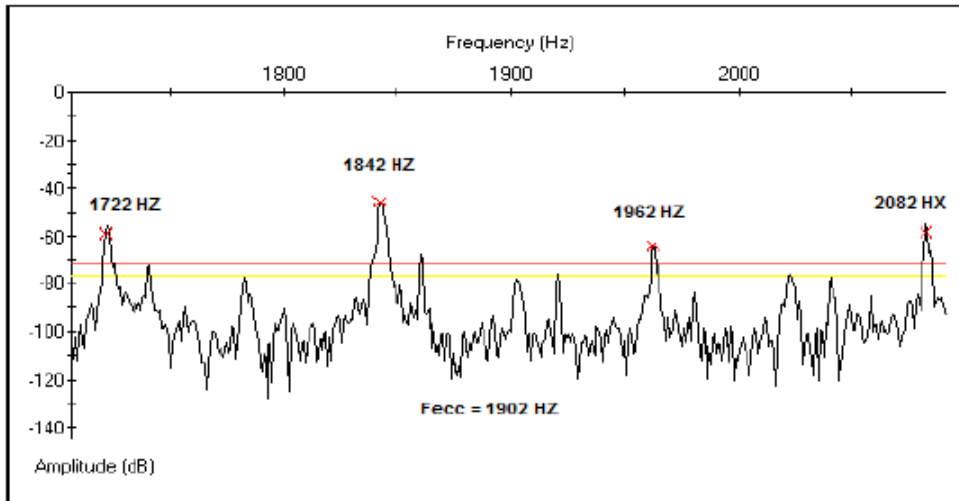
- f_1 - frekvencija napajanja;
- R - broj rotorskih slotova;
- n - koeficijent (1,3,5,...);
- p - broj pari polova;

Proizvođači obično za velike motore dozvoljavaju maksimalnu ekscentričnost rotora od 5%. Kako su zazori u motoru obično mali i iznose par milimetara, to i najmanja greška pri montaži velikih motora može dovesti do značajnih problema vezanih za ekscentricitet. A problem koji izaziva ekscentricitet vazdušnog zazora motora je pojava jake radijalne sile koja je usmjerena u pravcu najmanjeg zazora. Ova sila teži da dodatno približi rotor statoru. Pri ovome opterećenje trpe ležajevi. Vremenom dolazi do oštećenja ležajeva, dodatnog smanjenja zazora i u krajnjem slučaju do zadiranja rotora za stator što može dovesti do potpunog uništenja motora.

Spektralne komponente koje izaziva ekscentricitet a koje su date izrazom (3) se razvijaju oko osnovne frekvencije ekscentriciteta

$$f_{ecc} = R * RPM / f_1 \quad (4)$$

Na slici 5. je prikazan strujni spektar elektromotora sa izraženim ekscentricitetom, gdje su prikazane karakteristične komponente spektra.

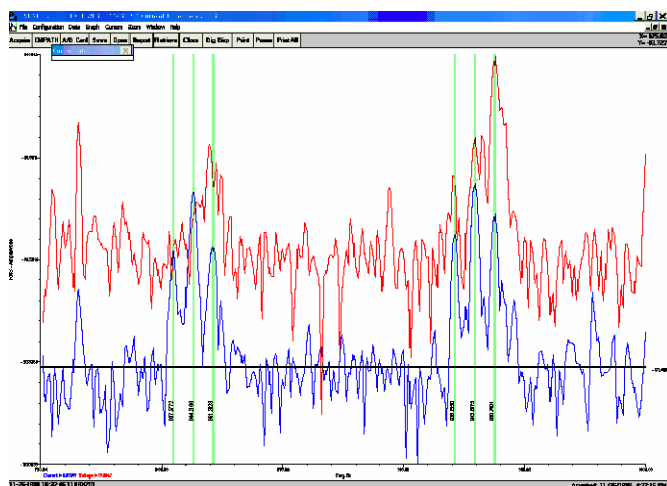


Slika 5. Strujni spektar motora sa ekscentricitetom

4.3. Detekcija međuzavojnog spoja u statoru

Međuzavojni spoj u statorskom namotaju dovodi do prekomjernog zagrijavanja statorskog namotaja i do strujnog debalansa. Ovo dovodi do lokalnog pregrijavanja u motoru, smanjuje izlaznu snagu i eventualno dovodi do zemljospoja. [4]

Na slici 6. je prikazan tipičan spektar struje elektromotora sa međuzavojnim spojem u statorskom namotaju.



Slika 6. Strujni spektar elektromotora sa međuzavojnim spojem

4.4. Detekcija oštećenja pumpe

U praksi je čest slučaj da pumpa ne daje dovoljno protoka. Analizom strujnog spektra može se utvrditi da je uzrok problema pumpa i preduzeti mjere za otklanjanje problema.

4.5. Detekcija oštećenja ležajeva

Svi ležajevi imaju jedinstveni set frekvencija defekata koji definiše proizvođač i koje omogućavaju definisanje defekta. Analizom strujnog spektra i uočavanjem velikih pikova struje na ovim frekvencijama može se definisati mjesto problema (unutrašnja staza, vanjska staza, kuglice, valjci, kavez...).

5. ZAKLJUČAK

Cilj ovog rada je da se skrene pažnja na mogućnosti koje pruža analiza strujnog spektra u određivanju stanja elektromotora i otkrivanja defekata u ranoj fazi kad još nije došlo do skupih ili nepopravljivih kvarova.

Prednost ove metode je da se neinvazivnom putem i u toku rada elektromotora procijeni stanje elektromotora ili detektuje oštećenje i procijeni stepen istog. Prednost ove metode u odnosu na dijagnostiku preko spektra vibracija je da se defekti uočavaju u početnoj fazi, dok nije došlo do progresa. Manifestacija električnih defekata u vibracionom spektru je sekundarni efekat, tako da se pojedini defekti mogu otkriti tek kad oštećenje dostigne značajan nivo.

Analogno *online* monitoringu vibracija može se vršiti *online* monitoring strujnog spektra tako da se na značajnim pogonima postavi analizator spektra koji će pratiti stanje motora i blagovremeno upozoriti na oštećenje. Kombinacijom ova dva sistema mogli bi se u potpunosti izbjeći neplanirani zastoji te gubici zbog zastoja proizvodnje i troškovi održavanja svesti na minimum.

Kako se svi defekti motora odražavaju na pojavu rotacionih komponenti fluksa, primjenom adekvatnih modela motora i korekcionih algoritama, moglo bi se aktivno djelovati na redukciju posledica defekta. Ovo se prije svega odnosi na redukciju

radijalne sile UMP kod ekscentriciteta motora i redukciju vibracija usled električnog defekta. Princip bi se zasnivao na blagovremenom uočavanju defekta, upozoravanju operatera i aktiviranju korektivnog algoritma koji bi omogućio rad pogona do prvog planiranog zastoja. S obzirom na sve veću primjenu regulisanih električnih pogona (frekventnih regulatora), neki od ovakvih korekcionih algoritama bi se mogao lako implementirati u softveru pogona i tako bez dodatnih troškova značajno pomoći u smanjenju cijene održavanja i izbjegavanju neplaniranih zastoja.

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INTEGRISANI PRISTUP STRUKTURNOJ OPTIMIZACIJI U CAD SOFTVERU

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Rezime: U ovom radu predstavljen je integrisani pristup strukturnoj optimizaciji prilikom konstruisanja mašinskih elemenata i sklopova. Ideja se sastoji u integraciji proračuna metodom konačnih elemenata tokom geometrijskog definisanja modela. U radu je predstavljena postupak definisanja problema integrisanog pristupa strukturnoj optimizaciji, definisanje modela, priprema modela za strukturnu analizu, sama strukturna analiza metodom konačnih elemenata, postupak optimizacije i primer. Primenom jednog ovakvog pristupa u ranom periodu razvoja konstrukcije moguće je identifikovati konstruktivne nedostatke. Shodno tome, moguće je izvršiti korekciju konstrukcije do postizanja optimalnih osobina. Takođe, moguće je razvijati više konstruktivnih varijanti, dovoljnom brzinom izvođenja strukturnih analiza, i u zavisnosti od funkcija cilja odabrati najpovoljnije rešenje po jednom ili više kriterijuma. Integrisani pristup strukturnoj optimizaciji u jednom softveru štedi vreme i novac.

Ključne riječi: CAD, MKE, strukturna optimizacija

INTEGRATED APPROACH TO STRUCTURAL OPTIMIZATION IN CAD SOFTWARE

Abstract: *This paper presents an integrated approach to structural optimization in the design of machine elements and assemblies. The idea is to integrate calculation by finite elements method during geometrical defining of the model. The paper presents the procedure of defining of the problem of integrated approach to structural optimization, defining of the model, preparation of the model for structural analysis, structural analysis according to finite elements method, optimization process and an example. By applying such an approach in the early phase of the development of a structure it is possible to identify deficiencies of a structure. According to that, it is possible to correct the structure until optimal characteristics are achieved. Likewise, it is possible to develop several versions of a structure, with sufficient speed of performing of structural analyses and, depending on objective functions, it is possible to choose the most suitable solution according to one or more criteria. Integrated approach to structural optimization in single software saves time and money.*

Keywords: CAD, FEA, structural optimization

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1. UVOD

Teoretske mogućnosti primene računara u projektovanju i konstruisanju su gotovo neograničene. Računar se uspešno koristi za obavljanje: proračuna, izradu crteža, sprovođenje raznih simulacija, optimizaciju i sl. Savremeni postupci u konstruisanju se svode na integraciju proračuna (simulacija, optimizacija, analiza napona, dinamike) u toku geometrijskog modeliranja. U današnje vreme, pri projektovanju i konstruisanju, takvu analizu i sintezu omogućavaju visoko sofisticirani programski alati. Problem strukturne optimizacije još uvek nije dovoljno istražen i predstavlja izazov koji obećava [1].

Numeričku optimizaciju baziranu na modelu konačnih elemenata pokrenuo je L.Schmit zajedno sa grupom studenata ranih šezdesetih godina prošlog veka. U početku, ove metode su korišćene za rešetkaste konstrukcije u građevinarstvu, gde su promenljive veličine bile površine poprečnog preseka. Kasnije, ove promenljive su generalizovane na dimenzije poprečnog preseka greda i debljine ploča. [2]

Primer strukturne optimizacije (optimizacija dimenzija, oblika i topologije) u CAD okruženju prikazan je u radu [3]. Od velike važnosti u toku postupka optimizacije je izbor metode i algoritma [4]. U ovom radu korišćen je algoritam simulacije kaljenja. Moguće je sprovesti optimizaciju skoro svih mašinskih elemenata u zavisnosti od ograničenja i funkcije cilja. Tako je na primer u radu [5] prikazana optimizacija zupčastih prenosnika.

Optimizacijom se teži minimizaciji negativnih efekata (napora, troškova, itd.) i/ili maksimizaciji pozitivnih efekata (dobiti) [4]. Takođe je moguće optimizovati proces proizvodnje [6].

U ovom radu predstavljen je integrisani postupak optimizacije počevši od definisanja modela, pripreme modela za strukturnu analizu, preko strukturne analize i same optimizacije. Na kraju rada dat je primer optimizacije rezervoara.

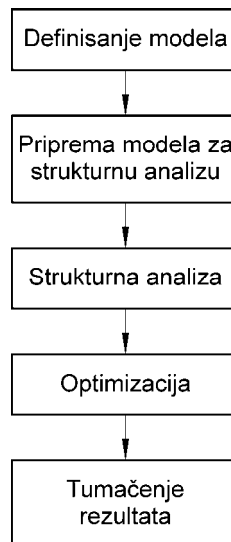
2. DEFINICIJA PROBLEMA

Da bi postupak integrisane strukturne optimizacije bilo moguće sprovesti neophodno je ispoštovati određenu proceduru koja se sastoji od nekoliko koraka. Prvo je neophodno parametarski definisati model, kako bi u kasnijoj fazi bilo moguće upravljanje tim parametrima u smislu dobijanja optimalnog rešenja. Takođe tom parametarskom modelu neophodno je dodeliti određeni materijal kako bi karakteristike materijala bile uključene u analizu. Funkcija cilja može biti izbor optimalnog materijala. U tom slučaju se na osnovu svih ostalih parametara bira materijal koji ima najbolje karakteristike bilo da se radi o mehaničkim karakteristikama, ceni, ili nekom drugom pokazatelju.

Nakon definisanja modela neophodno je pripremiti model za strukturnu analizu. Priprema modela se odnosi na diskretizaciju modela na konačne elemente, definisanje oslonaca i ograničenja. Prilikom strukturne analize neophodno je definisati vrstu analize, izabrati metod za rešavanje dobijenih jednačina i samo rešavanje jednačina. Nakon ovoga sledi optimizacija i tumačenje rezultata kao što je prikazano na slici 1.

3. DEFINISANJE MODELA

Strukturna analiza metodom konačnih elemenata započinje najpre izradom geometrijskog modela. U zavisnosti od složenosti, geometrijski model može biti linijski, površinski i prostorni. Odgovarajući model se može napraviti u okviru grafičkog interfejsa samog programa za strukturnu analizu. Takođe model može biti napravljen u



Sl.1 Postupak integrisane strukturne optimizacije

CAD softveru a onda povezan sa programom za analizu konačnim elementima. CATIA nudi mogućnost definisanja geometrije dela, nakon čega sledi strukturna analiza mašinskog dela i na kraju postupak optimizacije. Bez obzira u kom programu se vrši geometrijsko modeliranje, pri dimenzionisanju i postavljanju relacija karakterističnih oblika u okviru modela, neophodno je voditi računa o tome u kom kontekstu će kasnije taj model biti korišćen. Ovo je posebno važno za modele koji će kasnije biti korišćeni u postupku optimizacije, jer je potrebno obezbediti nesmetanu varijaciju parametara, a da se pri tome ne naruši koncept geometrije, a u slučajevima poznate topologije i sama topologija.

4. PRIPREMA MODELA ZA STRUKTURNU ANALIZU

Posle definisanja početne geometrije, sledeći korak u strukturnoj analizi, odnosno strukturnoj optimizaciji jeste priprema modela za analizu. Prvo što treba definisati jeste materijal modela. Moguće je izabrati materijal iz već postojeće biblioteke materijala koju sadrže CAD softveri. Takođe je moguće napraviti novi materijal i dodati ga u bazu podataka.

Da bi bilo moguće izvršiti statičku analizu, neophodno je definisati ograničenja kretanja odgovarajućih delova modela pomoću adekvatnog izbora oslonaca. Na ovaj način sprečava se da deformabilno telo pod dejstvom spoljašnjeg opterećenja počne da se kreće kao kruto telo. Prilikom uvođenja ograničenja kod svakog izabranog geometrijskog entiteta, treba definisati mogući broj stepeni slobode kretanja, u odnosu na usvojeni koordinatni sistem. Prilikom izbora mesta i načina oslanjanja neophodno je voditi računa o tome da oslanjanje u tački ili po liniji može da izazove koncentraciju napona i teoretski beskonačno veliko naprezanje u konačnim elementima, koji su direktno izloženi opterećenju. Takođe izbor i način mesta oslanjanja je izuzetno bitan, jer se na njima generišu sile i momenti reakcije, usled dejstva spoljašnjih opterećenja. Pored toga što je potrebno definisati način i mesto oslanjanja, neophodno je i definisati

spoljašnja opterećenja koja deluju na model.

Analiza metodom konačnih elemenata zahteva izbor konačnih elemenata koji adekvatno opisuju ponašanje mašinskog dela pri dejstvu spoljašnjih opterećenja. Da bi se obezbedila numerička stabilnost i konvergencija rešenja strukturne analize, neophodno je pravilo izabrati tip konačnih elemenata, uz adekvatno definisanje graničnih uslova u fazi modeliranja. Prilikom diskretizacije deformabilnog tela konačnim elementima, moguće je izabrati jednu vrstu konačnih elemenata ili upotrebiti njihovu kombinaciju u zavisnosti od vrste problema. Određivanje broja konačnih elemenata međusobno povezanih zajedničkim čvorovima, kojima se domen kontinuuma modela deformabilnog tela aproksimacijom diskretizuje na mrežu konačnih elemenata, predstavlja najvažniji korak, kojim se direktno utiče na numeričku stabilnost i konvergenciju rešenja strukturne analize. [7]

Nakon definisanja prethodno navedenih karakteristika sledi kreiranje mreže, koje je u većini savremenih programskim paketa automatsko. Automatski kreirana mreža nije uvek povoljna za proračun, pa postoje načini da se ona poboljša, u zavisnosti od kompleksnosti i zakrivljenosti geometrije modela, uz uzimanje u obzir postojanja i ostalih geometrijskih entiteta izraženih u promeni forme usled otvora, žljebova, ispupčenja, zaobljenja, nagiba, suženja ili proširenja.

5. STRUKTURNA ANALIZA

Formiranjem diskretnog modela stvaraju se uslovi za pokretanje strukturne analize u cilju istraživanja ponašanja modela, pri zadatoj kombinaciji opterećenja i graničnih uslova [8]. Na ovaj način moguće je dobiti informacije o tome u kojoj meri će materijal izdržati naprezanja kome je deo izložen, hoće li doći do pojave loma (analiza napona), gde će se javiti lom (analiza deformacija), koliko će početni oblik pretrpeti promene (analiza pomeranja), kolike su reakcije na mestima oslanjanja i drugo. Pravci napona na kojima je u posmatranoj tački materijala smičući napon jednak nuli, zovu se glavni pravci napona. U slučaju ravanskog naprezanja postoje dva glavna pravca. U opštem slučaju prostornog naprezanja postoje tri međusobno upravna glavna pravca napona u svakoj tački. Glavni naponi kod prostornog stanja napona mogu se napisati u sledećem obliku [9]:

$$\sigma_1 = \frac{I_1}{3} + \frac{2}{3} \left(\sqrt{I_1^2 - 3I_2} \right) \cos \alpha, \quad (1)$$

$$\sigma_2 = \frac{I_1}{3} + \frac{2}{3} \left(\sqrt{I_1^2 - 3I_2} \right) \cos \left(\alpha + \frac{2\pi}{3} \right), \quad (2)$$

$$\sigma_3 = \frac{I_1}{3} + \frac{2}{3} \left(\sqrt{I_1^2 - 3I_2} \right) \cos \left(\alpha + \frac{4\pi}{3} \right), \quad (3)$$

gde su

$$\alpha = \frac{1}{3} \arccos \left(\frac{2I_1^3 - 9I_1I_2 + 27I_3}{2(I_1^2 - 3I_2)^{2/3}} \right) \text{ i} \quad (4)$$

$$I_1 = \sigma_x + \sigma_y + \sigma_z, \quad (5)$$

$$I_2 = \sigma_x \sigma_y + \sigma_y \sigma_z + \sigma_z \sigma_x - \tau_{xy}^2 - \tau_{yz}^2 - \tau_{zx}^2, \quad (6)$$

$$I_3 = \sigma_x \sigma_y \sigma_z - \sigma_x \tau_{yz}^2 - \sigma_y \tau_{zx}^2 - \sigma_z \tau_{xy}^2 + 2\tau_{xy} \tau_{yz} \tau_{zx}. \quad (7)$$

Veličine I_1, I_2, I_3 su poznate kao invarijante napona. Za određivanje stepena sigurnosti konstrukcije koristi se Fon Mizesov napon (jednačina (8)).

$$\sigma_{VonMises} = \sqrt{I_1^2 - 3I_2} \quad (8)$$

Zamenom jednačina (1) do (7) u jednačini (8) dobija se:

$$\sigma_{VonMises} = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2 - \sigma_x \sigma_y - \sigma_y \sigma_z - \sigma_z \sigma_x + 3\tau_{xy}^2 + 3\tau_{yz}^2 + 3\tau_{zx}^2} \quad (9)$$

Senzor je fizička veličina koja predstavlja izlaz iz proračuna i opciono može da bude ograničen na određenu oblast. Senzori „mere“ posmatranu veličinu i omogućavaju da se ta veličina dalje koristi u modulu za optimizaciju. U CATIA-i postoje dve vrste senzora globalni i lokalni. Globalni senzori koji mogu biti korišćeni u postupku optimizacije su: energija (Energy), greška u energiji (Error in Energy), globalna greška (Global Error Rate (%)), maksimalno pomeranje (Maximum Displacement), maksimalni Fon Mizesov napon (Maximum Von Mises) i masa (Mass). Dostupni lokalni senzori u CATIA-i su: amplituda pomeranja (Displacement Magnitude), vektor pomeranja (Displacement Vector), Fon Mizesov napon (Von Mises Stress), greška (Error), tenzor napona (Stress Tensor), glavno smicanje (Principal Shearing), tenzor glavnog napona (Principal Stress Tensor), tenzor glavne deformacije (Principal Strain Tensor), tenzor deformacije (Strain Tensor), sila (Force) i energija elastične deformacije (Elastic Energy).

6. OPTIMIZACIJA

Nakon statičke analize sprovedene na prethodno definisan način, može se zaključiti da li analizirano konstruktivno rešenje ispunjava postavljene zahteve ili ne. Međutim, i kada analiza da zadovoljavajuće rezultate, proces projektovanja treba da se nastavi, jer skoro je sigurno da rešenje, dobijeno na taj način, ne predstavlja optimalnu konstrukciju u tom okruženju. Modulima za optimizaciju, koje poseduju savremeni programi, automatizuje se proces traženja optimalnih vrednosti parametara. Bez automatizovanog procesa, svi koraci od kreiranja nove strukturne analize sa razvijanjem modela za analizu, diskretizacije modela na konačne elemente i analize rezultata, morali bi da se ponove za svaku promenu parametra. Svi ovi koraci u CATIA – i se izvršavaju simultano, izborom odgovarajućeg optimizacionog algoritma, u cilju obezbeđivanja ciljne funkcije optimizacionog procesa, variranjem izabranih parametara do ispunjavanja zadatih graničnih uslova, koje optimalna konstrukcija treba da zadovolji.

Da bi se sproveo postupak optimizacije potrebno je proći kroz nekoliko faza: izbor optimizacionog algoritma, definisanje funkcije cilja, zadavanje graničnih uslova,

određivanje optimalne konstrukcije varijacijom parametara.

Od izbora algoritma u mnogome zavisi tačnost i konvergencija rešenja. U programskom paketu CATIA postoji mogućnost izbora pet različitih algoritama i to: lokalni algoritam za ograničenja i prioritete (Local Algorithm For Constraints and Priorities), algoritam simulacije kaljenja (Simulated Annealing Algorithm), algoritam za ograničenja i karakteristike koje imaju izvode (Algorithm for Constraints & Derivatives Providers), gradijentni algoritam bez ograničenja (Gradient Algorithm Without Constraint) i Gradijentni algoritam sa ograničenjima (Gradient Algorithm With Constraint(s)) [10]. U ovom radu korišćen je algoritam simulacije kaljenja. Više o algoritmu simulacije kaljenja može se pronaći u literaturi [11-14].

7. PRIMER

U primeru prikazan je rezervoar čiji je početni oblik cilindar prečnika d , visine L , debljine oboda t_1 i debljine čeonog dela t_2 . Zadata unutrašnja zapremina cilindra je $40dm^3$. U unutrašnjosti rezervoara deluje pritisak od $p=10MPa$. Optimizacija posmatranog primera rađena je u softverskom paketu CATIA. U prvom koraku određuje se optimalni odnos parametara d i L tako da se dobije najmanja zapremina koju zauzima materijal, tj. masa rezervoara. Dolazi se do zaključka da parametri d i L teže da se izjednače. Početne vrednosti parametara su $d=300mm$ i $L=565.884mm$, dok je vrednost zapremine koju zauzima materijal $V_m=10.966dm^3$. Posle optimizacije vrednosti parametara su se izjednačile, tako da sada iznose $370.672mm$. U ovom koraku smanjenje zapremine $V_m=10.519dm^3$ nije relevantno jer nije uziman u obzir napon.

U drugoj fazi optimizacije funkcija cilja je minimalna zapremina koju zauzima materijal (masa rezervoara) dok su promenljive debljina t_1 i t_2 . Početne vrednosti debljina su $t_1=t_2=15mm$, dok su ograničenja $V_u=40dm^3$, $\sigma_{VM}\leq 250MPa$. Posle postupka optimizacije dolazi se do sledećih vrednosti debljina $t_1=10.244mm$ i $t_2=19.032mm$ uz ograničenje da Fon Mizesov napon ne pređe $250MPa$. To je i logično jer čeonni deo trpi veće opterećenje od oboda. Zapremina koju zauzima materijal smanjena je na $V_m=9.104dm^3$.

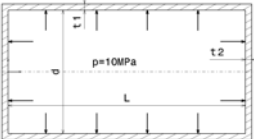
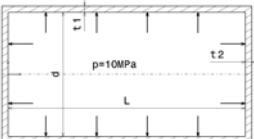
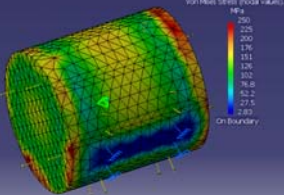
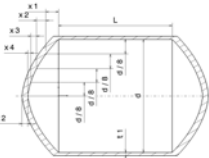
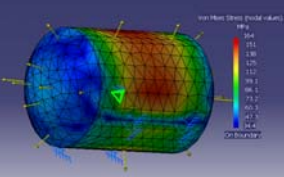
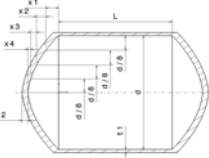
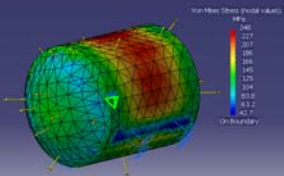
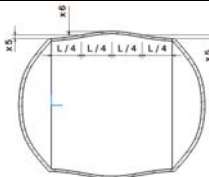
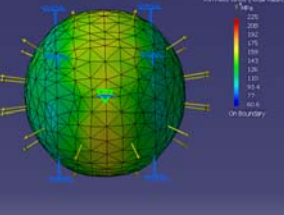
Pošto je čeonni deo opterećeniji u sledećoj fazi izvršice se optimizacija oblika čeonog dela. Promenljive veličine su d , L , x_1 , x_2 , x_3 , x_4 . Ograničenja su $38\leq V_u\leq 40dm^3$, $\sigma_{VM}\leq 250MPa$. Zapremina koju zauzima materijal rezervoara se smanjila na $V_m=8.926dm^3$.

Posle ovog postupka optimzacije može se uočiti da je napon dosta ispod dozvoljene granice. Kao promenljive veličine uzimaju se parametri d , L , t_1 , t_2 . U ovoj fazi optimizacije ukupna zapremina koju zauzima materijal smanjena je na $V_m=4.833dm^3$.

Može se primetiti da je napon po obodu dosta veći od napona u čeonom delu. Iz tog razloga na kraju se vrši optimizacija oblika oboda rezervoara. U ovoj fazi optimizacije promenjen je način oslanjanja kako bi se omogućila nesmetana promena oblika oboda rezervoara. Nakon ovog postupka optimizacije dolazi se do oblika koji je blizak lopti što je i logično. Ukupna zapremina je smanjena na $V_m=4.526dm^3$.

U tabeli 1 prikazane su skice na kojima mogu da se vide gore pomenuti parametri, naponsko stanje i oblik rezervara po izvršenim pojedinim fazama optimizacije, promenljive, ograničenja, funkcije cilja i Fon Mizesov napon.

Tabela 1 Prikaz rezultata

Skica	Naponsko stanje	1. Parametri 2. Opterećenje 3. Funkcija cilja	Zapremina koju zauzima materijal, Fon Mizesov napon
		1. d, L 2. $p=10MPa$ 2. $V_v=40dm^3$ 3. najbolji odnos d, L	$V_m=10.519dm^3$
		1. t_1, t_2 2. $p=10MPa$ 3. $V_v=40dm^3$ $\sigma_{VM} \leq 250MPa$ 4. V_m	$V_m=9.104dm^3$ $\sigma_{VM}=250MPa$
		1. $d, L, x_1, x_2, x_3, x_4,$ 2. $p=10MPa$ 3. $38 \leq V_v \leq 40dm^3,$ $\sigma_{VM} \leq 250MPa$ 4. V_m	$V_m=8.926dm^3$ $\sigma_{VM}=164MPa$
		1. d, L, t_1, t_2 2. $p=10MPa$ 3. $38 \leq V_v \leq 40dm^3,$ $\sigma_{VM} \leq 250MPa$ 4. V_m	$V_m=4.833dm^3$ $\sigma_{VM}=248MPa$
		1. x_5, x_6 2. $p=10MPa$ 3. $38 \leq V_v \leq 40dm^3,$ $\sigma_{VM} \leq 250MPa$ 4. V_m	$V_m=4.526dm^3$ $\sigma_{VM}=225MPa$

8. ZAKLJUČAK

Primenom ovakvog pristupa u ranom periodu razvoja konstrukcije identifikuju se nedostaci. Shodno tome, vrši se korekcija konstrukcije do postizanja optimalnih osobina. Moguće je istovremeno razvijati više konstruktivnih varijanti, dovoljnim brzinama izvođenja strukturnih analiza, i zavisno od ciljeva odabrati najpovoljnije rešenje. Matematička optimizacija ne može uspešno da reši sve probleme koji se javljaju u toku postupka projektovanja, ali može da posluži za određivanje optimalnih dimenzija, oblika i topologije konstrukcije. Bez postupka optimizacije projektant bi

mogao samo na osnovu intuicije i iskustva da vrši varijaciju pojedinih parametara, kako bi se približio optimalnom rešenju. Metodama optimizacije obezbeđuje se automatska promena modela posle svakog koraka proračuna, dok se metodom konačnih elemenata vrši ponovna analiza svojstava konstrukcije koja omogućava ocenu njenih funkcionalnih svojstava u procesu optimizacije i konvergenciju ka optimalnom rešenju. Može se reći da se metode optimizacije i metoda konačnih elemenata međusobno nadograđuju i upotpunjavaju.

U primeru pokazan je postupak optimizacije dimenzija i oblika rezervoara. Cilj optimizacije bio je smanjenje zapremine koju zauzima materijal, tj. mase rezervoara. Početni oblik rezervoara bio je cilindar. Tokom postupka optimizacije oblik je promenjen iz cilicndričnog u sferni. Pokazalo se, a to je i logično, da je sferni oblik rezervoara idelan. Zapremina koju zauzima materijal (masa rezervoara) smanjena je sa $V_m=10.519dm^3$ na $V_m=4.526dm^3$.

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THERMO-MECHANIC ANALYSIS OF CEMENT TRANSPORT WAGON - IDENTIFICATION OF THE CAUSE OF CRACKS

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Miroslav Milutinović⁵

Summary: *The paper represents a solution example of a specific engineering problem using thermo-mechanical analysis. The paper provides theoretical basis of numerical solving the problem of heat conducting through continuum using the finite element method. Calculation of heat conducting using the finite element method determines the temperature field used as an input for thermo-mechanical calculation. The basic task of thermo-mechanical calculation was the identification of the cause of cracks on the powder material transport wagon. After the analysis of the wagon crack causes, repair of the cracks is suggested. Repeating of the FEM analysis on the reconstructed model confirms that the wagon satisfies the criteria of static and fatigue strength appointed by the standards.*

Key words: *heat conducting, FEM analysis, cracks, wagon strength*

1. INTRODUCTION

Modern constructions of various purposes as a rule represent a combination of thin-wall elements such as shells, plates or beams being under the influence of different type of loads. Some of these loads have a completely defined character and elaborate methods of calculations. Use of software for integrating of differential equations enabled solving numerous practical examples of continuum mechanics.

Finite element method – FEM represents the most general numerical method being unavoidable in solving scientific and practical examples in almost all the fields of the science and technics. FEM is today successfully used for solving the problem of physical quantities such as heat conducting, heat and mass transfer, fluid mechanics, electrotechnics and other.

The paper presents theoretical bases of numerical solving the problem of heat conducting through continuum using the finite element method. FEM analysis identifies the main causes of cracks on powder material transport wagon. Constructive solutions of crack repair are offered as well. Thermo-mechanical calculation of the strengthened

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construction should confirm that such strengthened construction satisfies the criteria of static and dynamic strength.

2. THEORETICAL BASES

Differential equation of the energy balance is based on the fundamental conservation of energy principle. Namely, change of the inner material energy in the unit of time, in elementary volume, is equal to the quantity of heat energy accumulated in that same volume in the unit of time, or it is valid for [1].

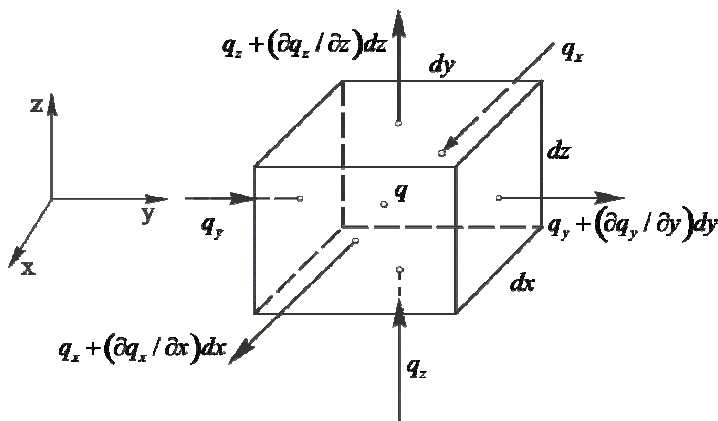
$$\frac{dQ}{dt} = \frac{dU}{dt} \quad (1)$$

Where dQ and dU are changes of the heat and inner energy in the volume dV in elementary time interval dt . Change of the inner energy can be formulated as:

$$\frac{dU}{dt} = \rho C_p \frac{dT}{dt} dV \quad (2)$$

where: ρ – material density, C_p – specific heat, a T – temperature. Using figure 1, dQ/dt can be formulated as:

$$\begin{aligned} \frac{dQ}{dt} = & \left(q_x + \frac{\partial q_x}{\partial x} dx - q_x \right) dydz + \left(q_y + \frac{\partial q_y}{\partial y} dy - q_y \right) dx dz + \\ & \left(q_z + \frac{\partial q_z}{\partial z} dz - q_z \right) dx dy - q dV \end{aligned} \quad (3)$$



Sl.1 Elementary volume dV with heat flux components

where q_x, q_y and q_z are the components of heat flux vector. These components represent the heat quantity, which in the unit of time passes through the unit surface. Power of heat source q represents the heat quantity in the unit of time and unit of volume. In the equation (3) signs of flux components are considered. Positive sign corresponds to the positive flux projection on the direction of the outer normal unit

vector on the surface whereas negative flux through the surface corresponds to the accumulation of heat energy dV . It is considered that $q > 0$ if there is a heat source in the volume dV (in the point of the material), but $q < 0$ in the case of the heat sink.

Heat conduction through continuum is defined by Fourier's law of heat conduction:

$$q_i = -\lambda_i \frac{\partial T}{\partial x_i} \quad i = 1, 2, 3 \quad (4)$$

where λ_i , or λ_x , λ_y and λ_z , are coefficients of heat conduction in the case of orthotropic material. In the case of isotropic material, the following is valid:

$$\lambda_x = \lambda_y = \lambda_z = \lambda \quad (5)$$

Replacing (2) and (3) in the equation of energy balance (1) and using (4), differential equation for isotropic material obtains the following form:

$$-\rho C_p \frac{dT}{dt} + \sum_{j=1}^3 \frac{\partial}{\partial x_j} \left(\lambda_j \frac{\partial T}{\partial x_j} \right) + q = 0 \quad (6)$$

In the practical problem solving it is the solution for the temperature field $T(x, y, z, t)$ that is searched for satisfying given initial and boundary conditions and representing a unique solution. Initial conditions are given only for unsteady problems and they mean that temperature distribution at the initial moment $t = 0$ is known:

$$T(x, y, z, 0) = f_0(x, y, z) \quad (7)$$

Boundary conditions can be:

- given fluxes on the contact surface:

$$q_n = q_n(x, y, z, t) \quad (8)$$

- given heat convection:

$$q_h = h(T_0 - T_s) \quad (9)$$

Temperature T_s is surface temperature, T_0 is environment temperature, h is coefficient of convection. Using Galerkin method, differential equation (6) transforms into the equation of construction balance whose solving is presented in references [1-3].

3. PROBLEM DESCRIPTION

The analysis subject is the wagon used for powder material transport. Regarding the construction, manufacture and equipment, the wagon corresponds to the valid regulations defining this field: UIC, RIV and DIN.

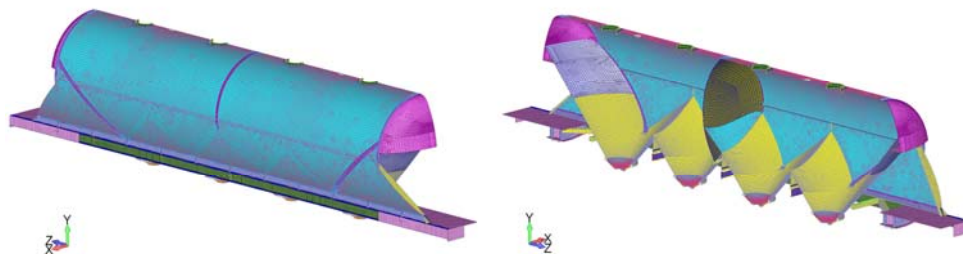
Visual examination of the powder material transport wagon reveals the cracks on the joint of the first and fourth tank with the longitudinal girder (figure 2). Prior to the reconstruction, the strength of wagon was analyzed in order to determine the types of load present in exploitation conditions causing the cracks. Due to that reason, all the combinations present in exploitation conditions of the wagon were analyzed.



Sl.2 Observed cracks on the construction

4. FEM MODEL DESCRIPTION

Wagon was modeled by using the software Femap [4], whereas the analysis was done in the software PAK MULTIPHYSICS [3] based on the finite element method. In accordance with the type of the construction shell elements of appropriate thickness and 3D finite elements were used to create finite element mesh. 3D elements were used for modeling the support plate, relief ring and flange. Apart from the loads present in exploitation conditions, dead load of the wagon was considered as well. The construction was modeled in details with 60408 elements and 61176 nodes. For result presentation and better clarity, we used the half a model mesh without bogies (figure 3). Colors on figure 3 correspond to different thicknesses of shell elements.



Sl.3 FEM model of wagon half

5. CALCULATION VARIATIONS AND CRITERIA

In order to determine the cause of the wagon cracks in exploitation conditions, analyses of the wagon in all load combinations appearing in exploitation conditions were done. Performed calculations are:

- thermo-mechanical calculation of the wagon during filling with heated cement
- thermo-mechanical calculation of the wagon loaded with cement of 50°C temperature, in motion
- calculation of dynamic strength due to the vertical load
- calculation of the wagon during motion in a curve
- calculation of the wagon during braking

Thermo-mechanical calculation of the wagon during filling

Wagon is filled with cement up to the height of filling corresponding to the maximum allowed loading capacity of the wagon, 64.5t. Cement density is 1400kg/m^3 . On the inner model side, which is in contact with cement, temperature increase is given corresponding to the temperature difference between the cement and surrounding. Three calculations were done with given temperature increases of 50°C , 80°C and 100°C . These temperature increases were used considering that the cement temperature ranges from 50°C to 80°C , and the temperature operating mode of the wagon is from -20°C to 50°C . The calculation of the heat conducting was done first to determine the temperature field on the whole wagon and then, the temperature field was used in thermo-mechanical calculation to determine thermal strains. It was given for the heat on the wagon top to be dissipated by convection whereas the heat transfer coefficient $h=10\text{ W/m}^2\text{K}$ and heat conducting coefficient $k=45\text{ W/mK}$ were used. The coefficient of linear expansion is given as $\alpha=12,6\cdot 10^{-6}\text{1/K}$.

Thermo-mechanical calculation of the wagon loaded with 50°C temperature cement during transport

Thermo-mechanical calculation during filling determined a significant influence of temperature increase on stresses. For that reason, the calculation of dynamic strength due to the vertical load of heated cement was done. It was adopted that the heated cement causes the temperature increase of 50°C , as it was stated on the wagon. Also, in this case, vertical loads are increased for 1.3 times (30%), in order to include both thermal loads and dynamic loads during transport [6,7].

Calculation of dynamic strength due to the vertical load

According to the standards TSI [5] and BS EN 12663:2000 [6], calculation of dynamic strength of freight car wagons due to the vertical load is done in the case of maximum allowed vertical load increased for 1.3 times (30%), in order to include dynamic loads during transport [6].

Based on the technical characteristics of the wagon, maximum vertical wagon load is obtained as the sum of maximum capacity of 64.5t and dead wagon load. Cement load of density 1400kg/m^3 is given by using the pressure effective up to the height of filling.

Calculation of the wagon during motion in a curve

According to the technical wagon characteristics, maximum velocity of the wagon with maximum vertical load is 100km/h , whereas the minimum radius of curve is 250m . Load of cement of density 1400kg/m^3 is given through hydrostatic pressure up to the height of filling, whereas the effect of inertial forces is considered by giving the adequate horizontal acceleration in the radial direction [6].

Calculation of the wagon during braking

According to the technical wagon characteristics, maximum velocity of the wagon with maximum vertical load is 100km/h , whereas the stopping distance when braking is 700m . Load of cement of density 1400kg/m^3 is given through hydrostatic pressure up to the height of filling. Also, in this case, inertial forces are considered by giving the adequate horizontal acceleration in the longitudinal direction.

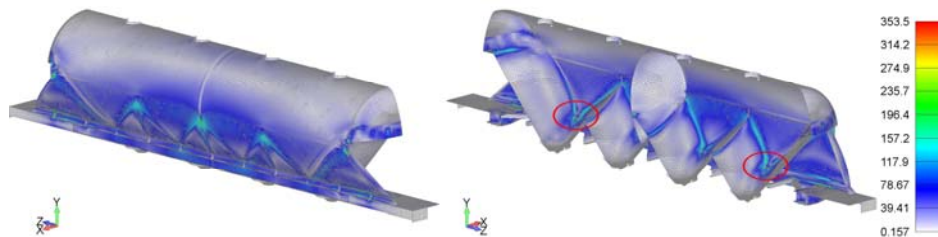
6. CALCULATION RESULTS BEFORE RECONSTRUCTION

The analyses were done for all the variations of load defined in the previous chapter. Results are presented only for the most favorable combinations of load as a base for identification of the causes of cracks on the joint of the first and fourth tank with the longitudinal girder.

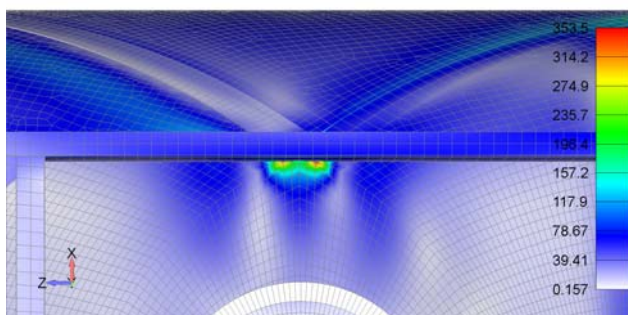
Thermo-mechanical calculation of the wagon during filling with 100°C temperature increase

Three calculations were done with the temperature increases of 50°C, 80°C and 100°C on the inner surface of the tank in contact with warm cement. Heat conduction calculation was done in order to determine the temperature field on the whole wagon and then, the temperature field was used in thermo-mechanical calculation for thermal strain determination.

Effective stress field for the case of 100°C temperature increase, is presented on the figure 4. Zone of maximum stress value is presented on the figure 5.



SI.4 Effective stress field on the wagon half



SI.5 Effective stress field on the welding of the first tank and longitudinal girder

Maximum effective stress value is 353.5MPa being on the welding of the first tank for the longitude girder as seen on the figures 5 and 4, (marked details). Obtained stress is above allowed stress in the case of the static load [5-6]. Crack on this spot from the inner side is presented on the figure 2 to the right whereas the welding spot from the outer side is seen on the figure 2 to the left.

According to the obtained values, it can be concluded that the load in the case of high temperature increases has a significant influence on appearing of the cracks on the joint of the first and fourth tank with the longitudinal girder, (figure 2).

7. RECONSTRUCTION AND CALCULATION RESULTS OF THE RECONSTRUCTED WAGON

According to the analysis of the stress and strain cause of cracks on the joint of the tank and longitudinal girder are thermal loads.

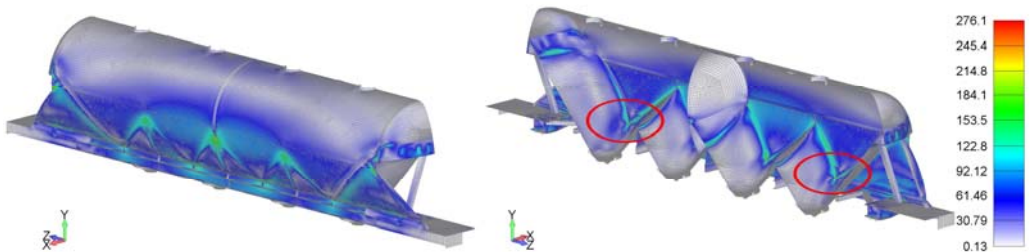
Crack repair is suggested on the cistern tank as well as the removal of weldings connecting the tank with the longitudinal girder (figure 6) with the clearance of at least.



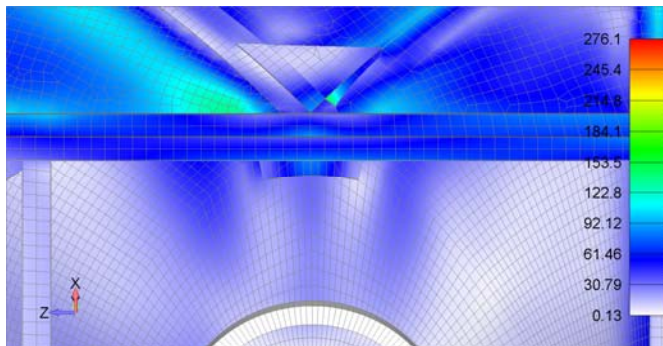
SI.6 Crack repair on the tanks

Thermo-mechanic wagon calculation during filling with 100°C temperature increase

Effective stress field in the case of 100°C temperature increase, is presented on the figure 7. Figure 8 shows the effective stress field in the zone of repaired crack on the first tank. Obtained stresses in the whole construction, as well as the stresses in the zone of repaired cracks, are below allowed stress for the static loads [5-7].



SI.7 Effective stress field on the reconstructed model



SI.8 Effective stress field in the zone of repaired crack on the first tank

8. CONCLUSION

The aim of this paper was to discover the causes of cracks on the heated cement transport wagon from the presented basic equations for heat conducting, implemented in the program PAK MULTIPHYSICS. Thermo-mechanic analyses of the existing construction identified the combinations of load causing damages on the wagon. In order to solve the problem, repair of the tank cracks is suggested as well as the removal of weldings connecting the tank with the longitudinal girder so the clearance of at least 5mm is reached. Repeated analyses, for all the load combinations, confirmed that all the stresses in the construction, as well as on the repair spots, are below allowed values. According to the presented results, it can be concluded that the reconstructed wagon for powder material transport satisfies all the requests in terms of the static and fatigue strength appointed by the mentioned standards.

ACKNOWLEDGMENT

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ISKUSTVA PRIMJENE VIBRORELAKSACIONE METODOLOGIJE UMANJENJA ZAOSTALIH NAPONA VELIKOGABARITNIH ZAVARENIH KONSTRUKCIJA

Nedeljko Vukojević¹, Fuad Hadžikadunić²

Rezime: U ovom radu je dat prikaz praktične implementacije vibrorelaksacione metodologije (VSR) umanjenja zaostalih napona na specifičnim industrijskim primjerima velikogabaritnih zavarenih konstrukcija. Primjenom vibrorelaksacionog procesa na velikogabaritnim konstrukcijama, kao alternativnog tretmana, potrebno je postići umanjenje zaostalih napona u strukturi uz postizanje dimenzionalne stabilnosti tretirane konstrukcije, tj. sprečavanje daljih dimenzionih promjena u smislu zadovoljenja geometrijskih tolerancija nakon procesa mašinske obrade, ili nakon transporta konstrukcije do mjesta montaže. Za implementaciju metodologije neophodno je pravilno definisanje parametara vibriranja konstrukcije. Monitoring VSR procesa pomoću mjernih senzora, za vrijeme i nakon procesa, su prikazani na konkretnim primjerima iz industrijske prakse.

Ključne riječi: VSR – vibrorelaksaciono umanjenje napona, zavarena konstrukcija, zaostali naponi, dimenziona stabilnost.

EXPERIENCES OF APPLICATION OF VIBRATORY RESIDUAL STRESS RELIEVING METHODOLOGY ON LARGE WELDED CONSTRUCTIONS

Abstract: In this paper the implementation procedure for vibratory stress relief (VSR) on specific models of welded construction for the needs of specialised industry is presented. With vibratory relaxation process application at large constructions it is usually necessary to release residual stresses in the structure with the realization of dimensional stability of the pieces, i.e. preventing further dimensional changes in terms of allowed geometric tolerance after machining process or after their transportation to the destination for assembling. To implement the procedure it is inevitable to define the parameters of vibration. Detailed monitoring of the process with measurement sensors is performed on each construction with stress or/and dimensional control during and after the process implementation on examples.

Keywords: VSR - Vibratory Stress Relief, welded construction, residual stress, dimensional stability.

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1. UVOD

Postoje dva tipa zaostalih napona kod zavarivačke tehnologije: *prinudni*, kao rezultat spajanja dijelova sa slobodnim krajevima, gdje se efekt pojavljuje samo na tretiranim elementima, i *reaktivni* koji se dešavaju u elementima čiji krajevi su spregnuti i spriječeni u slobodnom širenju i prenose unutrašnje napone na cijelu zavarenu strukturu. Zaostali naponi, kreirani na oba opisana načina, su multiaksijalni i u kombinaciji sa drugim naponima ili niskim temperaturama mogu kreirati uslove za postizanje osobina "krte" konstrukcije.

U proteklih 60 godina, metodologija umanjena zaostalih napona vibracionim postupkom (VSR) se razvila iz malo poznatog područja u respektabilan primarni proces, koji je uspostavljen kao alternativni postupak termičkom tretmanu odlivaka, proizvoda, komada koji zahtijevaju dodatnu mašinsku obradu i nemetalnih materijala. Efekti umanjena zaostalih napona u različitim prethodnim istraživanjima imaju širok dijapazon od 20% do 95%. Efekti VSR metoda zavise od mnogih faktora, kao što su: tip konstrukcije, geometrija i dimenzije, težina i krutost konstrukcije, karakteristike VSR opreme, oslonci konstrukcije, itd. Procedura umanjena zaostalih napona na konstrukciji se može izvršiti na nekoliko načina, najbolji rezultati se postižu termičkim tretmanom, ali zbog ograničenja u dužini konstrukcije koju treba tretirati razvijene su i alternativne metode. Jedna od njih je vibraciona metoda, [1,2].

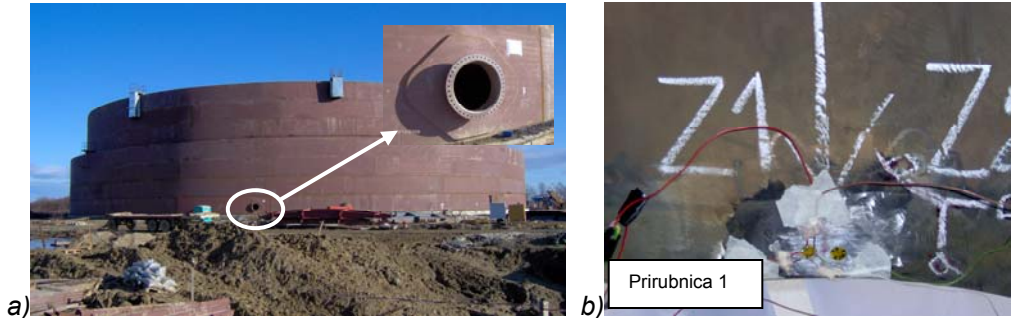
2. VSR TRETMAN ZAVARENE PRIRUBNICE

Prvi primjer predstavlja skraćeni prikaz postupka i rezultata primjene VSR metoda u zoni zavarenih prirubnica na vertikalnom rezervoaru tečnog goriva sa plutajućim krovom, slika 1a. To je zavarena čelična konstrukcija velikih dimenzija koja se u pojedinim zonama obično tretira sa aspekta umanjena napona. Izvršeno je početno mjerenje zaostalih napona t.j. definisanje "nultog stanja" kao i mjerenje promjena zaostalih napona izazvanih vibracionim tretmanom, koja je primijenjena u svrhu umanjena zaostalih napona. Procedura primjene VSR metodologije (nakon zavarivanja) na mjestu spoja prirubnice i otvora rezervoara i provođenje monitoringa tretmana se odvijala u sljedećim fazama: preliminarna dinamička analiza konstrukcije rezervoara i prirubnice, priprema i instalacija tenzometarskih mjernih traka, detaljno mjerenje zaostalih napona korištenjem metode "zabušenja rupe", monitoring promjena deformacija za vrijeme VSR procedure, pozicioniranje pobuđivača sile u dva ortogonalna pravca na prirubnici, monitoring procesa relaksacije, post-procesuiranje podataka, mjerenje zaostalih napona nakon završetka kompletne procedure. U ovom radu će biti prezentovane samo neke od faza ukupne procedure sa rezultatima.

Umanjenje zaostalih napona korištenjem VSR procedure je izvršeno na tri prirubnice rezervoara, koje imaju iste geometrijske osobine. Prirubnice su spojene na strukturu rezervoara zavarivanjem po tačno propisanoj tehnologiji. Prirubnica je prečnika \varnothing 750 mm, debljine stjenke 23 mm, a debljina stjenke oplata rezervoara je 31 mm u zoni prirubnice. Sa aspekta geometrijskih karakteristika u zoni prirubnice, te geometrije i količine zavara, radi se o zonama značajne koncentracije napona.

VSR oprema je Meta-Lax tipa, opsega radne frekvence 0-100 Hz i 20-100% ekscentriciteta. Oprema se sastoji od pobuđivača sile, pretvarača i upravljačko-akvizicione konzole. Izvršeno je "skeniranje" konstrukcije u zoni prirubnice i pokazana je osjetljivost konstrukcije u području od 45-80 Hz. Zato su primijenjene frekvence u tom dijapazonu u trajanju od 30-40 minuta.

Na osnovu ovih indikatora, parametarska procedura je primijenjena na sve tri prirubnice. Mjerenje zaostalih napona je izvedeno na početku i kraju procesa u smislu potvrde djelotvornosti tretmana, slika 1b.



Sl.1 Rezervoar kapac. 85.000 m³ TNG: a) položaj prirubnice, b) mjerna mjesta

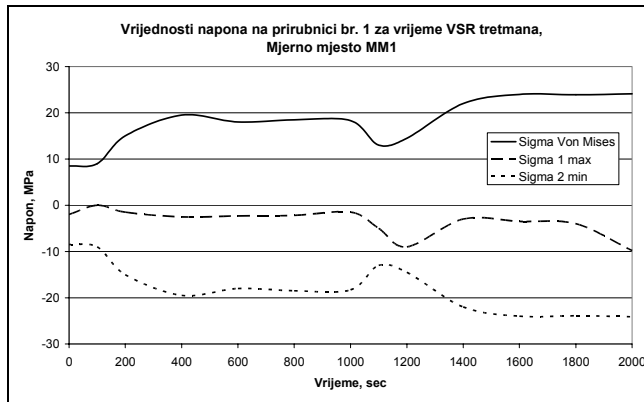
Mjerenje zaostalih napona je izvedeno korištenjem automatskog sistema "MTS-3000" korištenjem metode "zabušenja rupe" prema ASTM 837-01. Akvizicija podataka je izvršena korištenjem sistema "Spider 8-30", mjernih rozeta i sotvera "Catman 5.0 Professional". Mjerne trake su instalirane na mjernim mjestima: Z1 - za mjerenje zaostalih napona prije VSR tretmana, Z2 - za mjerenje zaostalih napona poslije VSR tretmana, MM1 do MM6 - mjerna mjesta za određivanje promjene napona za vrijeme VSR tretmana u dva ortogonalna pravca prirubnica br. 1 do 3, (nije prezentovano u cjelosti zbog obima rada). Mjerenja prije primjene VSR procesa su ukazala na činjenicu da su najviše vrijednosti glavnih napona u zoni zavara. Sva izmjerena zaostala naprezanja imaju zatezni karakter.



Sl.2 Vibracioni tretman prirubnice

Sve tri prirubnice su tretirane u istim uslovima, sa pozicijama pobuđivača u dva ortogonalna pravca, a vrijednosti pobude konstrukcije su varirane u dijapazonu od 60-90 Hz, slika 2.

Promjena napona na mjernom mjestu MM1, kao rezultat primjene vibracija, je prikazana na slici 3.



Sl.3 Promjena napona u toku VSR tretmana

Izmjerene deformacije na svim mjernim mjestima za vrijeme VSR procesa su negativne ukazujući na to da su početne deformacije bile zatezne, što je uobičajeno za zavarene spojeve. Komparativne vrijednosti izmjerenih promjena u zaostalim naponima, prije i poslije vibracione relaksacije, su date u tabeli 1.

Tabela 1 Rezultati mjerenja zaostalih napona

Uzorak	Mj. mjesto	$\sigma_{1 \max}$ [MPa]	$\sigma_{2 \min}$ [MPa]	σ_{ekv}^M [MPa]	σ_{ekv}^T [MPa]
Prije VSR	Z1	132	109	122	132
Nakon VSR	Z2	104	84	95	104

gdje su: $\sigma_{1 \max}$ - max. glavni napon,

$\sigma_{1 \min}$ - min. glavni napon,

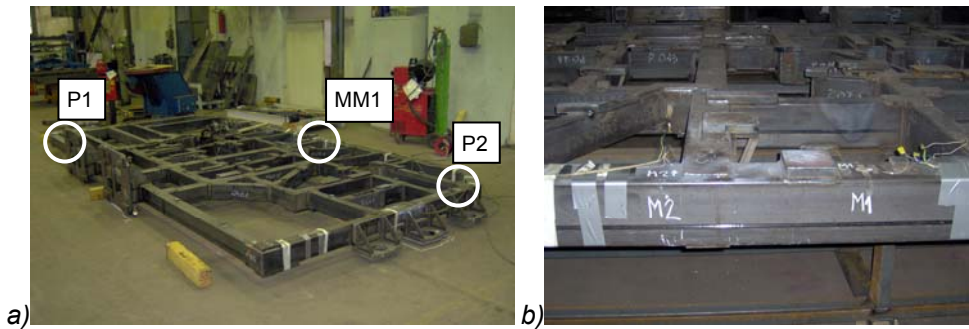
σ_{ekv}^M - ekvivalentni napon prema hipotezi Von-Mises,

σ_{ekv}^T - ekvivalentni napon prema hipotezi Tresca.

Poređenje izmjerenih vrijednosti napona, prije i poslije vibrorelaksacije, pokazuje da redukcija zaostalih napona korištenjem vibracione pobude prirubnica rezervoara jeste u rasponu 18-28%.

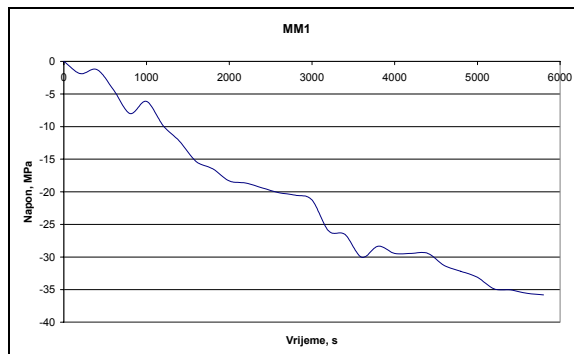
3. VSR TRETMAN ZAVARENE REŠETKASTE KONSTRUKCIJE

Sljedeći primjer korištenja VSR procesa je gredna rešetkasta zavarena konstrukcija, slika 4. Geometrijske karakteristike su: 6300 x 3100 x 600 mm, sa pravougaonim profilima 160x80x4; 160x120x6; debljine ploča 30, 25, 15, 10 i 8 mm, ukupne mase 2400 kg. Svrha primjene VSR metodologije u ovom slučaju je postizanje dimenzione stabilnosti komponente u zahtijevanim vrijednostima tolerancija. Procedura vibracione relaksacije podrazumijeva oslanjanje konstrukcije prema utvrđenom planu pozicioniranja oslonaca i pobudu strukture prema odgovarajućim vibracionim frekvencama i modovima oscilovanja, [3].

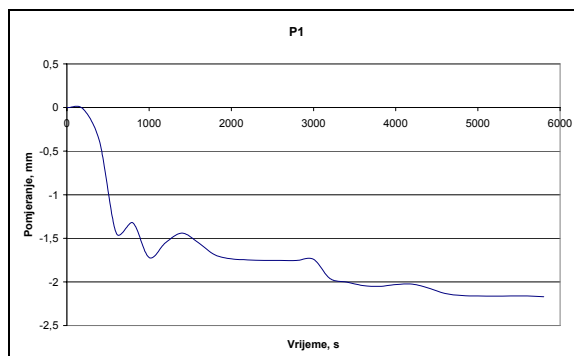


Sl.4 *Tretman konstrukcije: a) mjerna mjesta, b) mjerne trake*

U cilju monitoringa procesa korišteni su odgovarajući senzori: tenzometarske mjerne trake LY-11 u smislu mjerenja promjene deformacije na određenom mjestu konstrukcije, davači ubrzanja Metrix i davači pomjeranja WA 100 i 200, slika 4 a i b. Akvizicija podataka je vršena sistemom "Spider 8-55", a rezultati su procesuirani korištenjem softvera "Catman 5.0 Professional". Za vibracionu pobudu strukture je korišten elektro-pobuđivač sa finom regulacijom. Nakon "skeniranja" konstrukcije "osjetljivost" konstrukcije je pokazana u dijapazonu od 20-30 Hz. Promjena napona na mjernom mjestu MM1 je prikazana na slici 5.

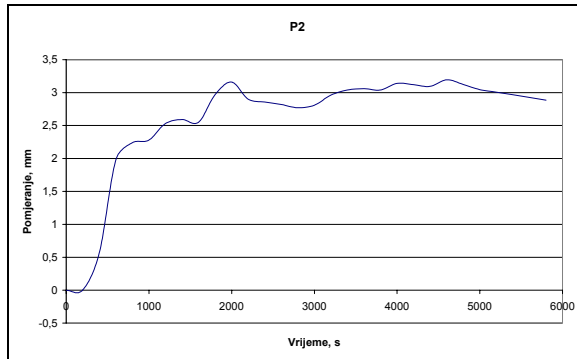


Sl.5 *Promjena napona na konstrukciji za vrijeme VSR tretmana*



Sl.6 *Promjena pomjeranja na konstrukciji za vrijeme VSR tretmana - mjesto P1*

Promjene pomjeranja na određenim mjernim mjestima konstrukcije (P1 i P2), kao posljedica uticaja VSR metodologije na geometriju konstrukcije, je prikazana na slikama 6 i 7.



Sl.7 Promjena pomjeranja na konstrukciji za vrijeme VSR tretmana - mjesto P2

Ukupna vrijednost promjene "relativnog napona" je -35,8 MPa, a promjene u geometriji konstrukcije na mjernim mjestima P1 i P2 su: -2.17 mm, +3.194 mm, respektivno.

4. ZAKLJUČAK

Na osnovu ranije izloženog moguće je zaključiti da VSR tehnologija ima uspjeh kao alternativni metod kod velikogabaritnih konstrukcija, ali i da je efektivnost tretmana povezana sa nekoliko ključnih parametara i karakteristika. Efekat vibrorelaksacionog metoda zavisi od mnogo faktora, kao što su: tip konstrukcije, dimenzije strukture, težina i krutost konstrukcije, karakteristike VSR opreme, oslonaca konstrukcije, itd. Na osnovu izmjerenih vrijednosti nakon primjene VSR postupka na oba primjera, može se zaključiti da primjena tretmana dovodi do promjena krutosti tretiranih uzoraka, odnosno dovodi do promjene naponskog stanja i geometrije konstrukcije, t.j. do dimenzione stabilnosti tretiranih uzoraka. Promjene deformacionog (naponskog) stanja i pomjeranja na mjernim mjestima tretiranih uzoraka jasno pokazuju njihovu međusobnu zavisnost, kao i efikasnost tretmana.

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STRESS - STRAIN ANALYSIS OF HYDRAULIC CYLINDER AT EXCAVATOR BUCKET MECHANISM

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Abstract: In this paper, stress–strain analysis of hydraulic cylinder that is used at excavator bucket mechanism is presented. The stress–strain analysis was done by analytic method, and after that, the results are compared with results obtained by finite element method with 3D tetrahedral finite element discretization. For this analysis, the one half of the cylinder was considered due to symmetry conditions. For the numerical simulation software Computer Aided-Three Dimensional Interactive Application CATIA V5R20 was used. The results obtained by different methods are compared and evaluated. On the basis of the results evaluation, the critical zones at the cylinder were discovered at which potential damage could be occurred due to increase of pressure and that could result to failure of the whole mechanism.

Keywords: hydraulic cylinder, pressure at cylinder, stress – strain analysis, cylinder damage

1. INTRODUCTION

Present machines and mechanical systems are usually equipped with hydraulic and electrical control devices that regulate their function and power. Hydraulic cylinders are positive-displacement linear hydraulic motors that transform energy of working fluid flow to useful work of linear movement of active elements (pistons or plungers) [1]. In relation to constructive solutions, the hydraulic cylinders can be classified as unidirectional and bidirectional. At bidirectional hydraulic cylinders, as it is analyzed in the paper, movement of active element is linear in two directions under the pressure of working fluid. Hydraulic cylinders are used at road and rail vehicles, internal transport machines, cranes and elevators, construction and agricultural equipment, mining machinery, ship equipment, material cutting machines, process systems, power plants and general machine engineering. The aim of investigation

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presented in this paper is to identify the optimal dimensions and form of hydraulic cylinder in relation to alterations of loads considering influence of form and stress concentration.

In the paper [2] discusses the results of the investigation of the stress states of the Bucket wheel boom (BWB) hoisting system connecting eyeplate. In the reference [3] the vibration analysis of a hydraulic cylinder subjected to dynamic loads is shown. The main topic in the paper [4] is to present results of strength and fatigue limit analysis applied to piston type hydraulic cylinders. This paper also shows advantages of application of the up-to-date digital chain of engineering analysis within which CAD tools are being used as well as strength and fatigue limit analysis. As a real case, in paper [5] appearance of typical damages of revolving platform structures for bucket wheel excavators (BWE) type TAKRAF SRs 1200×24/4 (400 kW) + VR is shown. Then, techniques for calculating their structure are presented in this paper, whose basis is made in two stages: set up of finite element mesh and analysis of loads. The paper [6] present researches of state stress of particular substructures of bucket wheel excavators (BWEs).

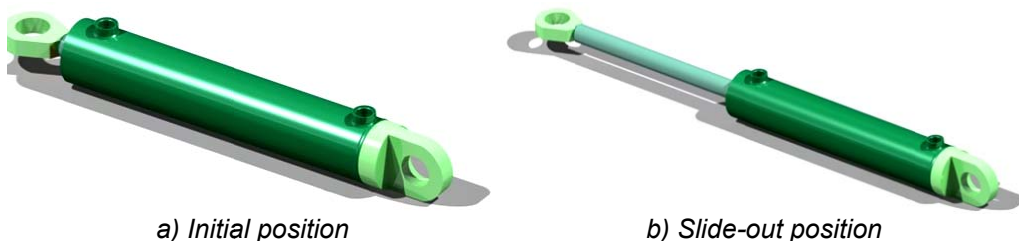


Fig.1 Hydraulic cylinder at extreme positions

2. STRESS-STRAIN ANALYSIS AT HYDRAULIC CYLINDER BARREL

The analysis of stress state and determination of maximal stresses and deformations at hydraulic cylinder barrel are very important due to wide usage of those cylinders at different machine systems. This analysis and precise determination of maximal stress-strain levels also provide optimizations of hydraulic cylinders dimensions and, by that, keep stress-strain levels within allowable limits. The object of investigation presented in this paper is hydraulic cylinder at mechanism of the excavator bucket that is presented at Fig. 1 at two extreme positions. Hydraulic cylinder barrel at mechanism of the excavator bucket is loaded by internal pressure in the hydraulic cylinder, but also, by pressure due to influences of other hydraulic cylinders that form the mechanism of the excavator bucket. The pressure inside of the cylinder acts on the cylinder barrel and, by that, loads it. This pressure is equivalent in all directions and loads the cylinder barrel uniformly. The calculation of maximal stress is done by analytical method and after that, the analyses of stress-strain state is done by finite element method in order to verify obtained results.

Calculations of stresses and strains by analytic method

Mechanical capacity calculations at hydraulic cylinder are generally limited to calculations of stresses due to loads of internal fluid pressure without considerations of complex stress states due to acts of external loads. Taking into account the thickness

of wall of the hydraulic cylinder barrel δ [mm], the classification of those cylinders can be define: thin wall ($D/d \leq 1.18$) and thick wall (when this ratio is higher than 1.18), when D and d are external and internal diameters of the cylinder [7]. The material of the hydraulic cylinder that is considered in this paper is steel St 52-3 N according to DIN or S355 J2G3 according to SRPS EN 10025 with tensional strength of $R_m = 560$ MPa and yield strength of $R_{eH} = 355$ MPa. As this type of hydraulic cilinders operate in extreme exploatative conditions, according to DIN 2448/1629 (EN 10201) and for material St 52-3 N (S355J2G3) and attest according to EN 10204-3.16 for the wall thickness of $\delta < 40$ mm, safety factor is equivalent to $\nu = 2.5$, so, on the basis of the presented data, the stress limit of $\sigma_d = 140$ MPa is adopted. Maximal pressure in exploitation at hydraulic cylinder, that act as load on cylinder barrel is equivalent to $p_{max} = 160$ bar. For calculation of wall thickness of hydraulic cylinder barrel made of material with higher toughness the following relation can be used [1]:

$$\delta \geq \frac{d}{2} \cdot \left[\sqrt{\frac{\sigma_d + p_{max} \cdot (1 - 2 \cdot \mu_p)}{\sigma_d - p_{max} \cdot (1 + \mu_p)}} - 1 \right] = 6.76 \text{ [mm]}. \quad (1)$$

In relation (1) internal diameter of the cylinder is nominated as d and it is equival to 125 mm, while μ_p is Poason ration that is for steel equivalent to 0.3. As calculated minimal wall thickness of hydraulic cylinder barrel is equivalent to 6.76 mm the next standardized dimensions are adopted as $D = 145$ mm for external diameter of cylinder and $\delta = 10$ mm for the wall thickness. On the basis of the adopted wall thickness, the value of stress at wall of the hydraulic cylinder barrel can be calculated by following relation [7]:

$$\sigma = \frac{D^2 + d^2}{D^2 - d^2} \cdot p_{max} = 108.59 \text{ [MPa]}. \quad (2)$$

The value of stresses at maximal fluid pressure that is obtained by calculation is smaller than value adopted as maximal stress limit for selected material and exploitative conditions that confirms the constructional dimension and proper selection of material. Obtained value of hydraulic cylinder barrel wall thickness, so as obtained stress level at cylinder barrel wall due to internal pressure and pressure induced by act of other hydraulic cylinders, provide calculation of required dimensions and form. Analytic method provides relevant results for calculation of wall thickness and stress level due to fluid pressure at hydraulic cylinder barrel. For analysis of stress-strain in details at real form of the hydraulic cylinder, finite element method must be used. By this method, beside stress state, strains can be, also, determined and result stress-strain state at zones with stress concentrations can be analyzed.

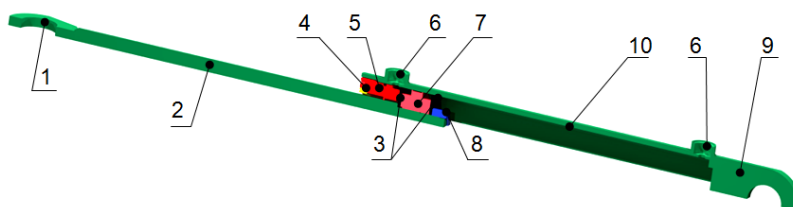


Fig.2 Main parts of hydraulic cylinder

Main parts of hydraulic cylinder, notated at one quarter of the considered cylinder, are presented at Fig. 2, where is: 1- Cylinder base, 2- Piston rod, 3- Head gland, 4- Linear bearing screw, 5- Linear bearing, 6- Plug, 7- Piston, 8- Screw, 9- Cylinder head, 10- Cylinder barrel.

Calculations of stresses and strains by numeric method

In the aim to identify the optimal constructive solution, dimensions and form of considered hydraulic cylinder, numeric analyze of stress-strain state was done by finite element method. The most of the numeric methods for calculation of stress at mechanical constructions are based on the finite element method. Finite element method can be used for precise determination of stress-strain state at critical zone on real form of machine element and obtained values are much precise than related values obtained by analytic calculations. Also, numeric method provides possibility of fast repetitions of analyzes after some alterations of details of the form [8]. Geometric Computer Aided Design (CAD) model of hydraulic cylinder is created of separate CAD elements. Load simulation at hydraulic cylinder barrel is done by using of software Computer Aided-Three Dimensional Interactive Application - **CATIA V5R20** and it is presented in this paper. The basic model that is used for numeric analysis is related to considered hydraulic cylinder. For material properties, the module of elasticity and Poisson ration are used as and . At first stage of generation of the numerical model, discretization is done by 3D tetrahedral finite elements with uniform distribution. The border conditions are defined in relations to theoretic considerations of hydraulic cylinder. The numeric calculations are done, firstly, at simplified model and after that, numeric analyze of stress-strain state due to different internal pressure is done.

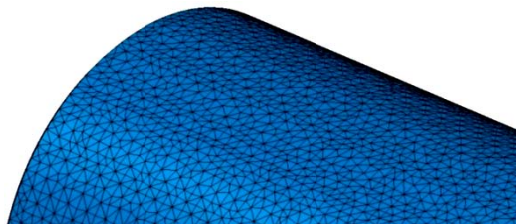


Fig.3 Discretization of one segent of the numeric model

For the every analysis, the hydraulic cylinder barrel was loaded in the same way at different values of pressure. Static system was defined by input parameters, geometric characteristics, act of loads and border conditions. After that, general problem of structural static analysis was considered.

3. RESULTS OF NUMERIC ANALYSES

In order to numeric calculation has been done, it is necessary to repeat the procedure of structural analysis for every value of pressure. The every analysis is done for different values of pressure in interval between $p=160$ bar and $p=400$ bar (160, 200, 250, 300, 350, 400 bar). As result of numeric analyze equivalent (*Von Mises*) stresses and deformations are obtained. Visualizations of results of calculations of stresses and deformation for same values of pressure are presented at Fig.4, Fig.5, Fig.6, Fig.7, Fig.8 and Fig.9.

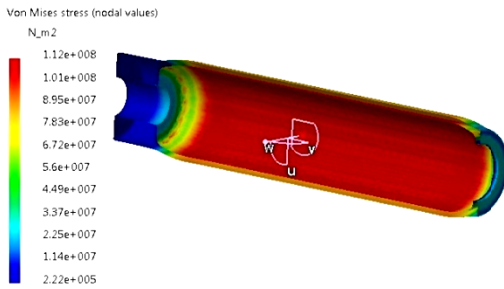


Fig.4 Stress at hydraulic cylinder barrel due to pressure

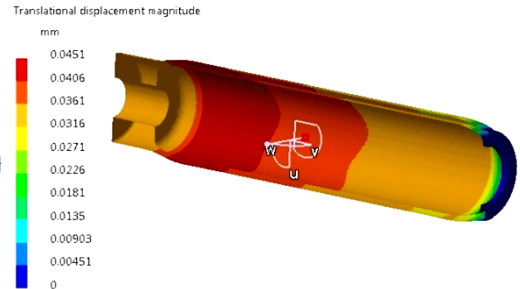


Fig.5 Strains at hydraulic cylinder barrel due to pressure

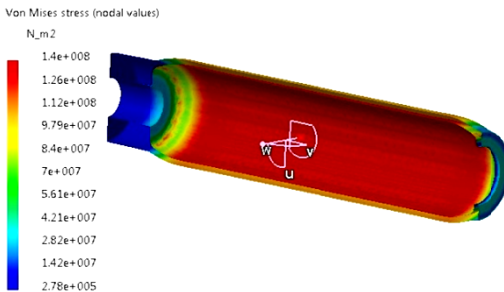


Fig.6 Stress at hydraulic cylinder barrel due to pressure

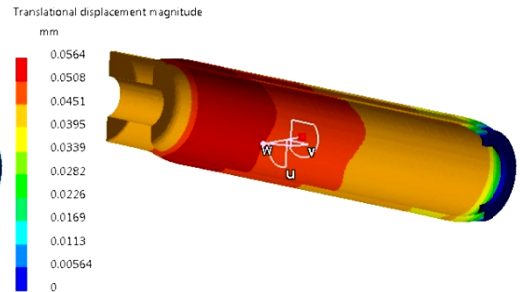


Fig.7 Strains at hydraulic cylinder barrel due to pressure

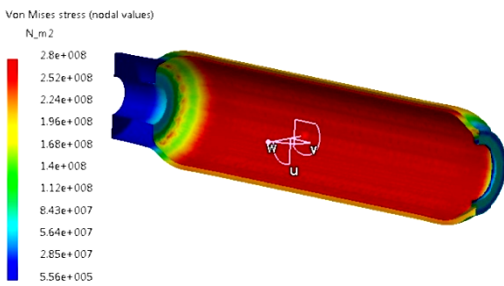


Fig.8 Stress at hydraulic cylinder barrel due to pressure

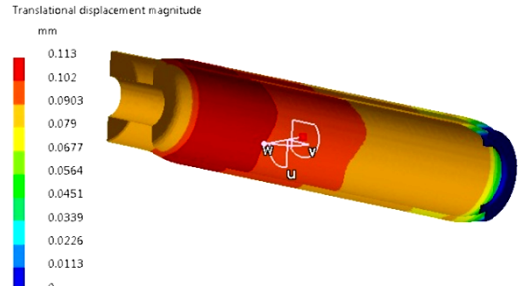


Fig.9 Strains at hydraulic cylinder barrel due to pressure

4. RESULTS EVALUATION

Evaluation of the results provides precise definition of stress-strain state at considered element of mechanical construction. Comparison of results obtained by analytic and numeric methods are presented at Fig. 10 provide comparative advantages of numeric methods due to fact that this method considers stress concentrations at critical zones. Linear increases of stress values calculated by

numeric method in relation to values obtained by analytic method provide precise calculation of stresses and strains.

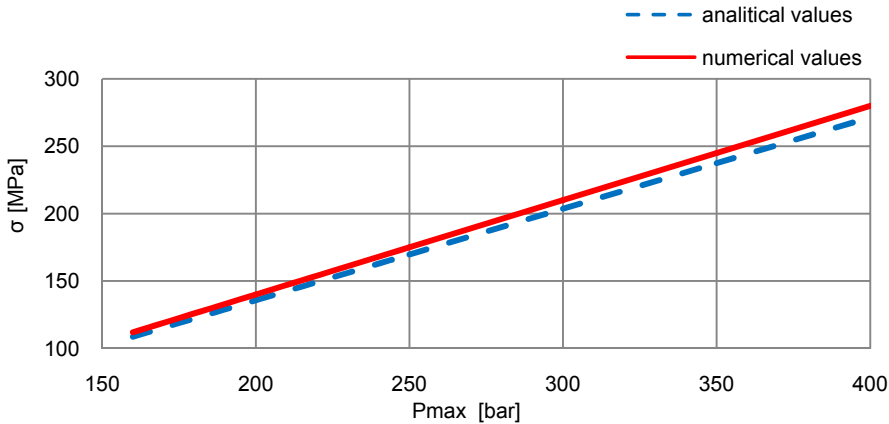


Fig. 10 Results of analytical and numerical calculations of maximal stresses and stress distribution as a function of the pressure variation

Diagram presentation of numeric analyze of resulted deformation at hydraulic cylinder barrel for different values of maximal pressure is shown at Fig. 11. Those deformations could influent to reduction of exploitation period of the cylinder and present one of the major causes of failures at excavator bucket mechanisms. The analysis of deformations implicate that at pressure higher than allowed, higher deformations are induced that overcome allowable deformations limit, so fluid pass between piston and cylinder barrel and failure at hydraulic mechanism occur.

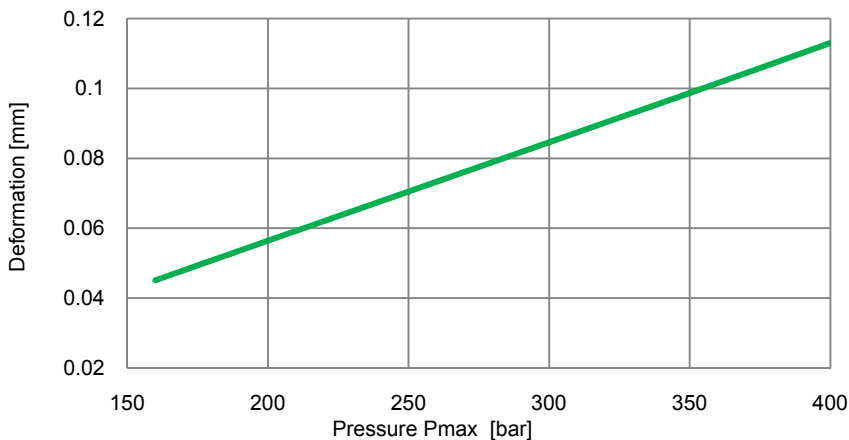


Fig. 11 Results of analytical calculations of maximal deformation as a function of the pressure variation

5. CONCLUSION

On the basis of the conducted evaluation of results, following general conclusions are implicated:

- Diagrams of stresses obtained by analytic and numeric method have the same trends, so considered model by numeric method is relevant and relate to adequate construction solution. The mathematical model that is formed can be taken for further analysis and testing in aim to obtain decrease of maximal stress level, so as dynamic and fatigue analysis.
- Values of stresses calculated by numeric method are higher than related values calculated by analytic method due to fact that this method does not consider stress concentration because of its complex determination, so it is implicated that for precise real stress state numerical method that considered real geometry and form must be used.

On the basis of those conclusions it is implicated that both analytic and numeric methods provide relevant results due to sensitivities to alterations of input parameters, but special care should be taken on influence of stress concentration at zones of the cylinders. The alterations of maximal result stresses at specific zones of hydraulic cylinder are highly influenced by alterations of maximal pressure inside the cylinder. Conducted analyses provide precise identification of optimal construction solution, so as identification of its optimal form and by that, provide prevention of damages and failures at maximal pressures during exploitation.

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DETERMINATION OF GEROTOR PUMP THEORETICAL FLOW

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Andreja Ilić⁵

Summary: The methodology for developing the mathematical expressions for determination of gerotor pump theoretical flow is presented in this paper. The theoretical flow is equal to current alteration of volume at working chambers that are linked with output side of the pump. For the calculation of the working chamber volume at gerotor pump the method that consider the influence of infinity small rotation angles of pump's working elements to elementary changing of volume are used and determination of working volume of chamber is done after integration. The developed analytical model is illustrated by numerical examples in which the influences of design parameters to variations of gerotor pump flow are analysed. The pump with fixed axes of shafts is considered in this paper but developed expressions by establishing specific kinematic relations can be, also, used at pumps with planetary motions.

Key words: trochoidal gearing, positive displacement pumps, gerotor pumps, volume of working chamber, volumetric flow

1. INTRODUCTION

Gerotor is the mechanism with internal trochoidal gearing that was realized by Myron F. Hill at 1906. The name GEROTOR is derived from the phrase GEnenerated ROTOR and described mathematical procedure for generating peritrochoid profile of inner gear by circular arc of the external profile. Gerotor can be used in cases where gear pumps with external gearing are present and, also, it can be used where gear pumps with internal or fixed displacement vane pump are present: for cooling and lubricating systems, so as for transfer of liquids.

Gerotor pumps belong to the group of rotational pumps and they have great advantages in relation to other types of rotational pumps. Some of the advantages are simple constructions and variety of applications. Due to specific geometry of gears

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profiles, continual contacts of all teeth are provided in exploitation that obtains the necessary separation between the low and high pressure zones. During the operation, teeth of the pump rotor act as pistons while chambers (the space between profiles of inner and gears) correspond to cylinders. According to the presented facts, the current volumes of chambers increase and decrease periodically while those chambers are connected alternately to input and output line. The single alteration of the current volume of the chamber from minimal to maximal value is indicated as one operation cycle. Due to specific construction of the pump, several operation cycles are done during one rotation of the shaft.

In order to obtain the high functional characteristics of the pump it is necessary to analyse the influences of numerous of different parameters to its output characteristics of the pump. According to that, the basis of the investigation presented in this paper is identification of influence of the geometric parameters variations to volumetric characteristics by contemporary analysis based on modelling and simulation.

2. MODELLING OF TROCHOIDAL GEARING AT THE GEROTOR PUMP

In this paper, gearing at the gerotor pump with profile of internal gear is determined by equidistant of the peritrochoid while external profile is determined by circular arc with radius r_c is considered.

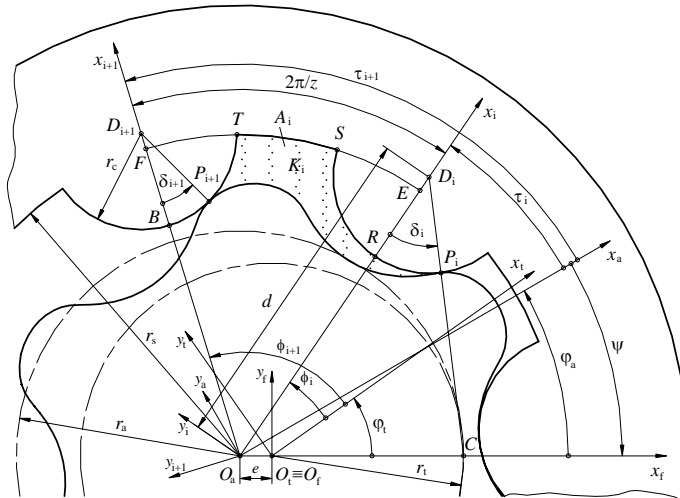


Fig. 1 Schematic presentation of the gerotor pump gear pair with basic geometrical dimensions

The basic geometric relations for the generation of peritrochoid, at the considered gear pump, are shown at Fig. 1, that are adopted for defining the relations to determine the current position of contact point P_i in coordinate system $O_a x_a y_a z_a$ in following form [7]:

$$\mathbf{r}_{P_i}^{(a)} = \begin{bmatrix} e[z\lambda \cos \tau_i - c \cos(\tau_i + \delta_i)] \\ e[z\lambda \sin \tau_i - c \sin(\tau_i + \delta_i)] \\ 1 \end{bmatrix}, \quad (1)$$

where is: z - number of the external gear teeth, e - eccentricity (center distance between the internal and external gear), λ - trochoid coefficient, $\lambda = d/ez$, d distance

between the generating point D and the center of the external gear, c equidistant coefficient, $c=r_o/e$, τ_i – angle that determined the position of the point D_i , $\tau_i = \frac{\pi(2i-1)}{z}$, $i=1, \dots, z$, δ - leaning angle [2-5]. For determination of angle δ the following relation is used:

$$\delta_i = \arctan \frac{\sin(\tau_i - \psi)}{\lambda - \cos(\tau_i - \psi)}, \quad (2)$$

where ψ is referent rotation angle.

3. DETERMINATION OF THE PUMP THEORETICAL FLOW

Instantaneous flow rate of the pump presents the volume variation of working chambers in time and can be calculated by following relation [1]:

$$Q = \sum_{i=m}^n \frac{dV_i}{dt}, \quad (3)$$

where is: V_i - current volume of considered working chamber, m, n - indexes of the beginning and final chambers which can be found at the same time in the thrust phase.

For calculation of the volume of the gerotor pump working chamber, the method that consider the analysis of influence of infinitesimal values of rotation angles of the pump's working elements is used. The volume of working chamber is calculated by integration. For calculation of the variation of the pump's working chamber, the equivalent system with fixed axis of gear pair elements is considered. The relation between the rotation angles of working elements is determined in following

form $d\varphi_t = \frac{z}{z-1} d\varphi_a$. The variation of working chamber volume is analysed by the area

of segments with form of circular fragment. In general cause, the area of A segment that are bordered with curve determined in polar coordinate system and the position vectors of points that correspond to polar angles α_1 and α_2 is calculated by the following formula [8]:

$$A = \frac{1}{2} \int_{\alpha_1}^{\alpha_2} \rho^2 d\alpha, \quad (4)$$

where ρ and α are polar coordinates of presented curve.

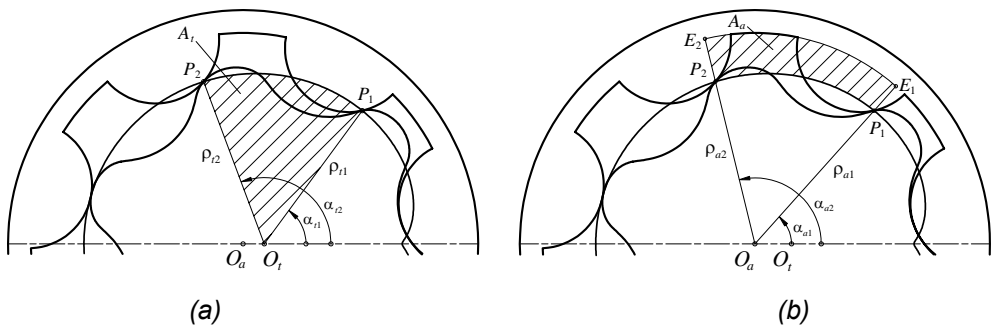


Fig. 2 Presentation of segments that are considered for determination the variation of working chamber volume

Firstly, the variation of volume V_t that is pushed by internal gear would be analysed. This volume is bordered, at cross section, by radius nominated as ρ_{t1} and ρ_{t2} of the consequent contact points P_1 and P_2 and by circular segment between those points (Fig. 2 (a)). During rotation of internal gear for angle of $d\varphi_t$, radius ρ_{t1} rotate for polar angle of $d\alpha_{t1}$ and by that, it push the volume of $\frac{1}{2}b\rho_{t1}^2d\alpha_{t1}$, while the alteration in the length of the radius is neglected because the considered values are infinitesimal (Fig. 3). As internal gear rotates faster than the point on contact line, relate to $d\varphi_t > d\alpha_{t1}$, the formed volume is $\frac{1}{2}b\rho_{t1}^2d\mu_{t1}$, where is $d\mu_{t1} = d\varphi_t - d\alpha_{t1}$. According to that, the variation of volume for contact point P_1 will be equivalent to $\frac{1}{2}b\rho_{t1}^2(d\alpha_{t1} + d\mu_{t1}) = \frac{1}{2}b\rho_{t1}^2d\varphi_t$. When the same analysis is done for contact point P_2 , the relation for calculation of volume variation of internal area of considered chamber can be formed as:

$$dV_{t1} = \frac{1}{2}b(\rho_{t2}^2 - \rho_{t1}^2)d\varphi_t. \quad (5)$$

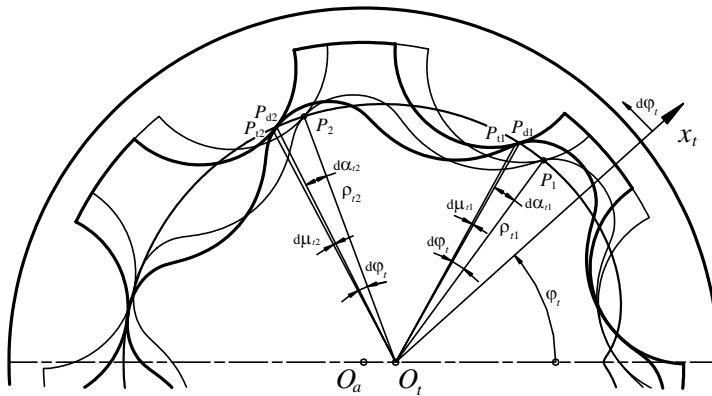


Fig. 3 Volume variation of internal area of working chamber

Now, by the similar method, the volume variation V_a that is pushed by external gear can be calculated. This volume is bordered, at cross section, by linear segments formed by extending of radius ρ_{a1} and ρ_{a2} of the consequent contact points P_1 and P_2 and with circular segment of contact line between mentioned points and circular arc E_1E_2 (Fig. 2 (b)). During rotation of external gear for angle of $d\varphi_a$, radius ρ_{a1} rotate for the polar angle of the $d\alpha_{a1}$ and by that push the volume of $\frac{1}{2}b(r_s^2 - \rho_{a1}^2)d\alpha_{a1}$ (Fig. 4). As external gear rotate slower than point on contact line, relate to $d\varphi_a < d\alpha_{a1}$, the formed volume would be $\frac{1}{2}b\rho_{a1}^2d\mu_{a1}$, where is $d\mu_{a1} = d\alpha_{a1} - d\varphi_a$. According to this, the variation of external volume for contact point P_1 will be equivalent to $\frac{1}{2}b(r_s^2 - \rho_{a1}^2)d\alpha_{a1} - \frac{1}{2}b\rho_{a1}^2d\mu_{a1} = \frac{1}{2}b(r_s^2 - \rho_{a1}^2)d\varphi_a$. When the same analysis is done for the contact point P_2 , the relation for calculation of volume variation of external area of considered chamber can be formed as:

$$dV_{a1} = \frac{1}{2} b (\rho_{a1}^2 - \rho_{a2}^2) d\varphi_a \quad (6)$$

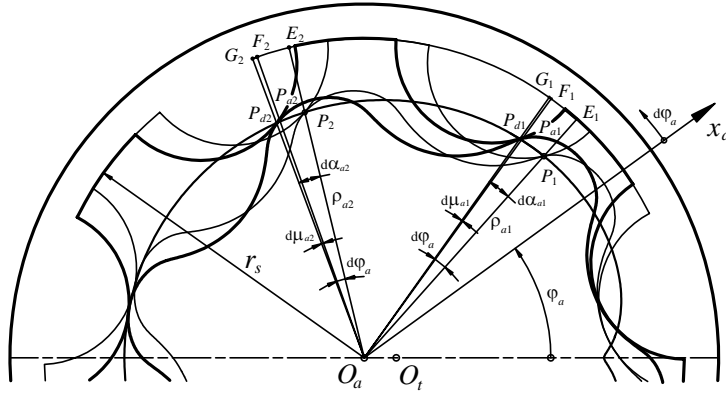


Fig. 4 Volume variation of external area of working chamber

The result volume variation of working chamber is equivalent to:

$$dV_1 = dV_{t1} + dV_{a1} \quad (7)$$

Starting from equation (5) and (6) it is implicate that:

$$dV_1 = \frac{1}{2} b [(\rho_{a1}^2 - \rho_{a2}^2) d\varphi_a + (\rho_{t2}^2 - \rho_{t1}^2) d\varphi_t], \quad (8)$$

and taking into account the relation between the rotation angles of gears, following form is obtained:

$$\frac{dV_1}{d\psi} = -\frac{1}{2} b \left[\rho_{a1}^2 - \rho_{a2}^2 + \frac{z}{z-1} (\rho_{t2}^2 - \rho_{t1}^2) \right] \quad (9)$$

and after that, it is transformed into the form suitable for determination of current geometrical flow:

$$\frac{dV_1}{dt} = \frac{1}{2z} b (z-1) \omega_t \left[\rho_{a1}^2 - \rho_{a2}^2 + \frac{z}{z-1} (\rho_{t2}^2 - \rho_{t1}^2) \right] \quad (10)$$

In order to obtain the simple form of final relations for integration for determination of current flow according to equation (3), the following relation can be established:

$$(CP_2)^2 - (CP_1)^2 = (z-1) \left[\rho_{a1}^2 - \rho_{a2}^2 + \frac{z}{z-1} (\rho_{t2}^2 - \rho_{t1}^2) \right] \quad (11)$$

When equation (11) compare to equation (9), the general relation for determination of chamber's volume variation can be written in the form:

$$\frac{dV_i}{d\psi} = -\frac{b}{2(z-1)} [(CP_{i+1})^2 - (CP_i)^2], \quad i=1, \dots, z. \quad (12)$$

The distance CP_i of contact point P_i from kinematic pole C is determined as intensity of vector $\mathbf{CP}_i^{(a)}$. Radius vector of the point C in the frame $O_a x_a y_a z_a$ could be written in the form

$$\mathbf{r}_C^{(a)} = \begin{bmatrix} ez \cos \psi \\ ez \sin \psi \\ 1 \end{bmatrix} = ez \cos \psi \mathbf{i}_a + ez \sin \psi \mathbf{j}_a . \quad (13)$$

Vector $\mathbf{CP}_i^{(a)}$ based on geometrical relations from the Fig. 1 and equation (1) and (13), can be expressed as

$$\mathbf{CP}_i^{(a)} = \mathbf{r}_{P_i}^{(a)} - \mathbf{r}_C^{(a)} = \begin{bmatrix} e[z\lambda \cos \tau_i - z \cos \psi - c \cos(\tau_i + \delta_i)] \\ e[z\lambda \sin \tau_i - z \sin \psi - c \sin(\tau_i + \delta_i)] \\ 0 \end{bmatrix}, \quad (14)$$

so it is:

$$(CP_i)^2 = |\mathbf{CP}_i^{(a)}|^2 = [x_{CP_i}^{(a)}]^2 + [y_{CP_i}^{(a)}]^2 = e^2 \left\{ z \left[1 + \lambda^2 - 2\lambda \cos(\tau_i - \psi) \right]^{\frac{1}{2}} - c \right\}^2 . \quad (15)$$

On the basis of the obtained relation with using of certain trigonometric transformations, the following formula for determination of theoretical flow variation in chamber K_i is formed as:

$$\frac{dV_i}{dt} = \omega_t b e^2 z \left\{ 2\lambda \sin \frac{\pi}{z} \sin \left(\frac{2\pi i}{z} - \psi \right) - \frac{c}{z} \left[1 + \lambda^2 - 2\lambda \cos(\tau - \psi) \right]^{\frac{1}{2}} \right\}_{\tau_i}^{\tau_{i+1}} . \quad (16)$$

4. TESTING OF THE MATHEMATICAL MODEL OF THE PUMP FLOW

The influence of different parameters to volume variation would be illustrated on numerical models. Two different gear pairs are considered (Fig. 5), the commercial one with mark GP-575, and other one gear pair, GP-850, with profile formed on the results of calculations presented in the paper [7]. Geometrical parameters of the considered gear sets are: gear set I $z=6, \lambda=1.575$ and $c=3.95$, gear set II $z=5, \lambda=1.850$ and $c=3.95$. The remaining parameters are: $e=3.56$ mm, $r_s=26.94$ mm, $b=16.46$ mm.

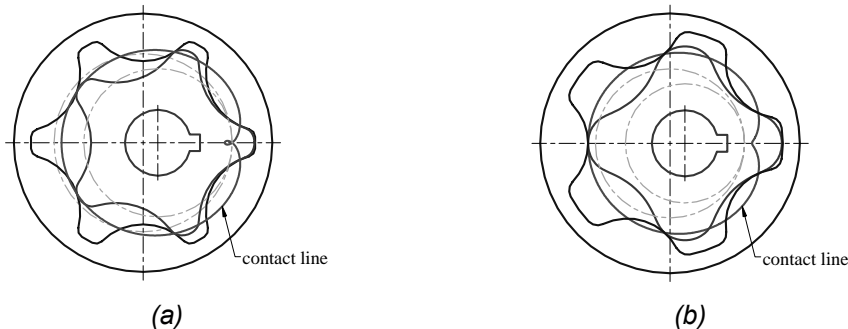


Fig. 5 Schematic presentation of the considered trochoidal pump models
(a) GP-575 (commercial) and (b) GP-850

By using of the computer program developed on the basis of the mathematical model of the pump geometrical flow, for the given parameters of the gear pump the results are obtained that are presented by graphics at the following figures. The fluctuations of flow rate of the pump for different chambers are presented at Fig. 6. On

the basis of the presented fluctuations the conclusions about value and variation of the current flow can be done. For the graphical interpretation the following dimensionless parameter is induced $\bar{V}_i = \frac{V_i}{e^2 b}$.

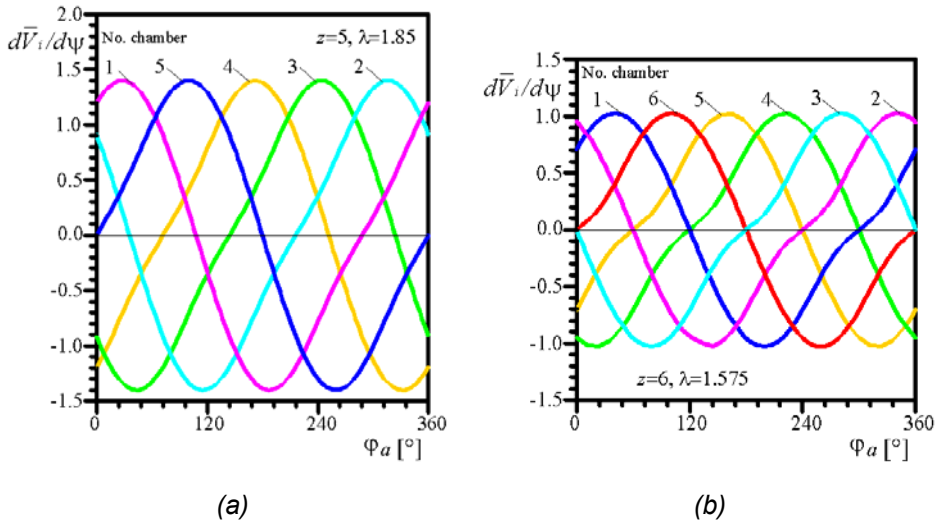


Fig. 6 Diagrams of flow rate variation at different chambers of the pump with five (a) and six (b) chambers

On the graph of the variation of current flow during ending of thrust and at the beginning of the suction phase the local extreme is present. At the pump with five chambers the variations are smaller. Diagrams of current flow pulsations at the pump with different number of teeth in relation to rotation angle of external gear are presented at Fig. 7.

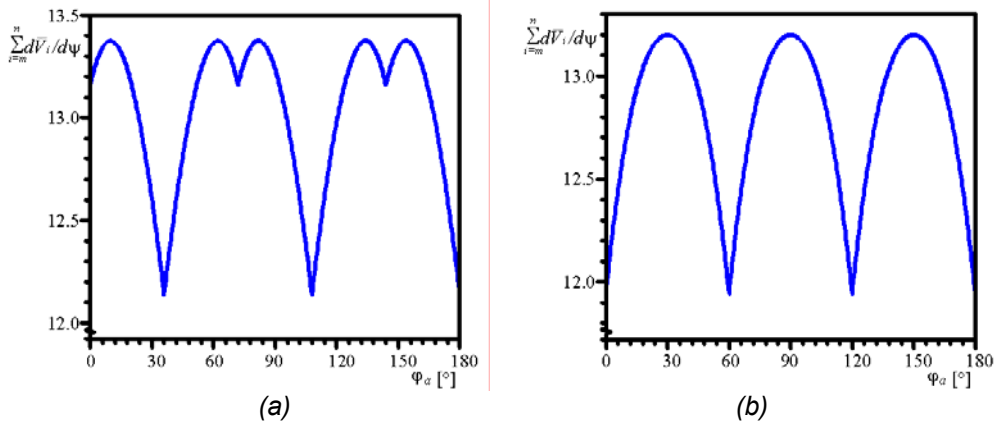


Fig. 7 Diagrams of instantaneous flow rate at the pump with five (a) and six (b) chambers

As measure of flow uneven the flow rate irregularity δ_q is induced that characterize the relation between current flow to average value of the flow [6]. For the pump with six chambers flow rate irregularity is equivalent to $\delta_q \approx 10\%$. For the pump

with five chambers flow rate irregularity is equivalent to $\delta_q \approx 9.7\%$ that conformed the fact that pumps with even number of chambers have bigger pulsations, so designs of the pumps with odd number of working chambers are recommended.

5. CONCLUSION

In order to obtain the functional relations that would provide design of the pumps on the basis of the given basic functional requirements, the mathematical model of volumetric characteristics of the pump with trochoidal gearing is developed. The mathematical model was tested and the results are analysed, so the relevant characteristics are identified that influent to pulsation of pump flow and to variation for the flow. The general conclusion is implicated that in order to reduce the pulsations of flow it is recommended to use the odd number of chambers at the pumps.

ACKNOWLEDGMENTS

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ANALYSIS OF HEAT TRANSFER THROUGH THE BEAM SUPPORT OF THE WAGON STRUCTURE CALCULATED BY SOFTWARE PAK MULTYPHISICS

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Abstract: Paper deals with heat transfer through beam supports of wagon structure for transportation of hot steel ingots. It is well known that changing of the material properties at high temperatures leading to reduced carrying capacity of structures. Therefore, it is necessary to know the temperature distribution in the carrying element to avoid disturbing the integrity of construction. Basic equations which governs the problem of heat transfer in terms of finite element method (FEM) are presented taking into account the initial and boundary conditions. Heat transfer through beam supports of wagon structure for transportation of hot steel ingots is solved by software PAK Multyphysics. It is shown that the temperature of carrying elements is slightly elevated, which does not affect the normal operation of wagon construction.

Keywords: heat transfer, finite element method, PAK, shell

1. INTRODUCTION

A number of numerical methods are developed to solve problems in the field of structural mechanics, heat transfer, fluid mechanics and coupled problems. Among the numerical methods, the fastest growth was experienced in finite element method (FEM) with many commercial software packages. FEM calculations in wagon design has a very significant role in the calculation of static and dynamic strength of wagon structure, heat transfer and failure criterions.

Flat wagons are special wagons' type for transportation of steel ingots. Hot steel ingots transfer heat by conduction, convection and radiation to the structure of the wagon. [Flat wagons](#) have no walls or low walls not higher than 60 cm. The influence of heat transfer must be calculated in order to avoid cracking and failure of certain parts of wagon structure.

This paper presents the basic equations of heat balance taking into account differential equation of the internal energy changes, Fourier's law of heat, initial and boundary conditions of the problem. As an application of the theoretical part, it is

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showed problem of the heat transfer through beam support of wagon structure. Finite element model is solved with finite element solver PAK-T [1] which is one of the software modules of PAK Multyphysics.

2. BASIC EQUATIONS OF HEAT BALANCE

Differential equation of heat balance through solid bodies consists of Fourier's law of heat and equation of change of internal energy as described in [2] and [3]. Differential equation of heat balance can be shown using matrix notation as:

$$-\rho c \frac{dT}{dt} + \dot{N}^T (k \dot{N} T) + q = 0$$

Solution for temperature field $T(x, y, z, t)$ that satisfies given initial and boundary conditions is to be found, in scope of practical solving of the problem. Initial conditions are given only for transient problems. Boundary conditions can be:

a) given temperature at S_1 part

$$T = T_s(x, y, z, t)$$

b) given flux at S_2 part

$$q_n = q_n(x, y, z, t)$$

c) given heat convection at S_3 part

$$q_h = h(T_0 - T_s)$$

d) given radiation at S_4 part

$$q_r = h_r(T_r - T_s)$$

where S_1, S_2, S_3 and S_4 are parts of the surface S , as symbolically represented in fig. 1. Temperature T_s is surface temperature, q_n, q_h and q_r are fluxes through the surface, T_0 is environment temperature, h is coefficient of convection, h_r is coefficient of radiation and T_r is the temperature of radiation source.

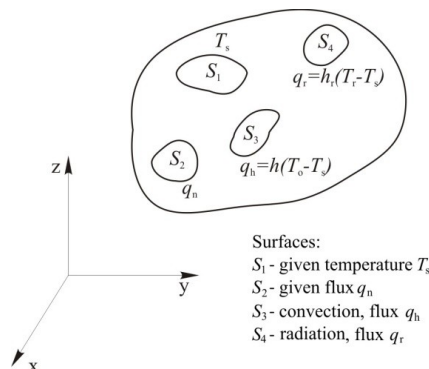


Figure 1 Boundary conditions for heat transfer through solid

Since the wagon structure is exposed to high temperatures, there is a significant change in the coefficients of heat depending on the temperature. Therefore, non-linear thermo-mechanical analysis can be implemented with implicit iterative method of solving non-linear problems:

$$\left(\frac{1}{\Delta t} \mathbf{C}^{(i-1)} + \mathbf{K}^{(i-1)} \right) \Delta \mathbf{T}^{(i)} = {}^{t+\Delta t} \hat{\mathbf{Q}}^{(i-1)}$$

where $\hat{\mathbf{Q}}^{(i-1)}$ are determined as:

$${}^{t+\Delta t} \hat{\mathbf{Q}}^{(i-1)} = {}^{t+\Delta t} \mathbf{Q}^{(i-1)} - \mathbf{K}^{(i-1)} {}^{t+\Delta t} \mathbf{T}^{(i-1)} - \frac{1}{\Delta t} \mathbf{C}^{(i-1)} ({}^{t+\Delta t} \mathbf{T}^{(i-1)} - {}^t \mathbf{T})$$

Matrix $\mathbf{K}^{(i-1)}$ contains matrices for conduction, convection and radiation respectively. Procedure of solving equation (6) is rather described in [2] and [3].

3. CALCULATION OF HEAT TRANSFER THROUGH BEAM SUPPORT OF WAGON STRUCTURE

This example considering a beam supports for steel ingots simultaneously exposed to thermal loads (fig. 2). In observed case of loading steel ingot have a temperature up to 500 °C. Steel ingots are placed on 8 beam supports. There is a floor panel as a thermal shield between beam supports and wagon structure.

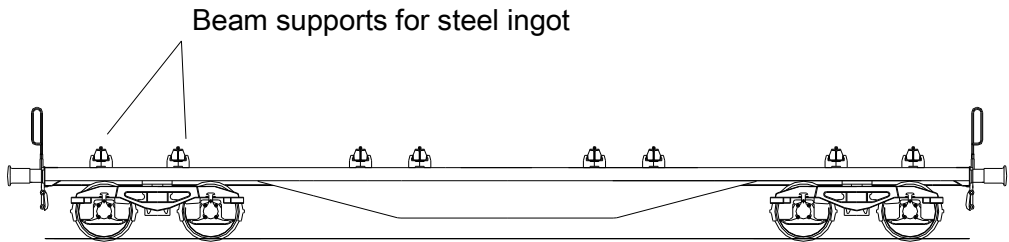


Figure 2 Drawing of wagon for transportation of steel ingots

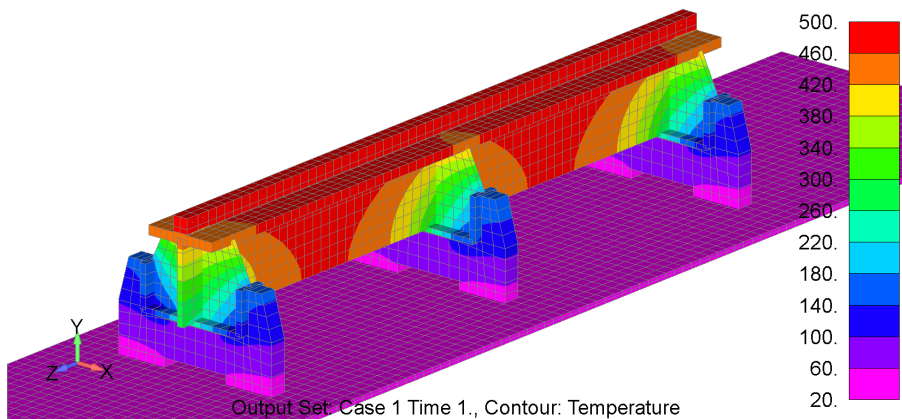


Figure 3 Temperature field of beam support-isometric view

Finite element mesh of beam support was created by shell and 3D elements. There are the following boundary conditions for this problem: (a) temperature of 500 °C at the surface where the ingots are loaded and (b) convection on surface where beam support is in contact with the floor panel of wagon structure. In figs 3. and 4. temperature field of beam support is shown.

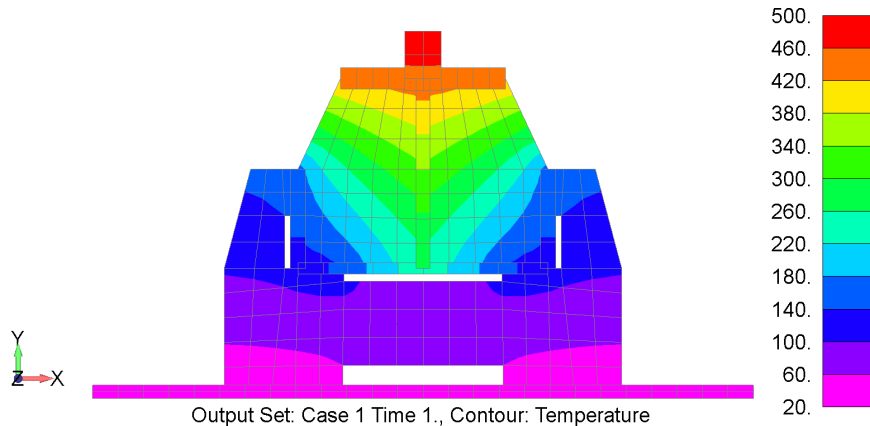


Figure 4 Temperature field of beam support-XY view

4. CONCLUSION

Analysis of wagons for transportation steel ingots is an example of how to successfully solve heat transfer problems in a practical example that is very commonly found in the railway industry.

Presented results proved that heat transfer analysis of beam support structure satisfy the criteria defined by mentioned standards and proposed boundary conditions. It can be seen that the effect of heat transfer through steel ingots has no influence on a floor panel at the given boundary conditions. Also, paper presents successful solution problem of heat transfer in software PAK-T.

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IMPROVEMENT AND INTEGRATION OF FEM SOLUTION USED FOR R&D INTO FEMAP

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Abstract: This Computer simulation and structure behavior researchers often develop their own FEM solution for testing new material models, element types or numerical procedures. Improvement and integration of user developed FEM solution into FEMAP which is state of the art pre and post-processing software has a purpose to enable researchers to focus more on their scientific investigation by reducing tedious workload that is result of inadequate UI of user developed solver. Developed methodology presented in this paper enables researchers to create analysis CAD model in FEMAP, perform FEM analysis testing new material models, element types or numerical procedures in user developed solver and view results back in FEMAP. Connection between FEMAP and user developed FEM solver is performed by automatic, programmatic customization of FEMAP and development of new features in FEM solution. These new features automate many tasks in model preparations. As a result, FEM solver looks and operates as integral part FEMAP and its functionality is greatly improved.

Key words: computer simulation, finite element method, pre-processing, post-processing, software customization

1. INTRODUCTION

Computational methods [1] such as Finite Element Method (FEM) [2] in particular, are used for stress analysis in many fields of engineering. Wide spread of FEM means its taught on many engineering universities as well as used in many research institutes. Numerous software companies developed their FEM solutions which are widely used by many manufacturing companies. Commercial FEM solvers have good pre-processing (geometry modeling and mesh generation) as well as good post-processing (visualization of results) [3]. Downside of commercial software is no or limited access to program code which hurdle independent researchers in testing behavior of new material models, element types or numerical procedures. To have advantages of both approaches, we used combination of researcher developed FEM

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solution and commercial program used for pre- and post-processing. In this paper we described linking of our R&D FEM solver with commercial program for pre and post-processing FEMAP. Second section of this paper describes current state of implementation of R&D FEM solution in Engineering Software Lab. In the third section we described methodology used to customize FEMAP UI and create new C++ program that links our software solution with FEMAP. In the fourth section of this paper we described new functionality of FEM solution integrated in FEMAP. In the conclusion we discuss benefits of new methodology.

2. CURRENT STATE OF IMPLEMENTATION OF R&D FEM SOLUTION WITH FEMAP

FEMAP is software used to create FEM models for different engineering problems [4],[5] and to display analysis results. FEMAP is solver neutral and provides comprehensive pre- and post-processing support for all of the major commercial solvers on the market, such as NX Nastran, which is built in FEMAP, and others. FEMAP can create input files for those solvers and it also can read result from their output files. To use FEMAP with unsupported solvers, such is our R&D FEM solution, users need to save analysis model into ASCII file called FEMAP Neutral (*.neu), which serves as universal data transfer interface (input and output) between FEMAP and any other program. Before analysis neutral file is generated manually by user from FEMAP and after FEM analysis R&D solver generates neutral file which is also inputted manually by user into FEMAP. FEM solver uses its own input file, which uses data from FEMAP Neutral, supplemented with data inputted by researcher needed for his specific research. Significant number of operations needed to perform FEM analysis with R&D solver is tedious work of FEM solver input file preparation and generation, manual starting of FEM analysis and loading results. We automated all these operations.

3. CUSTOMIZATION OF FEMAP USER INTERFACE

FEMAP allows users to customize its UI through options accessible through main program menu by choosing *Tools->Toolbars*. User can create *User Commands* which can be used for starting user's own program from FEMAP. Once created, *User Command* can be placed in main menu, some sub menu or any toolbar. In our case we want to create user command that, when clicked, starts out FEM solution.

For programmatic customization of FEMAP we used FEMAP Application programming interface (API) [6] that allows users to customize FEMAP to meet their specific needs and contains hundreds of methods that can be called from Visual Basic, VBA (Excel, Word, Access, ...), C, or C++.

To customize FEMAP we needed access to application object [6]. We developed solution that programmatically create FEMAP *User Command* and place it in FEMAP main Menu Bar by calling FEMAP API methods. Our next step was to create Windows Installer Package which unpacks FEM solution after which automatic programmatic customization is performed.

4. AUTOMATION OF ANALYSIS PROCESS USING FEMAP AND R&D FEM SOLUTION

The procedure to convert FEMAP model into research solver input file begins with creation of FEMAP neutral file.

After the FEM solution is started from FEMAP, there are several actions it performs:

- attach itself to FEMAP using FEMAP API
- create FEMAP neutral file using API methods
- read data from FEMAP neutral file

Creation of R&D solver input file is a relatively straightforward process in which translator program writes data obtained from FEMAP neutral file into solver input file. Some additional analysis parameters (not present in FEMAP neutral file) can be inputted in translator. Translator can start FEM analysis, from within FEMAP, of previously generated input file. Creation of solver input file without starting analysis is used when researchers use one computer for modeling in FEMAP, and server or a cluster for FEM analysis. Batch file is generated which is used to start R&D solver, which is a console application programmed in FORTRAN, and feeds it with previously generated input file. To start batch file we used *_spawnl* method which will start analysis process and pause execution of translator segment of our FEM solution until analysis in R&D solver is finished. When analysis is finished, execution of FEM solution will continue and new pop-up dialog will be created alerting user that analysis is finished and that results are available for loading.

5. RESULTS AND DISCUSSION

Translator program, customization program and R&D solver (*pak.exe*) are all part of our FEM solution [7]. Windows Installer Package is used for FEM solution installation. Users need to start setup program and if they desire, change installation directory. Everything else is carried out automatically and users are not aware of FEMAP customization process that runs in the background. After the setup is complete users can start FEM solution called PAK from FEMAP Main Menu (Figure 1).

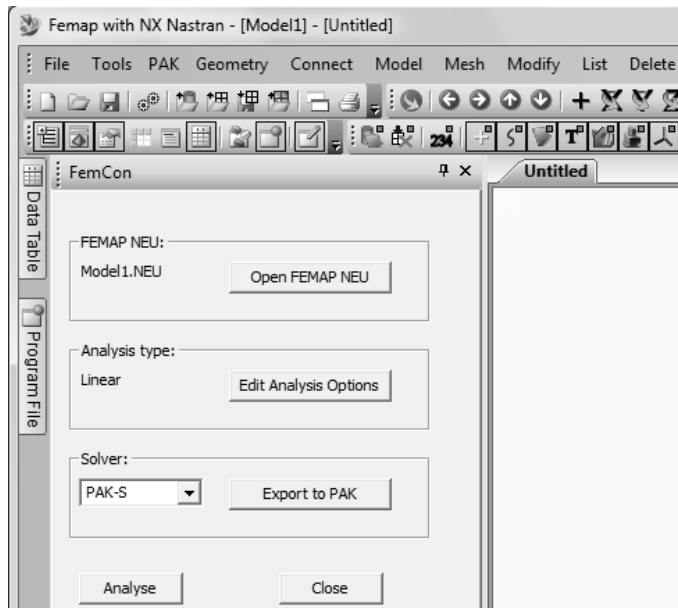


Fig.1 R&D FEM solution integrated in FEMAP

Following simple example is used to demonstrate new methodology [8]. Example shows the application of iterative arc-length method, follows the history of deformation of the structure with snap-through and snap-back effects. Circle arc having unsymmetrical supports is loaded by force (Fig. 2). Force increase causes large displacements of a structure. Material is isotropic and elastic.

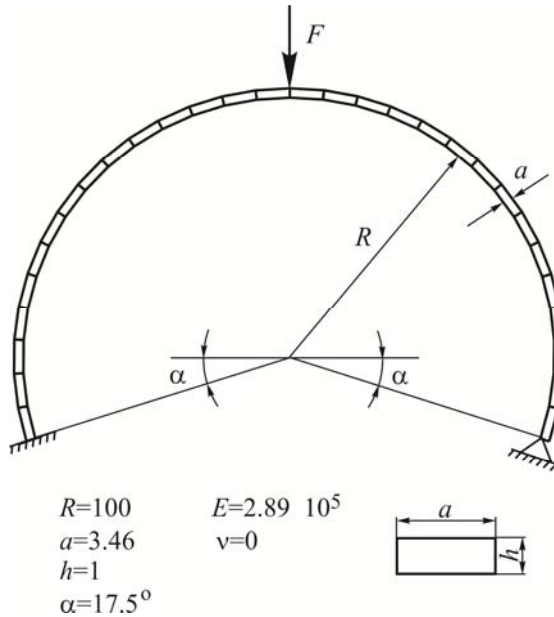


Fig.2 Arc analysis in R&D solver PAK

Modeling in FEMAP is described in FEMAP User Manual [6]. First step is definition of material with characteristics shown on Figure 2.

Young's Modulus, E is $2.89E5$

Shear Modulus, G is 0

Poisson's Ratio, ν is 0

Second step is property definition, in this case users should choose **Membrane Plane Elements** with **Thickness T1** equal 1.

Third step is geometry creation, in this case two arcs defined by their center, start and end point.

First circle arc:

Center: $x: 0 ; y: 0 ; z: 0$

Start: $x: 97.022 ; y: -30.951 ; z: 0$

End: $x: -97.022 ; y: -30.951 ; z: 0$

Second circle arc:

Center: $x: 0 ; y: 0 ; z: 0$

Start: $x: 93.722 ; y: -29.550 ; z: 0$

End: $x: -93.722 ; y: -29.550 ; z: 0$

After creation of two arcs, users need to make a surface from them.

Fourth step is mesh generation. In this step users need to set mesh size for surfaces then select surface to mesh and finally, select property defined in step 2.

Fifth step is constraints definition. Unsymmetrical supports (Fig. 2.) are modeled by constraining translation of both lowest nodes on the left side and inner lowest node on the right side in X and Y direction. Permanent constrains are set for all nodes disabling translation in Z direction and rotation in all directions.

Sixth step is definition of load. Nodal force of -1 in Y direction is set on top node. After definition of load, model is ready for analysis (Fig. 3).

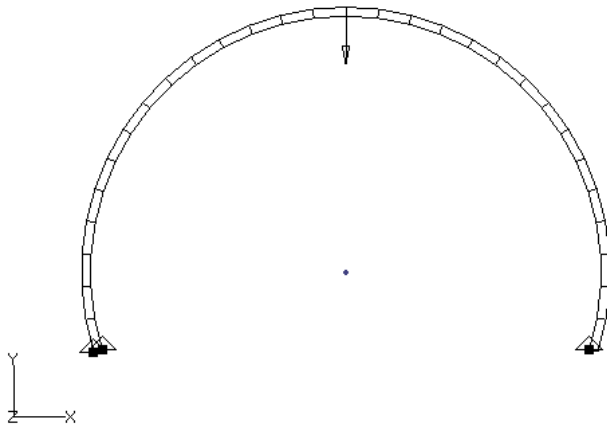


Fig.3 Model in FEMAP ready for analysis

Researchers can start translator program by clicking on a "PAK" option that is added in FEMAP Main Menu (Fig. 1). When started, translator attaches itself to top leftmost panel of FEMAP (Fig. 1). Now researchers need to set up analysis parameters by clicking on button **Edit Analysis Options** (Fig. 1). First parameter is **Analysis type**; in this case **Total Lagrangiane** (Fig. 4).

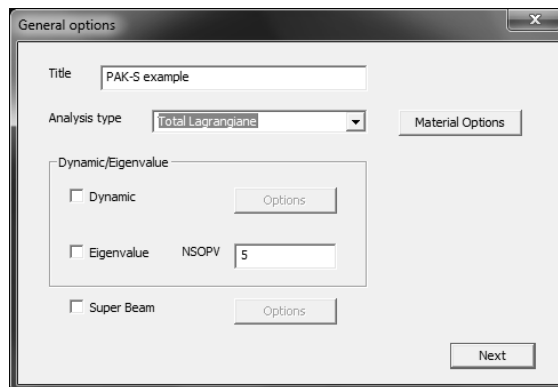


Fig.4 Translator dialog for selecting analysis type

In the next dialog researchers need to define number of steps (in this case 180) and time step increment of 1 (Fig. 5).

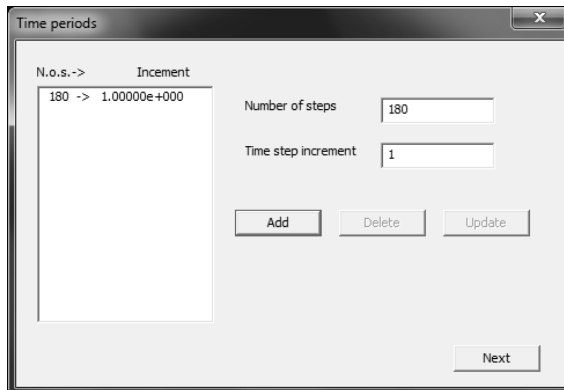


Fig.5 Translator dialog for selecting time periods

Next step is set up of **Iteration method (Arc length + full Newton)** and data for automatic load stepping (Fig. 6)

- Node Number: 47
- Direction: 2 (2 represents y direction)
- Value: -1 (initial displacement)
- AG :2 (coefficient of increase of displacement)
- DS: 2 (coefficient of arc length increase)

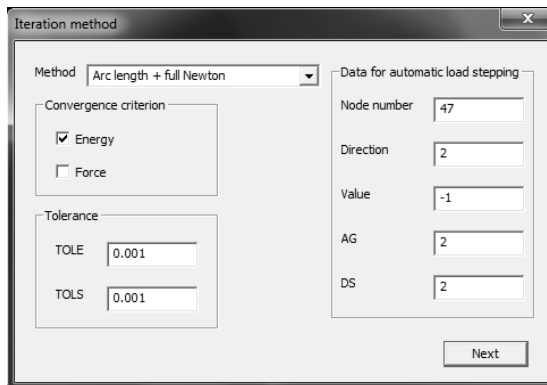


Fig.6 Translator dialog for selecting iteration options and automatic load stepping

After researchers have entered all necessary data, they can start FEM analysis by clicking **Analyze** button (Fig. 1). This action starts analysis in R&D solver PAK, and when the analysis is finished users can load analysis results (Fig. 7).

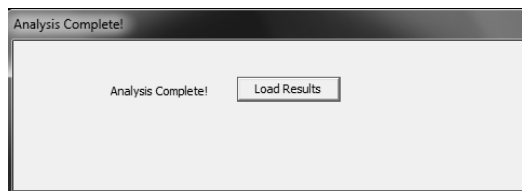


Fig.7 Analysis Complete dialog

When researchers click on **Load Results** button (Fig. 7). results are loaded into FEMAP and translator (Fig. 1) is closed. In order to view values of interest, such as stress or displacement, users need to select option from FEMAP Menu *View->Select* [6]. In *View Select* dialog users can select *Deform* and *Contour* as style and click on *Deformed and Contour Data...* button which opens dialog *Select PostProcessing Data* in which users need to select what data to display. For example, selection of *Solid Von Mises Stress* and click on *OK* button on this and previous dialog gives stress values displayed on deformed shape (Fig. 8).

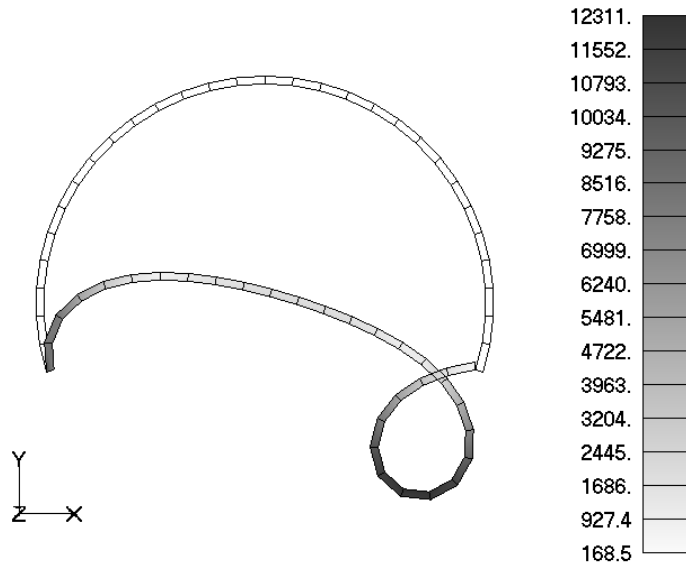


Fig.8 Analysis results: Solid Von Misses Stress

View Select dialog can be used to plot XY charts as well. if users want to export chart data they can use *List->Output->XY Plot* which will write data in specified *.rtf file. From that file data can be copied into Excel. Excel charts showing displacement of the node at which the force acts is shown on Figure 9 and Figure 10.

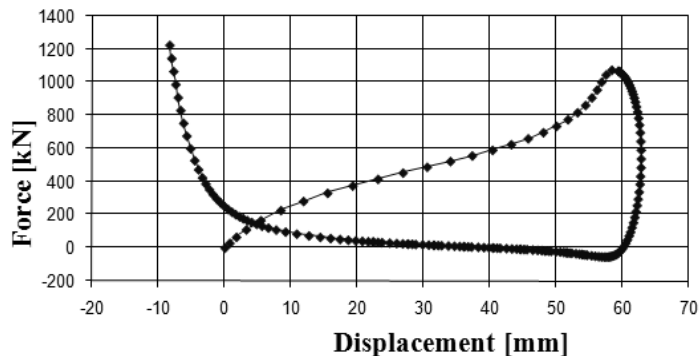


Fig.9 Displacement in X direction of the node at which the force acts

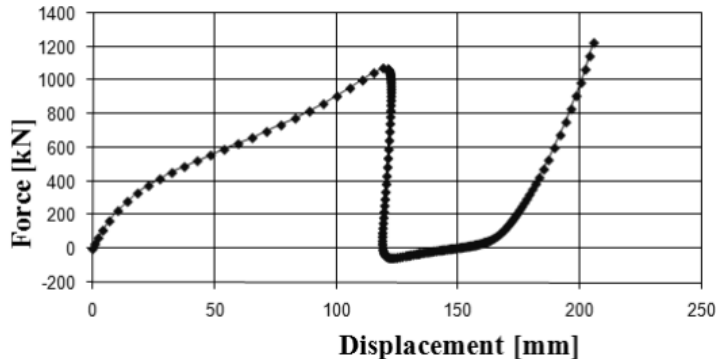


Fig.10 Displacement in Y direction of the node at which the force acts

6. CONCLUSION

R&D FEM solution PAK offers researchers opportunity to work on development of FEM program, to test their new material models, element types or numerical procedures. In this paper we described how we connected pre- and post-processing program FEMAP with PAK. Automatic generation of solver input file as well as automation of entire FEM analysis process is described. Implementation of new translator significantly reduced tedious workload that hurdles researchers in their research giving them more time to do actual research.

ACKNOWLEDGEMENT

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Session III ***DEVELOPMENT OF PRODUCTS AND*** ***MECHANICAL SYSTEMS***

Session III-1: DESIGN OF POWER ***TRANSMISSIONS***



RELIABILITY-BASED DESIGN OF BUCKET WHEEL EXCAVATOR GEAR DRIVE UNITS

Miloš Ristić¹, Milosav Ognjanović²

Abstract: In the field of Engineering Design various methods are established for technical systems development. Gear transmission units are really a complex structure with various indicators of their behavior, such as the level of reliability, vibration and sound level, etc. This article contains the application of property-based design approach to gear unit reliability system structuring, and then the application of elementary reliability as a design constraint in design parameters definition. A specific way for elementary reliability and system reliability is introduced. At example of bucket wheel gear unit elementary reliability is presented. Robust and axiomatic design of gear unit components is adapted for design parameters definition.

Keywords: Planetary gears, Reliability, Design, Property, Robust, Axiomatic

1. INTRODUCTION

Property-based design and product development is a specific approach that provides the possibility to obtain a mature product in the first attempt. In general, technical systems (products) are the relations established between the function structure, the organ (machine parts) structure and the system behavior.

The main task of the design process is to provide for the system behavior in order to satisfy necessary functional requirements (user needs). In the product design process, it is necessary to start with functional requirements and finish with the product behavior. Product behavior is the result of product components' properties and characteristics. For this purpose, in Fig. 1 the V-model of design process presented according to DIN-2206. This presentation explains the basis of the approach presented in this article. Reliability in the sense as shown in Fig. 1 can be a user need (functional requirement), an assembly or a part property and a product behavior indicator (parameter). The machine part property elementary reliability can be used as the design constraint in defining the design parameters of the part, assembly and complete design structure.

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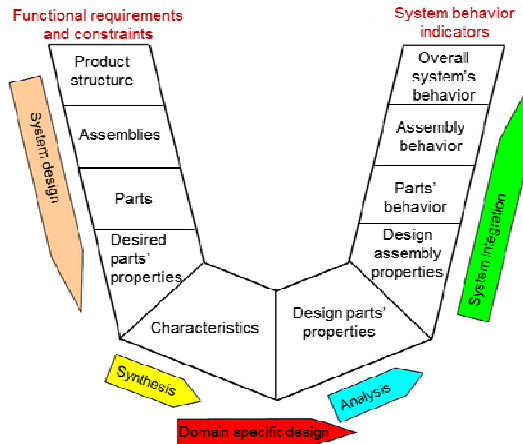


Fig. 1. Model for the property-based product development

2. GEAR SYSTEM RELIABILITY

Before deducing functional requirements, it is necessary to deduce design structure into components suitable for hierarchy processing of requirement indicator. In Fig.2a gear transmission unit for bucket wheel traction of bucket wheel excavator is presented. For hierarchy processing (deduction) of total gear unit reliability, gear unit is structured into three sub-units i.e. transmission steps. The first stage (I) contains bevel gear pair together with planetary set for auxiliary drive. The second (II) and third (III) stages are planetary sets connected between each other. Physically, decomposition is realised by dismounting the middle screw bolted joint.

In Fig.2b is presented the structure of elementary reliability for all three stages of the gear drive unit i.e. reliability three. The second II and third III stages include reliability of planetary gear set - PGS, reliabilities of the two bearings supporting planetary carriers - Bg and reliability of the bearings supporting satellite gears - BS. These three bearings SB are equal and have to be removed when the first of them fails. This is the reason why the reliability SB is equal to one of the three equal reliabilities of the three satellite gears. Presentation in Fig.2b contains reliabilities of the three sealing sets Se, one at the III-stage i.e. at the output shaft, one at the input shaft and one at auxiliary traction shaft (stage-I).

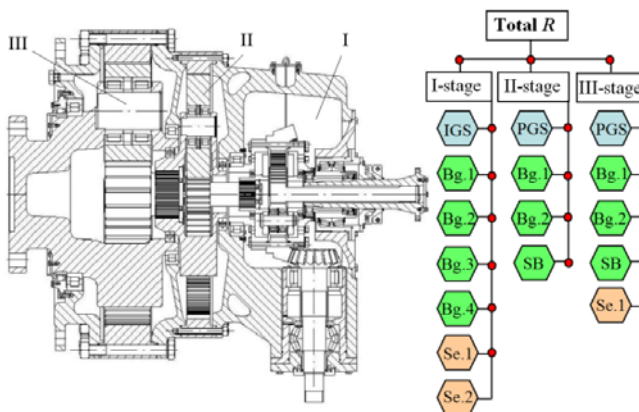


Fig.2. Planetary gear drive unit of the wheel of bucket wheel excavator:
a) Gear drive drawing, b) structure of elementary reliability – reliability tree

The first stage of the sub-system is presented in Fig.3. This is the gear system which consists of bevel gear pair and planetary gear set settled inside the bevel gear. The bevel gear pair transmits torque from the main traction motor to the second stage of planetary gear set. In the course of this operation inside the planetary gear set is fixed by the shaft for auxiliary drive. When the mine traction motor (shaft with the bevel gear) is fixed, auxiliary drive is acting via planetary gear set and bevel gear presents the inside toothed ring of this planetary set. Bevel gear and inside toothed ring of planetary set is the same machine part. Failure of the bevel gear pair (RBG), or failure of the planetary gear set (RPG), requires the replacement of both, bevel gear pair and planetary gear set. This is why the reliability of all gears in I-stage assembly R_g (Fig.3) is equal to minimal reliability of RBG and RPG. This planetary gear set contains four bearings B-1, B-2, B-3 and B-4, and each of them in the reliability three in Fig.3b is presented by a single elementary reliability. Also, satellite gears are supported by bearings and elementary reliability of one of them S_b is included in the reliability system. The reason for this was explained above. The satellite carrier can be damaged in the spleen connections and elementary reliability is presented by SC. Elementary reliabilities of gears, bearings of planetary gear set and satellite carrier, multiplied between each other, all present the reliability of input gear set IGS (RIGS). The system of reliability of the I-stage gear unit is completed by elementary reliabilities of bearings Bg-1, Bg-2, Bg-3, Bg-4 and reliabilities of seals Se-1 and Se-2. These bearings are supporting bevel gear pair and the whole assembly of bevel gear pair and planetary gear set inside the bevel gear hub.

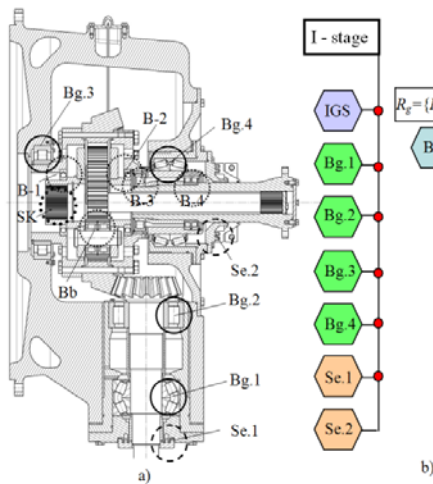


Fig.3. First stage of the gear drive unit presented in Fig.2: a) Design structure, b) Structure of reliability system

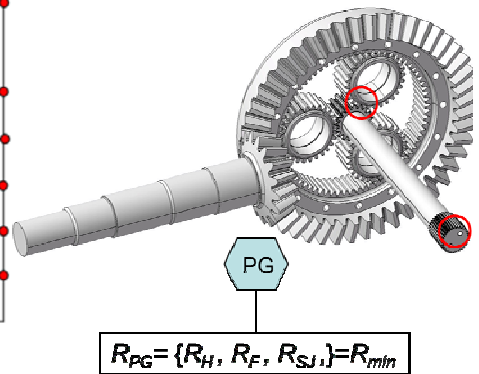


Fig. 4 Relation of teeth wears in planetary gear set

Gear pair can be damaged by wear of the teeth flanks or by teeth fracture. For both damages, unreliability (elementary reliability) can be defined and calculated. The question raised is how to define total reliability of the gear pair. It is necessary to consider the next facts: (a) If one gear is damaged, it is necessary to remove both – complete gear pair; (b) Gear pair has to be removed when the first damage arises – wear or fracture. These are the reasons why total reliability of the gear pair is equal to lesser reliability connected to wear or fracture. In the dominant number of cases gear wear reliability is lesser and this is the total reliability of gear pair.

3. GEAR UNIT DESIGN

Design parameters of gear unit components provide fulfilment of the overall design behavior. Design robustness based on axiomatic rules is suitable approach for design parameters definition. Necessary properties of components are constraints in this process. Axiomatic approach contains two axioms, the axiom of independency and the axiom of information minimum. Transformation matrix $[A]^{-1}$ (Fig.5) defines the relations in design component, which are constrained by numerous limitations, such as safety or reliability, stiffness, standards, rules, etc.

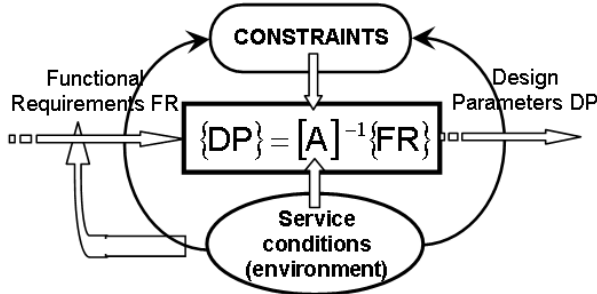


Fig. 5. Relations in axiomatic approach

4. ELEMENTARY RELIABILITY AS DESIGN PROPERTY

Elementary reliability R is defined at the level of machine part or assembly and connected to a certain failure of this component. In contrast to reliability there stands unreliability $F_p=1-R$ that presents the complex probability. This is a combination of service conditions probability p and failure probability P_F under these service conditions, gear wear unreliability can be calculated as

$$F_p = \sum_{i=1}^n p_i P_{Fi}; \quad p_i = \frac{n_{\Sigma i}}{n_{\Sigma}}; \quad P_{Fi} = 1 - e^{-\left(\frac{\sigma_{Hi}}{\eta_i}\right)^{\beta_i}} \quad (1)$$

Teeth wear (failure) probability is presented by Weibull's functions, where the parameters of those functions are defined for every stress level and cycle number (see Fig.6).

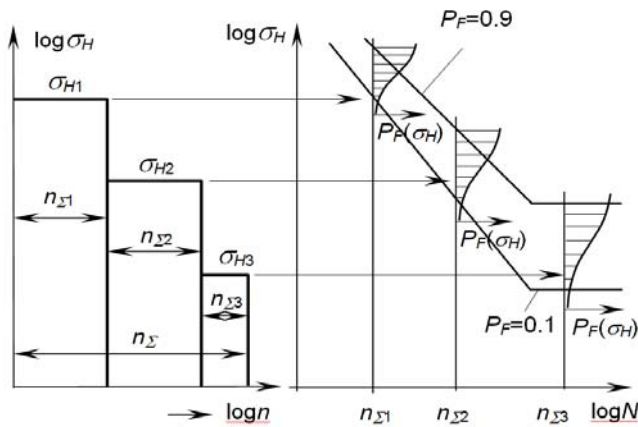


Fig. 6. Relation between service stress varying and gear wear probability

5. SERVICE CONDITIONS, LOAD SPECTRUM AND RELIABILITY OF CENTRAL PINION OF OUTPUT TRANSMISSION STAGE

Planetary gear drive is declared for nominal operating conditions. The service it is exposed to the effect of work load whose size reaches an upper acceptable limit. These conditions can occur occasionally or frequently. Service regime in this regard is the statistical evaluation of the representation of the stress from the same set of their sizes, depending on the conditions of operation. In this sense we can speak of light, medium and heavy work regime. The ratio of participation of large and small stresses (loads) can be displayed in load spectrum. In this article we will consider heavy load regime in life period of 10 years.

Service regime of the excavator wheel is the result of analysis of the levels of wheel torque, which are the result of material resistance during service life. By measurement, calculation and assessment it is possible to define a few torque levels which can characterize the operating regime. Maximal torque is limited by control system of excavator. This relation is at the level of 1.6 of nominal torque. Lowest level of torque is less than nominal but not too less because excavator exploitation is oriented to the full use of the system capacity. The number of wheel revolutions along the service life can be also calculated and assessed. Usability of the dredger along service life has also to be considered in this assessment. For every level of torque, it is necessary to assess and calculate the number of wheel revolutions. Using of this approach in Fig.7 shows the load spectrum of bucket wheel. Fig.7 present the range of load spectrum between the middle service regime and the heavy regime.

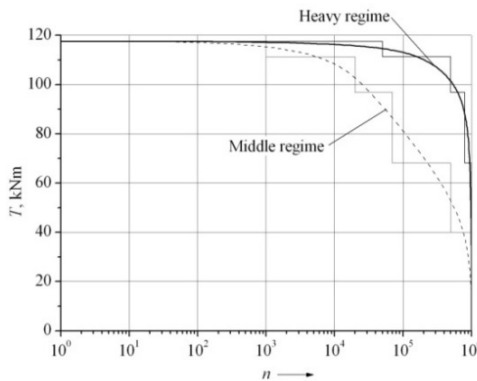


Fig. 7. Load spectrum range of bucket wheels

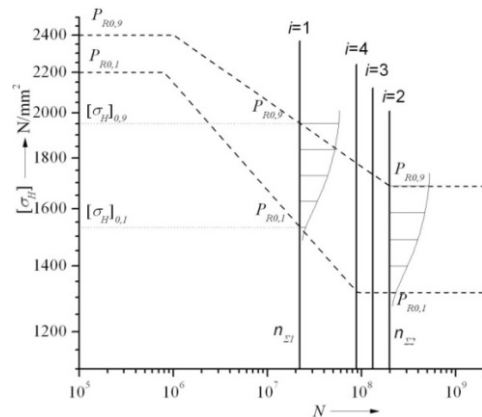


Fig. 8. Wear probability distribution of carbonized teeth flanks for the stress cycles number along 10 years of service life

Reliability of central pinion of output transmission stage is $R=1-F_p$. Unreliability F_p is complex probability composed of the probability that certain value of the operating stress will appear $p_i(\sigma_{Hi})$ and the probability that wear failure of teeth flanks will appear under effect of that stress $P_{Ri}(\sigma_{Hi})$. Parameters η_i and β_i used in (1) are parameters of Weibull's function for each stress cycles number $n_{\Sigma i}$. The parameter η_i is expressed in units of stress and β_i is the dimensionless exponent. They are defined on the basis of limit values of teeth flank endurance σ_{HN} for the failure probability $P_R=0.1$ and $P_R=0.9$ (see Fig.8). The first limit corresponds to the visual beginning of surface failure of teeth flank, and the second corresponds to the thickness of layer removed by wear $0.3m_n$ (m_n – gear module).

Table 1. Wear unreliability calculation of central planetary pinion (Heavy service regime in duration of 10 years)

i	1	2	3	4
T_{z7} , kNm	117.6	111.3	96.9	68.2
σ_{Hi}	1511.2	1470.1	1371.9	1150.9
$n_{\Sigma i}$	$2.2 \cdot 10^7$	$1.98 \cdot 10^8$	$1.32 \cdot 10^8$	$8.8 \cdot 10^7$
$[\sigma_{Hi}]_{0.1}$	1532	1315	1315	1318
$[\sigma_{Hi}]_{0.9}$	1952	1687	1733	1779
$\beta_i(\sigma_{Hi})$	12.73	12.38	11.17	10.28
$\eta_i(\sigma_{Hi})$	1828.2	1577.1	1608.4	1640.4
$P_{Ri}(\sigma_{Hi})$	0.08473	0.34229	0.15561	0.02580
$p_i = n_{\Sigma i} / n_{\Sigma}$	0.05	0.45	0.3	0.2
$p_i \cdot P_i(\sigma)$	0.0042365	0.1540305	0.046683	0.00516

Using the presented approach and mathematical model in table 1, calculation results for 10 years' service life are presented. Calculated unreliability is $F_p=0.206$ and reliability $R=0.794$.

6. CONCLUSION

The presented methodology shows a few new approaches to design of technical (mechanical) systems applied for gear transmission units design. Some of the new approaches and applications are as follows:

- Property-based product development is presented and applied for gear units design. Gear unit reliability is treated as a functional requirement at the beginning of the development process, as a structural component property in order to design parameters definition, and as an indicator of product behavior at the end of the process.
- The new and specific way of gear units reliability structuring is presented. Reliability is connected to possible failures at the elementary level, at the assembly level, and at the system level. Structuring of the system reliability is also specific.
- Axiomatic approach and robust design methodology are also adapted for application in gear transmission units design.

This article contains a few specific results presented in the form of models applicable in the design process of gear drive units for bucket wheel excavator. Planetary gear drive units are really new in this area of application. Load regime in the course of service life is also presented in the form of load spectrum. A specific model for reliability calculation of this transmission unit is presented and applied for the extreme conditions of excavator exploitation.

Acknowledgment

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SOME IRREGULARITIES WHICH MAY OCCUR DURING IMPLEMENTATION HCR GEARING

Milan Rackov¹, Siniša Kuzmanović², Željko Kanović³, Miroslav Vereš⁴

Abstract: Special kind of basic involute profile of non-standard gearing is called high contact ratio (HCR) gearing, when the contact ratio is higher and there are always at least two pairs of teeth in contact ($\varepsilon_\alpha \geq 2$) and where unit addendum height is not equal one like for standard gearing, so the tooth height is increased and it is bigger than one. HCR profiles are more complicated than standard involute profiles, they have greater predisposition for occurring interference, pointed tip thickness, but also undercut of teeth during the production (primary production interference). Due to increased addendum height, there is larger possibility of occurring some interference or pointed tooth tip. Therefore it should prevent these errors and check if all equation and constraints are satisfied.

Keywords: gears, HCR gearing, geometry, optimization.

1. INTRODUCTION

Contact ratio can be defined as a number of pairs of teeth in contact during the course of action. The physical significance of the contact ratio lies in the fact that it is a measure of the average number of teeth in contact during the period in which a tooth comes and goes out of contact with the mating gear.

$$\varepsilon_\alpha = \frac{\text{length of contact}}{\text{base pitch}} = \frac{g_\alpha}{p_{bt}} \quad (1)$$

The minimum acceptable contact ratio for smooth operation is 1.2. Gears should not generally be designed having contact ratios less than about 1.2, because inaccuracies in mounting might reduce the contact ratio even more, increasing the possibility of impact between the teeth as well as an increase in the noise level. To ensure smooth and continuous operation, the contact ratio must be as high as possible, which the limiting factors permit. A minimum contact ratio of 1.4 is preferred, and larger is better. Contact ratios for conventional gearing are generally in the range 1.4 to 1.6 [1]; so the number of tooth engagements is either one or two.

Special kind of basic involute profile of non-standard gearing is called high contact ratio (HCR) gearing, when the contact ratio is higher and there are always at

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least two pairs of teeth in contact ($\epsilon_\alpha \geq 2$) and where unit addendum height is not equal one like for standard gearing, so the tooth height is increased and it is bigger than one ($h_a^* > 1$). General distribution of applied force in characteristic points of HCR gear tooth flank is shown in Fig.1-2. When comparing these both kind of gearing, it is clearly obvious that in the case of involute gearing the maximum force is applied when one pair of teeth is in contact (between points BD, Fig.1-1), which can be considered 100% of the value of the force F . The biggest applied force in the HCR gearing (between points BB' and DD') can be considered about 50%, when two pairs of teeth are in contact. Consequently, the size of the applied force is decreased when three pairs of teeth are in contact. So, the value of involute gearing $2/3F$ is decreased to $1/3F$, and value $1/3F$ is decreased to $1/6F$, which means the load distribution is more favorable in the HCR gearing.

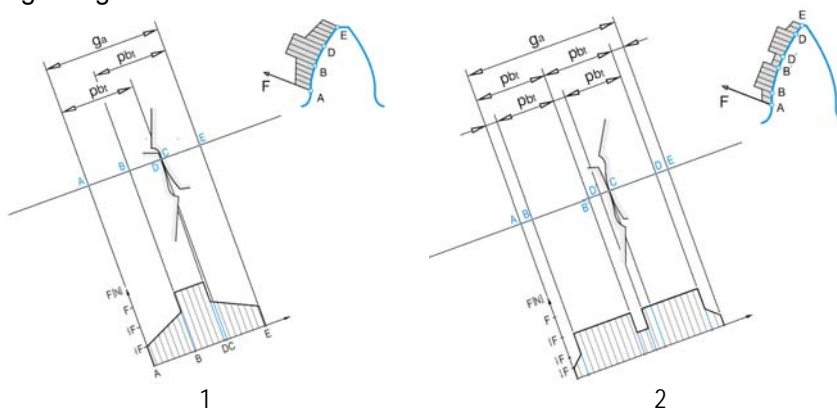


Fig.1. Distribution of tooth load during normal contact ratio (1) and distribution of tooth load during high contact ratio (2)

2. THE EFFECT OF HCR GEARING ON OPERATING OF GEAR PAIR

Contact ratio is better to be as large as possible because HCR gears are less sensitive with respect to manufacturing errors, the vibration and gear noise are less, the load capacity is higher and the load distribution is more favorable in the HCR gearing. But when HCR gearing is used, there is a greater risk of interference due to a greater height of tooth. Advantage of the HCR gearing is also a higher resistance (load distribution is shared on the more pairs of teeth at the same time) and lower relative noise level of gearing, which can be significantly reduced by using integer HCR factor ϵ_α . HCR profiles are more complicated than standard involute profiles, they have greater predisposition for occurring interference, pointed tip thickness, but also undercut of teeth during the production (primary production interference). In high precision and heavily loaded spur gears, the effect of gear errors is negligible, so the periodic variation of tooth stiffness is the principal cause of noise and vibration. High contact ratio spur gears could be used to exclude or reduce the variation of tooth stiffness.

It is well known that increasing the average number of teeth in contact leads to excluding or reduction of the vibration amplitude. First, it was established experimentally that dynamic loads decrease with increasing contact ratio in spur gearing [2]. Moreover, in order to get a further reduction of the vibration, HCR gear

profiles can be optimized. Sato et al. [3] found that HCR gears are less sensitive with respect to manufacturing errors. In particular, such kind of gears allows larger tolerance in the tip relief length. Moreover, they found that, in the absence of pressure angle error, the best contact ratio should be about 2; otherwise, it is better to have a contact ratio about 1.7 or higher than 2.3. Kahraman and Blankenship [4] published an experimental work on HCR gear vibration; they found that the best behaviour is obtained with an integer contact ratio, even though other specific non integer (rational) contact ratios can minimize the amplitude of some specific harmonics of the static transmission error. It is important to note that in Ref. [4] HCR gears were obtained by modifying the outside diameter; the other macro-geometric parameters, e.g. the number of teeth, were left unchanged. Other parameters can also influence on operation noise level, such as module, rack shift factor of gearing, gear ratio, gear manufacturing deviations, and also the gear lubrication.

$$\varepsilon_{\alpha} = f(h_a, \alpha) \quad (2)$$

The increase in contact ratio can be implemented in two ways: by decreasing pressure angle and by increasing tooth height. Obviously, the use of a standard pressure angle and standard tools is preferable [5]. Therefore, the most favorable solution is obtained by increasing addendum height, but however there are a lot of geometrical and manufacturing constraint that has to be satisfied which limits increasing the contact ratio.

The equation (1) shows that $\varepsilon_{\alpha} = f(g_{\alpha}, p_{bt})$. Tooth pitch on the base circle of standard involute gearing is equal to base pitch on HCR gearing, and it is considered as constant. This means that achieving the greatest value of the contact ratio ε_{α} has to be obtained by the greatest possible increase of length of line of action g_{α} .

The main optimization parameter at this level can be addendum heights of teeth h_{a1} , h_{a2} , and factors of correction x_1 and x_2 [5]. For a given distance between centers of the wheels, x_c can be defined as relationship between x_1 and x_2 . So, that means contact ratio is the aim function of both addendum heights and correction factor of pinion $\varepsilon_{\alpha} = f(h_{a1}^*, h_{a2}^*, x_1) \geq 2$, i.e. optimization parameters h_{a1}^* , h_{a2}^* , x_1 make a nonlinear optimization of triple constraint, with limitations requirements defined for constraints which occur in HCR gearing like removal of meshing interference, minimum arc thickness of the tooth tip and also distribution x_c to x_1 , x_2 has to be done through balancing specific slips, strength, or a particular condition, respectively compromise their combinations [6]. There are several constraints which should be satisfied that these irregularities should not occur. If some constraint can not be satisfied, the gear can not be produced with high contact ratio, or it will be produced with interference or undercut teeth.

3. INTERFERENCE DURING THE PRODUCTION

This interference occurs in the production process of gear forming when the tooth of the rack tool is in collision with a produced transition curve of the gear wheel, resulting in a so-called undercut tooth.

This phenomenon largely depends on the method of manufacturing process. Unfavorable conditions arising with manufacturing by tool rack, so if it is not known in advance the means of production, always should check the production interference of gearing for production by tool rack.

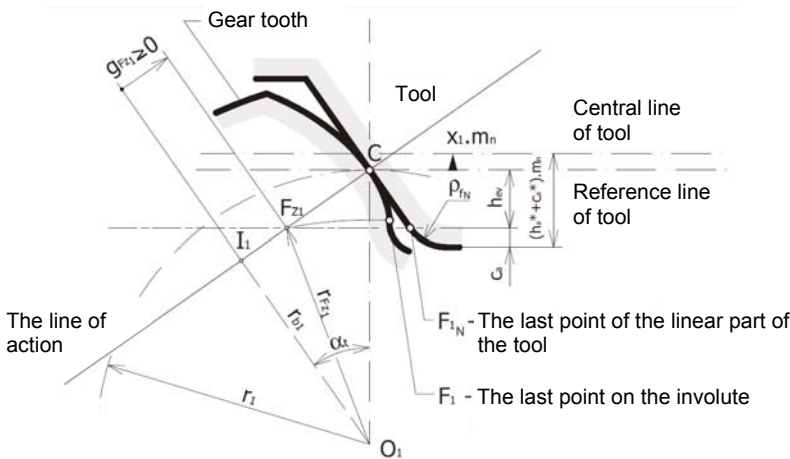


Fig. 2. Interference during the production with tooth rack tool

Interference during the production will not occur if following condition is satisfied:

$$g_{Fz1} \geq 0 \quad (3)$$

where the expression is also valid for the length g_{F2} (Fig. 2):

$$g_{Fz1} = I_1C - F_{z1}C = r_{b1} \cdot \tan \alpha_t - \frac{h_{ev}}{\sin \alpha_t} = r_{b1} \cdot \tan \alpha_t - \frac{m_n}{\sin \alpha_t} (h_{a1}^* - x_1) \quad (4)$$

$$h_{a1}^* \leq \frac{r_{b1} \cdot \sin^2 \alpha_t}{m_n \cdot \cos \alpha_t} + x_1 ; \quad h_{a2}^* \leq \frac{r_{b2} \cdot \sin^2 \alpha_t}{m_n \cdot \cos \alpha_t} + x_2 \quad (5a),(5b)$$

It is very important that the unit value of addendum height h_{a1}^* for pinion satisfy the condition (5), so the interference during production will not occur. Similar for gear wheel the condition for h_{a2}^* should be satisfied (5b).

4. MESHING INTERFERENCE

Meshing interference is referred in the case of a collision between curves of teeth profiles as interference between these curves. It means that the meshing interference may occur as a collision of head of gear and the transition curve of pinion (Fig. 3) and / or head of pinion and the transition curve of gear wheel.

According to Fig. 3 it is possible to assess the interference between meshed head of gear wheel and transition curve of pinion, where the correct image in this case is only possible if the head wheel comes into engagement with the pinion of the involute part which is bordered with the meshing line and point F_{z1} (last point on the pinion involute).

According to Fig. 3, meshing interference will not occur only if distance g_{FZA} is bigger than distance g_{Fz1} , so only if engagement takes place on involute part first of all on the root of pinion tooth and on the addendum tooth of gear wheel. The position of the point F_{z1} was described by equation (4).

$$g_{FZA} = a_w \cdot \sin \alpha_{wt} - r_{a2} \cdot \sin \alpha_{at2} \quad (6)$$

Distance g_{FZA} should be bigger than distance g_{FZ1} , so:

$$g_{FZA} \geq g_{FZ1} \tag{7}$$

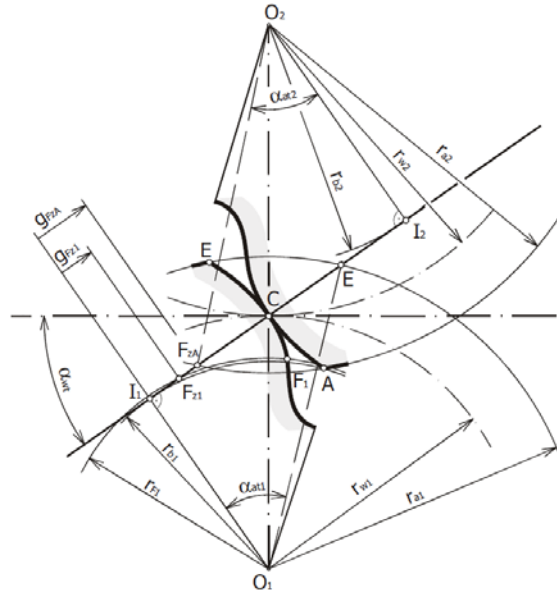


Fig. 3. Meshing interference between head of gear wheel and transition curve of pinion

Since the magnitude of the angle α_{at2} is a function of the addendum unit coefficient, i.e. $\alpha_{at2} = f(h_{a2}^*)$, the maximum value of h_{a2}^* for which meshing interference will not occur, so in which the tooth will not be shortened due to meshing interference, it is necessary to solve the transcendental equation (8):

$$h_{a2}^* \leq \frac{1}{m_n} \left[a_w \frac{\sin \alpha_{wt}}{\sin \alpha_{at2}} - r_{b1} \frac{\tan \alpha_t}{\sin \alpha_{at2}} + \frac{m_n}{\sin \alpha_t \cdot \sin \alpha_{at2}} (h_{a1}^* - x_1) - r_2 \right] - x_2 \tag{8a}$$

A similar relationship is also used for the parameter h_{a1}^* :

$$h_{a1}^* \leq \frac{1}{m_n} \left[a_w \frac{\sin \alpha_{wt}}{\sin \alpha_{at1}} - r_{b2} \frac{\tan \alpha_t}{\sin \alpha_{at1}} + \frac{m_n}{\sin \alpha_t \cdot \sin \alpha_{at1}} (h_{a2}^* - x_2) - r_1 \right] - x_1 \tag{8b}$$

5. MINIMUM THICKNESS OF THE TOOTH HEAD CIRCLE

Changing addendum height, h_{a1}^* will certainly influence the total thickness of the tooth on tip circle. Greater tooth height, as well as a positive correction factor, may affect the thickness of the tooth on tip circle under the permissible value.

According to equations according to Fig. 4 [6], tooth thickness on the tip circle is given by:

$$s_{a1} = d_{a1} \left(\frac{s_{kt1}}{d_1} + \text{inv} \alpha_t - \text{inv} \alpha_{at1} \right) \tag{9}$$

The same as for all conventional involute gearing, the thickness of HCR teeth on the tip circle is given by condition $s_a \geq (0.25-0.4) m_n$. For case-hardened teeth this value should be $s_a \geq 0.4 m_n$, due to lower risk of abrasion the tip of tooth.

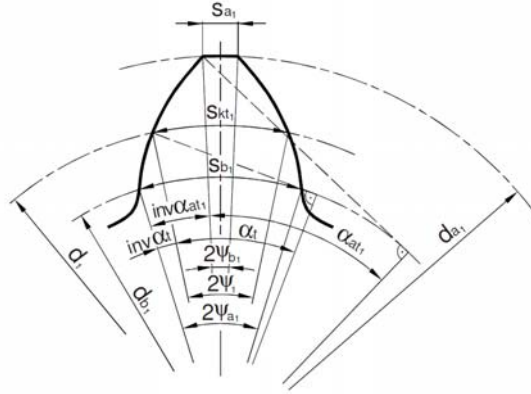


Fig. 4. Determination of the tooth thickness on the tip circle d_a

As mentioned earlier [6], the size α_{at1} angle is also a function of the unit addendum height $\alpha_{at1} = f(h_{a1}^*)$. Then for case-hardened teeth, after arranging the inequality becomes:

$$h_{a1}^* \leq \frac{0.2}{\frac{p_t + 4 x_1 m_n \tan \alpha_t}{d_1} + 2 \cdot (\text{inv} \alpha_t - \text{inv} \alpha_{at1})} - \frac{d_1}{2 m_n} - x_1 \quad (10)$$

A similar pattern is valid for the unit addendum height h_{a2}^* .

$$h_{a2}^* \leq \frac{0.2}{\frac{p_t + 4 x_2 m_n \tan \alpha_t}{d_2} + 2 \cdot (\text{inv} \alpha_t - \text{inv} \alpha_{at2})} - \frac{d_2}{2 m_n} - x_2 \quad (11)$$

6. SLIDE-CONDITIONS IN THE HCR INVOLUTE GEARING

When teeth of two gears are meshing, relative movement occurs between two meshed teeth due to different tangential speeds. Different tangential speeds cause the mutual slip velocity of tooth flanks. For qualitative assessment of sliding ratios between teeth, specific sliding coefficients are defined.

Regarding the length of tooth flanks, the situation that occurs in HCR gearing with velocities on tooth flanks is significantly less favorable compared to the standard profile.

A gear can work due to the fact that mating teeth slide and roll. Sliding causes wear and overheating, i.e. energy lost. Therefore the value of the gear efficiency is lower than the unit. In order to define the importance of sliding it is preferable to consider the relation of the sliding speed to the rolling speed at each point of contact. This relation is called specific sliding. It is positive on one wheel when the mating gear wheel slides on the other or when the wheel undergoes sliding. It is negative when sliding is caused by the considered tooth. [6]

If the points A and E on the line of action represents the beginning and the end of meshing, at the beginning of meshing the value of the specific sliding reaches the top on the driving wheel. When it ends its value reaches the top on the driven gear wheel. Specific sliding causes wear that concentrates particularly on the root at the tooth. All the precautions taken to reduce the value of specific sliding turn out to have strengthened the tooth resistance to wear [4].

To reduce losses during the meshing, specific sliding at the beginning and end of meshing should be balanced. This means that each sliding at the tooth root of one wheel must be equal to the size of the tooth addendum sliding of the other wheel. For this reason, there are conditions:

$$g_{1A} = g_{2E} \quad , \quad g_{1E} = g_{2A} \tag{12}$$

Then the condition of balancing specific sliding at the beginning and the end of the meshing has the following form:

$$\frac{1}{\tan\left(\arccos\frac{r_{b1}}{r_1 + (h_{a1}^* + x_1) \cdot m_n}\right)} + \frac{i}{\tan\left(\arccos\frac{r_{b2}}{r_2 + (h_{a2}^* + x_2) \cdot m_n}\right)} = \frac{1+i}{\tan\left(\arccos\left(\frac{a}{a_w} \cdot \cos\alpha_t\right)\right)} \tag{13}$$

Equation (13) is a transcendental equation which can be solved by some numerical methods, for example iterative method of dividing the interval [4].

7. APPLICATION OF HCR ON DIFFERENT GEAR PAIRS

Because of different constraints, there are some gear pairs which can not apply high contact ratio, so their ϵ_α is smaller than two. If the constraints are not satisfied, some interference can occur or tooth thickness is sharp and smaller than minimum.

Table 1. Calculation of contact ratio for different teeth numbers, modules and axis distance

z_1		12	13	14	15	16	17	18	19	20
$a_w = 90 \text{ mm}$										
$m_n = 3 \text{ mm}$	z_2	48	47	46	45	44	43	42	41	40
	ϵ_α	1.71	1.79	1.87	1.94	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2
$m_n = 4 \text{ mm}$	z_2	33	32	31	30	29	28	27	26	25
	ϵ_α	1.71	1.79	1.87	1.93	1.96	1.97	1.98	1.99	1.99
$m_n = 5 \text{ mm}$	z_2	24	23	22	21	20	19	18	17	16
	ϵ_α	1.54	1.56	1.57	1.58	1.59	1.59	1.59	1.59	1.59
$a_w = 100 \text{ mm}$										
$m_n = 3 \text{ mm}$	z_2	54	53	52	51	50	49	48	47	46
	ϵ_α	1.71	1.79	1.87	1.95	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2
$m_n = 4 \text{ mm}$	z_2	38	37	36	35	34	33	32	31	30
	ϵ_α	1.71	1.79	1.87	1.95	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2
$m_n = 5 \text{ mm}$	z_2	28	27	26	25	24	23	22	21	20
	ϵ_α	1.68	1.71	1.74	1.75	1.76	1.77	1.77	1.77	1.77

For example, calculation of high contact ratio is done for gear pairs depending on different number of teeth, axial distance and modul. If contact ratio reaches $\epsilon_\alpha = 2$,

HCR can be applied for gear pair, but there are gear pairs which cannot reach two pairs of teeth in contact with satisfying all constraints.

It can be concluded that contact ratio is decreasing with increasing of module and it is increasing with increasing teeth number of pinion and/or with increasing the axial distance. High contact ratio cannot be obtained for every gear pair due to undercutting, interference and other constraints connected with its manufacturing.

8. CONCLUSIONS

There are several limitation requirements defined for achieving high contact ratio of gear pair defined for: removal of meshing interference, minimum arc thickness of the tooth tip $s_{a1,2}$, distribution of correction factors has to be done through balancing specific slips, strength, or a particular condition, respectively compromise their combinations. Due to increased addendum height, there is larger possibility of occurring some interference or pointed tooth tip. Therefore it should prevent these errors and check if all equation and constraints are satisfied. Both conditions for teeth on pinion and gear wheel in order not to occur interference during the production – equations (5a) and (5b), conditions not to occur meshing interference – equations (8a) and (8b), conditions for minimal thickness of the tooth head circle of both gears – equations (10) and (11) and additional condition (13) balances specific sliding at the beginning and end of meshing in order to reduce losses during the meshing. However, due to these constraints high contact ratio cannot be obtained for every gear pair.

After researching gear pairs and defining kinematic conditions for obtaining contact ratio of two, there is still a questions can the gears achieve expected load carrying capacity for defined interval of time. So, that means will the flanks of teeth sustain loading for enough time, but not to occur pitting or scuffing, or some other premature damage of teeth. This requires introducing of new constraints and conditions related to load carrying ability of tooth, influence of temperature on tooth and that is everything for condition of high contact ratio of gears. This complicates the existing way of solving tasks and means defining the multiple task of achieving contact ratio equalized by two and loading the torques with no premature damaging of tooth flanks.

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PRORAČUN NOSIVOSTI OSOVINA I VRATILA PREMA DIN 743

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Rezime: DIN 743 [1] postoji već 12 godina. Ovaj standard je namenjen za proveru nosivosti štapnih oblika konstrukcionih elemenata- osovina i vratila. Zasniva se na proverenim osnovama, pre svega na nekadašnjem standardu TGL 19340 i brojne istraživačke i razvojne radove. Ovaj standard daje preporuke za proračun statičkog i dinamičkog stepena sigurnosti osovina i vratila, koji su opterećeni različitim opterećenjima. U radu je dat predlog proračuna stepena sigurnosti osovina i vratila, kada je opterećenje dato u vidu spektra opterećenja.

Ključne riječi: Proračun nosivosti, Osovine, Vratila, DIN 743, Spektar opterećenja

CALCULATION OF LOAD CAPACITY OF AXLES AND SHAFTS ACCORDING TO DIN 743

Abstract: DIN 743 [1] has been introduced 12 years ago and it defines the procedure of estimating load capacity of the rod-shaped structural elements – axles and shafts. The standard is primarily based on the former standard TGL 19340, numerous researches and engineering projects. It gives recommendations for the calculation of static and dynamic safety factors of axles and shafts, loaded with variant loads. The paper presents a novel procedure of safety factor calculation of an axle or a shaft, when the load is given as a load spectrum.

Keywords: Calculation of load capacity, Axle, Shaft, DIN 743, Load spectrum

1. UVOD

Najčešći problem inženjera u procesu konstruisanja je određivanje stepena sigurnosti za određenu konstrukciju.

Pitanje koje se najčešće postavlja je: koje opterećenje i pod kojim uslovima određena konstrukcijamože izdržati a, da ne dođe do njenog deformisanja.

Sveopštim razvojem znanja i informacija svakodnevno se pronalaze nove

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metode za proračun stepena sigurnosti. Često su te metode specijalizovane za određeni tip konstrukcije. Inženjeri koji se bave konstruisanjem i oblikovanjem osovina i vratila, nakon tzv. „projektnog proračuna”, imaju zadatak da odrede stepen sigurnosti na kritičnim preseccima tj. na mestima geometrijskih diskontinuiteta gde dolazi do velikog porasta napreznja.

DIN 743 standard obuhvata izraze i jednačine za određivanje stepena sigurnosti na kritičnim preseccima osovina i vratila i to prema dva kriterijuma:

- sigurnost u odnosu na plastičnu deformaciju dela (statički stepen sigurnosti).
- sigurnost u odnosu na dinamičku izdržljivost materijala (dinamički stepen sigurnosti)

Proračun razmatra opterećenja na zatezanje/pritisak, savijanje i uvijanje. Napreznja na smicanje nije uzeto u obzir.

Rezultati dobijeni po standardu DIN 743 otklanjaju nedoumice po pitanju sigurnosti na kritičnim mestima osovina i vratila i time omogućuju inženjerima uspešnije i preciznije, dimenzionisanje osovina i vratila.

2. PRORAČUN STEPENA SIGURNOSTI

2.1. Statički stepen sigurnosti

Statički stepen sigurnosti izračunava se pri maksimalnom opterećenju vratila. Ova opterećenja se uglavnom javljaju prilikom pokretanja ili za zaustavljanja vratila. Ova retka ali vrlo visoka opterećenja izazivaju maksimalna napreznjana na kritičnim preseccima osovina i vratila.

Izračunata vrednost statičkog stepena sigurnosti treba biti veća ili jednaka minimalnoj sigurnosti S_{min} ($S \geq S_{min}=1,2$).

U slučaju istovremenog opterećenja osovina i vratila na zatezanje/pritisak, savijanje i uvijanje statički stepen sigurnosti se određuje prema izrazu (1):

$$S = \frac{1}{\sqrt{\left(\frac{\sigma_{zd \max} + \sigma_{b \max}}{\sigma_{zdFK} + \sigma_{bFK}}\right)^2 + \left(\frac{\tau_{t \max}}{\tau_{tFK}}\right)^2}} \quad (1)$$

gde su:

$\sigma_{zd \max}$ - maksimalni normalni napon pri opterećenju na zatezanje/pritisak;

$\sigma_{b \max}$ - maksimalni normalni napon pri opterećenju na savijanje;

$\tau_{t \max}$ - maksimalni tangencijalni napon pri opterećenju na uvijanje;

σ_{zdFK} - granica tečenja mašinskog dela pri opterećenju na zatezanje/pritisak;

σ_{bFK} - granica tečenja mašinskog dela pri opterećenju na savijanje;

τ_{tFK} - granica tečenja mašinskog dela pri opterećenju na uvijanje;

Granice tečenja određuju se prema, izrazu (2) za slučaj opterećenja na zatezanje/pritisak, i prema izrazu (3) za slučaj opterećenja na uvijanje:

$$\sigma_{zd, bFK} = K_1(d_{eff}) \cdot K_{2F} \cdot \gamma_F \cdot \sigma_S(d_B) \quad (2)$$

$$\tau_{tFK} = K_1(d_{eff}) \cdot K_{2F} \cdot \gamma_F \cdot \sigma_S(d_B) / \sqrt{3}, \quad (3)$$

gde su:

$K_1(d_{eff})$ - tehnološki faktor uticaja veličine;

- K_{2F} - faktor statičke izdržljivosti;
 γ_F - faktor povećanja granice tečenja;
 $\sigma_{s(dB)}$ - granica tečenja materijala (pobne epruvete).

Prema standardu DIN 743 faktor statičke izdržljivosti K_{2F} ima vrednost od 1 do 1,2, dok faktor povećanja granice tečenja γ_F ima vrednost od 1 do 1,15. Ove vrednosti mogu povećati statički stepen sigurnosti za 10 do 20%. Važno je napomenuti da na statički stepen sigurnosti bitno utiče tehnološki faktor veličine $K_1(d_{eff})$.

2.2. Dinamički stepen sigurnosti

Dinamički stepen sigurnosti određuje se iz odnosa amplituda dinamičkih izdržljivosti i amplitudnog napona u kritičnim preseccima vratila. Kao i kod statičkog stepena sigurnosti potrebno je tačno odrediti koja naprezanja deluju na kritičnim preseccima kao i njihove srednje i amplitudne vrednosti. Pri naprezanju na zatezanje/pritisak ili savijanje je:

$$S = \frac{\sigma_{zd,bADK}}{\sigma_{zd,ba}} \quad (4)$$

Izračunata vrednost dinamičkog stepena sigurnosti treba biti veća ili jednaka minimalnoj sigurnosti $S \geq S_{min}=1,2$.

U slučaju istovremenog opterećenja osovina i vratila na zatezanje/pritisak, savijanje i uvijanje dinamički stepen sigurnosti se određuje prema izrazu (5):

$$S = \frac{1}{\sqrt{\left(\frac{\sigma_{zda}}{\sigma_{zADK}} + \frac{\sigma_{ba}}{\sigma_{bADK}}\right)^2 + \left(\frac{\tau_{ta}}{\tau_{tADK}}\right)^2}} \quad (5)$$

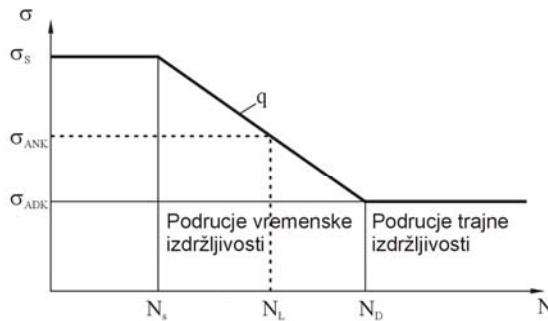
gde su:

- σ_{zda} - amplitudni napon pri opterećenju na zatezanje/pritisak;
 σ_{ba} - amplitudni napon pri opterećenju na savijanje;
 τ_{ta} - amplitudni napon pri opterećenju na uvijanje;
 σ_{zADK} - amplituda dinamičke izdržljivosti pri opterećenju na zatezanje/pritisak;
 σ_{bADK} - amplituda dinamičke izdržljivosti pri opterećenju na savijanje;
 τ_{tADK} - amplituda dinamičke izdržljivosti pri opterećenju na uvijanje.

2.3. Proračun stepena sigurnosti u području vremenske dinamičke izdržljivosti

U području vremenske izdržljivosti vremenska dinamička izdržljivost se proračunava koristeći podatak o trajnoj dinamičkoj izdržljivosti na osnovu jednačine SN krive (Slika 1)

$$\sigma_{ANK} = q \sqrt{\frac{N_D}{N_L}} \cdot \sigma_{ADK} \quad (\sigma_{ANK} \leq \sigma_{FK}) \quad (6)$$



Sl.1 Velerova kriva u koordinatnom sistemu $(\log)\sigma-(\log)N$

Osim ako nije drugačije navedeno, može se uzeti $q = 5$ za savijanje, odnosno zatezanje/pritisak i $q=8$ za uvijanje. Jednačina (6) važi za $N_L \leq N_D$. (Pri proračunu prema metodi Palmgrin-Miner-osnovna, područje trajne dinamičke izdržljivosti ne postoji. Ovde važi jednačina (6) i za $N_L > N_D$.) Za prelomne tačke Velerove linije pretpostavlja se $N_D=10^6$ odnosno $N_S=10^3$ ($10^2 \dots 10^4$) (slika 1).

Stvarna opterećenja mašina u eksploatacionim uslovima nisu uvek jednaka nominalnim. Uslovi u kojima mašine rade mogu biti stacionarni i nestacionarni uslovi. Mašine uglavnom rade u nestacionarnim uslovima eksploatacije, pa su i opterećenja takvih mašina nestacionarno promenljiva. Naponi koji se javljaju u delovima mašina u toku eksploatacije su često veća od trajne dinamičke izdržljivosti, što dovodi do akumulacije oštećenja u materijalu, a posle određenog vremena do preloma.

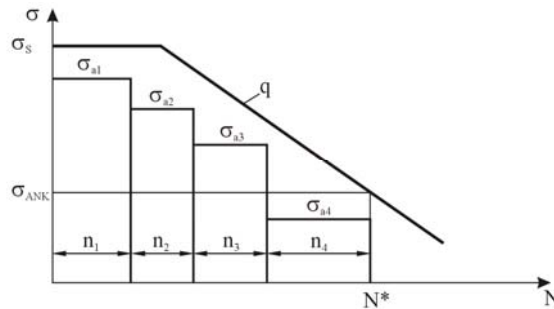
Visok stepen tačnosti pri dimenzionisanju i proveru sigurnosti protiv razaranja može se postići merenjem eksploatacionih opterećenja i identifikacijom spektra opterećenja vitalnih elemenata mašina. Spektri opterećenja dobijaju se na osnovu eksploatacionih merenja mašinskog sistema u procesu rada za određene uslove, pa prema tome svaki spektar opterećenja ima svoju verovatnoću pojave. Izbor merodavnog spektra rešava se uvođenjem više spektara reprezentata za određene radne uslove, čime se omogućuje dovoljno tačna procena za sve među uslove.

Najpogodnija forma prikaza karakteristika slučajnih procesa radnih opterećenja, kakav je obrtni moment na vratilu prenosnika je eksploataciono merenje obrtnog momenta i njegova diskretizacija, a zatim i statistička obrada u cilju dobijanja spektra opterećenja.

Na osnovu spektra opterećenja proračunava se i dobija spektra napona. Kada se poseduje spektar napona vrši se izaberu hipoteze između: Palmgrin-Miner-elementarna, Palmgrin-Miner-originalna, Palmgrin-Miner-proširena i Palmgrin-Miner konsekvantna.

2.3.1. Hipoteza Palmgrin-Miner-elementarna

Kod hipoteze Palmgrin-Miner-elementarna pretpostavlja se da ne postoji trajna izdržljivost, odnosno da svi blokovi spektra doprinose oštećenju. Dakle, moraju da se uzmu u obzir svi blokovi spektra. Ova pretpostavka se često ocenjuje kao suviše pesimistička. Sa ovom metodom određena ekvivalentna amplituda napona smatra se količinski (po kvantitetu) suviše velikom, a time određeni stepen sigurnosti prema DIN 743 će biti manji u odnosu na sračunate stepene sigurnosti drugim ovde spomenutim postupcima.



Sl.2 Palmgrin-Miner-elementarna

Kod hipoteze Palmgrin-Miner-elementarna pretpostavlja se da, svi blokovi spektra doprinose oštećenju odnosno trajna dinamička izdržljivost ne igra ulogu. Stepen sigurnosti se određuje prema jednačini:

$$S = \frac{\sigma_{ANK}}{\sigma_a}, \quad (7)$$

gde je σ_a - ekvivalentni amplitudni napon određen prema jednačini:

$$\sigma_a = \frac{\sigma_{a1}}{K_{Koll}} \quad (8)$$

Pri čemu je:

σ_{a1} – amplitudni napon koji odgovara delu spektra koji reprezentuje najveće opterećenje,

K_{Koll} – faktor spektra koji se određuje prema izrazu:

$$K_{Koll} = \sqrt[q]{\left(\frac{1}{v^q} - 1\right) \cdot D_M + 1}. \quad (9)$$

Stepen punoće v se određuje prema izrazu:

$$v = \sqrt[q]{\sum_{i=1}^j \left(\frac{n_i}{N^*}\right) \cdot \left(\frac{\sigma_{ai}}{\sigma_{a1}}\right)^q} \quad (10)$$

gde ako nije drugačije navedeno ili poznato: $q = 5$ za zatezanje / pritisak ili savijanjem, odnosno $q = 8$ za uvijanje.

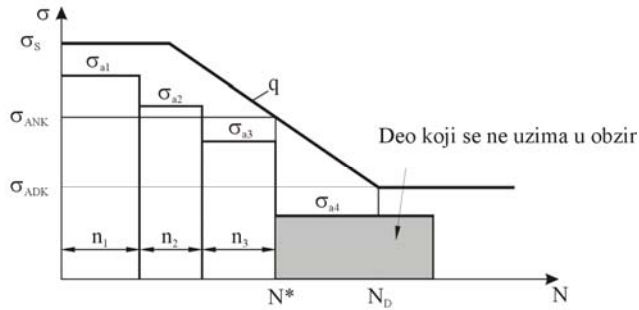
Kod ove hipoteze važi:

$$N^* = \sum_{i=1}^j n_i \quad (11)$$

Pri čemu je j poslednji blok datog spektra. Ova metoda se preporučuje kod agresivnih medija i otvrdnutih čelika, npr. čelika za kotrljajne ležaje i slično.

2.3.2. Hipoteza Palmgrin-Miner-originalna

Hipotezom Miner-originalna se pretpostavlja da se bilo koje naprezanje ispod trajne dinamičke izdržljivosti može izdržati bez loma (slika 3). Sa ovom pretpostavkom dati blok spektra ispod trajne dinamičke izdržljivosti nema udeo u oštećenju. To znači da se svi blokovi opterećenja datog spektra opterećenja kod kojih $\sigma_{ai} < \sigma_{ADK}$ (i-broj bloka spektra) zanemaruju.



Sl.3 Palmgrin-Miner-originalna

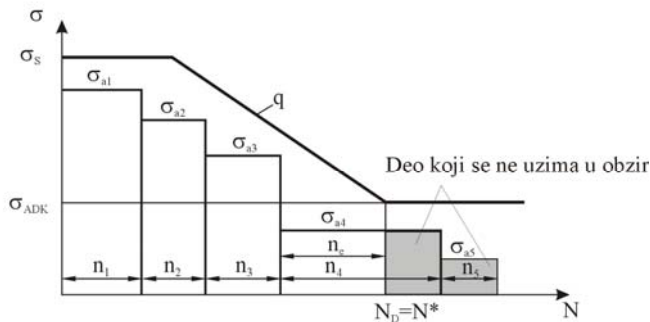
Stepen punoće je:

$$v = \sqrt[q]{\sum_{i=1}^{j^*} \left(\frac{n_i}{N^*}\right) \cdot \left(\frac{\sigma_{ai}}{\sigma_{a1}}\right)^q} \quad (12)$$

gde je $N^* = \sum_{i=1}^{j^*} n_i$ sa $j^* = p-1$ (kada je $N^* > N_D$ onda je $N^* = N_D$), a pri čemu je p prvi blok spektra ispod trajne dinamičke izdržljivosti.

2.3.3. Hipoteza Palmgrin-Miner-proširena

Za razliku od hipoteze Palmgrin-Miner-original ovde se polazi od činjenice, da samo blokovi spektra čija suma je manja ili jednaka N_D doprinose oštećenju. Blokovi spektra koji prevazilaze granicu N_D se odbacuju (slika 4).



Sl.4 Palmgrin-Miner-proširena

Onda se umesto n_i poslednjeg bloka spektra koristi n_e (slika 4).

$$n_e = N_D - \sum_{i=1}^{k-1} n_i \quad (13)$$

Poslednji blok spektra k je prvi koji prelazi preko prelomne tačke Velerove linije (primer na slici 4a, stepen 4; $k=4$). Za K_{koll} važi jednačina (9), v se određuje prema jednačini (10) sa

$$N^* = \sum_{i=1}^j n_i \text{ kada je } \sum_{i=1}^j n_i < N_D$$

odnosno

$$N^* = N_D \text{ i } j^* = k \text{ kod } \sum_{i=1}^j n_i \geq N_D.$$

2.3.4. Hipoteza Palmgrin-Miner- konsekventna

Postupkom Palmgrin-Miner-konsekventna se direktno uzima u obzir da se smanjenje udela trajne dinamičke izdržljivosti događa sa povećanjem oštećenja [1]. Prema [2] i novijim istraživanjima treba ovaj postupak da daje bolje rezultate u smislu podudaranja sa stvarnim ponašanjem komponenti.

Stepen sigurnosti se mora odrediti ovde iterativnim postupkom. Počevši od početne vrednosti S_{step0} , varira se stepen sigurnosti S_{step} kao zamišljeno povećanje opterećenja, do dobijanja broja promene opterećenja \tilde{N} , koji odgovara zahtevanom broju promena opterećenja N^* .

$$\tilde{N} = [(A_{kon} - 1) \cdot D_M + 1] \cdot \left(\frac{\sigma_{ADK}}{S_{Step} \cdot \sigma_{a1}} \right)^q \cdot N_D \quad (14)$$

Sa

$$A_{kon} = \left(\frac{S_{Step} \cdot \sigma_{a1}}{\sigma_{ADK}} \right)^{q-1} \cdot \left(\frac{Z1}{N1} + \sum_{\lambda=p}^j \frac{Z2}{N2} \right) \quad (15)$$

$$Z1 = \left(\frac{\sigma_{ADK}}{S_{Step} \cdot \sigma_{a1}} \right)^{q-1} - \left(\frac{\sigma_{ap}}{\sigma_{a1}} \right)^{q-1} \quad (16)$$

$$Z2 = \left(\frac{\sigma_{a\lambda}}{\sigma_{a1}} \right)^{q-1} - \left(\frac{\sigma_{a(\lambda-1)}}{\sigma_{a1}} \right)^{q-1} \quad (17)$$

$$N1 = \sum_{i=1}^{p-1} \frac{n_i}{N^*} \cdot \left(\frac{\sigma_{ai}}{\sigma_{a1}} \right)^q \quad (18)$$

$$N2 = \sum_{i=1}^{\lambda} \frac{n_i}{N^*} \cdot \left(\frac{\sigma_{ai}}{\sigma_{a1}} \right)^q \quad (19)$$

Pri tom je j broj blokova spektra, a p broj blokova spektra ispod σ_{ADK} . Pri svakom iteracionom koraku određuje se novo p , pošto se svi blokovi spektra povećavaju sa faktorom S_{Step} . U jednačinama (14) do (19) koriste se blokovi napona σ_{ai} (izlazni podaci). Za iteracioni ciklus neophodno je σ_{aj+1} . S toga je preporučeno da se dodatno uvede stepen napona $(j+1)$ sa $n_{j+1}=0$ i $\sigma_{aj+1}=0$.

Za zahtevani radni vek uzimaju se u obzir svi blokovi spektra:

$$N^* = \sum_{i=1}^j n_i$$

3. ZAKLJUČAK

Na osnovu napred navedenog može se zaključiti sledeće:

- DIN 743-1-3 postoji već 12 godina. Ovaj standard je namenjen za proveru nosivosti osovina i vratila. Ovaj standard je 2008 godine dopunjen 4. delom koji se odnosi na proračun nosivosti osovina i vratila za slučaj opterećenja definisanog spektrom opterećenja. Standard još uvek nije usvojen, već je varijanta draft.
- Visok stepen tačnosti pri dimenzionisanju i proveru sigurnosti protiv razaranja može se postići merenjem eksploatacionih opterećenja. Najpogodnija forma prikaza karakteristika slučajnih procesa radnih opterećenja, kakav je obrtni moment na vratilu prenosnika je eksploataciono merenje obrtnog momenta i njegova diskretizacija, a zatim i statistička obrada u cilju dobijanja spektra opterećenja.
- Na bazi definisanog spektra opterećenja sračunava se spektar napona, a zatim primenom izabrane hipoteze Palmgrin-Miner vrši provera stepena sigurnosti vratila i osovina.

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EKSPERIMENTALNA IDENTIFIKACIJA RAZARANJA I PRORAČUN ELEMENTARNE POUZDANOSTI ZUPČANIKA PLANETARNIH PRENOSNIKA SNAGE

Predrag Živković¹

Rezime: Pouzdanost planetarnih prenosnika, može se određivati praćenjem pojave neispravnosti tokom eksploatacije ili ispitivanjem komponenata ili sistema u celini u laboratorijskim uslovima. Uzroci koji dovode do pojave i nastanka oštećenja kod planetarnih prenosnika su kompleksni. Osim toga, oštećenja mogu biti posledica većeg broja odstupanja, kao što su odstupanja koraku zubaca zupčanika, neravnomernost raspodele opterećenja na parove zubaca u sprezi, neravnomernost raspodele opterećenja na bokove zubaca, neravnomernost raspodele opterećenja među satelitima, netačnost izrade, neredovno podmazivanje, neredovno praćenje stanja (održavanje). Radi praćenja oštećenja najpre treba locirati mesta u planetarnom prenosniku gde se pojavljuju oštećenja, a to su najčešće bokovi zubaca zupčanika i ležaji. Praćenjem ovog stanja treba odvojiti ili preduprediti oštećenja i velike havarije koje bi mogle nastati. Što je veoma dugotrajan proces. Cilj rada je identifikacija oštećenja centralnog zupčanika, ispitivanjem, na probnom stolu koji je razvijen za tu svrhu, određivanje elementarne pouzdanosti, i verifikacija dobijenih rezultata. U tom cilju razvijena je metoda identifikacije oštećenje komponenata planetarnih prenosnika, ubrzanim ispitivanjem u zatvorenom kolu snage (back – to - back), kojom je verifikovana proračunska metoda pouzdanosti komponenti planetarnog prenosnika.

***Ključne reči:** pouzdanost, oštećenje, identifikacija*

EXPERIMENTAL IDENTIFICATION OF FAILURE AND RELIABILITY CALCULATION OF ELEMENTARY PLANETARY GEARS POWER TRANSMISSIONS

Abstract: *Reliability of planetary gears, can be determined by monitoring the appearance of faults during exploitation or testing of components or entire systems in the laboratory. The causes that lead to the occurrence of damage and the planetary gears are complex. In addition, the damage may be due to a numerous variations, such as variations step gear teeth, uneven load distribution between pairs of teeth in conjunction, uneven load distribution on the flanks of teeth, uneven load distribution among the satellites, inaccuracy of made, irregular lubrication, irregular monitoring (maintenance). In order to improve monitoring place in the planetary gears where defects occur, and these are usually flanks of gear teeth and bearings should be*

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determined. The monitoring of this state should separate or prevent the damage and major disasters that could occur. That is a very time consuming process. The aim was to identify damage of the central gear by investigation on the, examining the test stand that was developed for this purpose, the determination of elemental reliability and verification of results. For this purpose a method for identifying the components of the planetary gear damage, accelerated testing in a closed power steering (back - to - back), where the reliability of the method was verified budgetary components of planetary gear train was developed.

Key words: reliability, failure, identification

1. UVOD

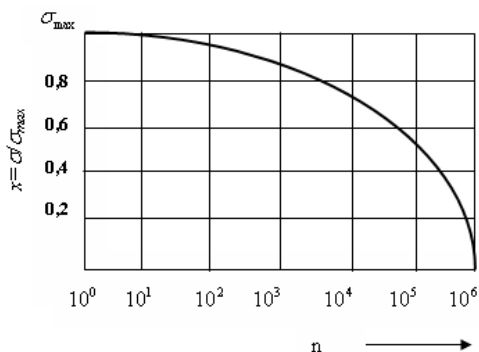
Pouzdanost planetarnih prenosnika, može se određivati praćenjem pojave neispravnosti tokom eksploatacije ili ispitivanjem komponenata ili sistema u celini, u laboratorijskim uslovima. Praćenje pojave neispravnosti u eksploataciji ostvaruje se pri održavanju tako što se neispravnosti evidentiraju, a pouzdanost sistema $R(t)$, posle t - časova rada određuje se: $R(t) = \frac{N_0 - n(t)}{N_0}$, gde je: $n(t)$ - broj evidentiranih neispravnosti

tokom t -časova rada, N_0 - broj istovetnih sistema (na primer reduktora) čija se pouzdanost određuje. Ovim postupkom, određivanja pouzdanosti, potrebno je dugotrajno praćenje stanja u eksploataciji i više istovetnih prenosnika. Uzroci koji dovode do pojave i nastanka oštećenja kod planetarnih prenosnika su kompleksni. Osim toga, oštećenja mogu biti posledica većeg broja odstupanja, kao što su odstupanja koraku zubaca zupčanika, neravnomernost raspodele opterećenja na parove zubaca u sprezi, neravnomernost raspodele opterećenja na bokove zubaca, neravnomernost raspodele opterećenja među satelitima, netačnost izrade, neredovno podmazivanje, neredovno praćenje stanja (održavanje). Radi praćenja oštećenja najpre treba locirati mesta u planetarnom prenosniku gde se pojavljuju oštećenja, a to su najčešće bokovi zubaca zupčanika i ležaji. Praćenjem ovog stanja treba odvojiti ili preduprediti oštećenja i velike havarije koje bi mogle nastati. Što je veoma dugotrajan proces. Cilj rada je identifikacija oštećenja centralnog zupčanika, ispitivanjem, na probnom stolu koji je razvijen za tu svrhu, određivanje elementarne pouzdanosti, i verifikacija dobijenih rezultata. U tom cilju razvijena je metoda identifikacije oštećenje komponenata planetarnih prenosnika, ubrzanim ispitivanjem u zatvorenom kolu snage (back - to - back), kojom je verifikovana proračunska metoda pouzdanosti komponenti planetarnog prenosnika.

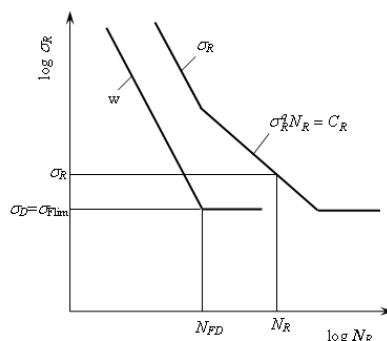
Osnovni oblici oštećenja bokova zubaca opisani su i objašnjeni u DIN 3979.

2. RADNA STANJA DELOVA PRENOSNIKA

Planetarni prenosnici se ugrađuju u mašinama kod kojih su radna opterećenja visokog intenziteta i složene promene u toku radnog veka. Promenljivost opterećenja, inercijalne sile visokih intenziteta i sopstvene vibracije čine da dinamičke sile budu relativno velike. Usled promenljivosti radnih otpora koji se savladavaju posredstvom prenosnika, na primer kod bagera, obrtni moment na izlaznom vratilu je promenljiv. Usled toga i naponi na/u zupcima zupčanika su promenljivi. Prikaz ovog stanja realizuje se posredstvom spektra opterećenja odnosno spektra napona.[3] Spektar napona je uredjeni skup napona (opterećenja) različite veličine koji pokazuje učešće svakog od napona u izabranom broju promena od 10^6 . (Slika 1.)



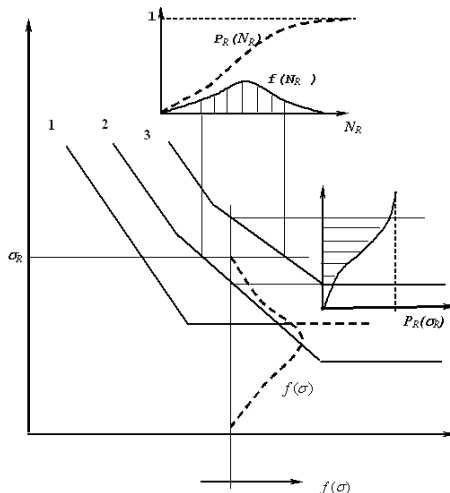
Sl. 1 Mogući spektar radnih napona



Sl. 2 Uticaj promenljivog opterećenja na izdržljivost u odnosu na lom zupca

Pod dejstvom napona stalne amplitude, zamor zubaca se ostvaruje u skladu sa Velerovom krivom tj. sa osnovnom dinamičkom izdržljivošću (W-sl.2). Pošto je opterećenje odnosno napon promenljiv u toku radnog veka, zamor se ostvaruje u skladu sa radnom izdržljivošću. To je najveći napon u spektru napona σ_R koji dovede do loma posle N_R promena napona svih veličina. Pošto manje amplitude promene napona ostvaruju manji uticaj na zamor to je potreban broj promena N_R mnogo veći od broja promena N koji odgovara Velerovoj krivoj. Usled toga je i radna izdržljivost veća od osnovne (Velerove). Oblik i položaj linije radne izdržljivosti (sl.2) zavisi od težine radnog režima odnosno od spektra napona na slici 2. [3] Osim navedenih promena usled uticaja radnih uslova, prisutni su još neki. Proces zamaranja je stohastičkog karaktera. Lomovi ne nastaju uvek pri istom broju ciklusa promene napona i nisu ponovljivi na isti način.

Usled toga u razmatranje se uvodi još jedan parametar, a to je verovatnoća razaranja. Ni Velerova kriva ni kriva radne izdržljivosti prikazane na slici 3. nisu linije već područja rasipanja tačaka koje definišu izdržljivost. Prikazane linije predstavljaju samo srednje vrednosti tj. odgovaraju verovatnoći razaranja od 50%. Na slici 3, umesto jedne linije radne izdržljivosti prikazano je ovo područje ograničeno linijama za verovatnoću razaranja od 10% ($P_R=0,1$) i za verovatnoću razaranja 90% ($P_R=0,9$). Ovo područje rasipanja

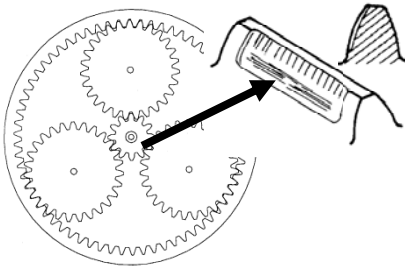


Sl. 3. Rasipanje radne izdržljivosti u oblasti radne izdržljivosti

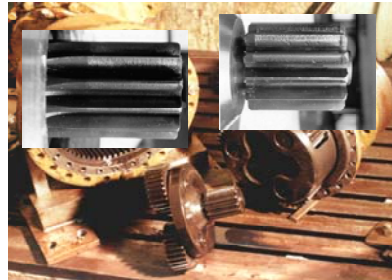
verovatnoće razaranja kada se preseče linijom koja određuje radnu izdržljivost σ_R , dobija se funkcija raspodele verovatnoće razaranja zavisna od broja promene napona $P_R(N_R)$. Kada se ovo područje preseče linijom koja odgovara broju promena napona u radnom veku n_T , dobija se funkcija promene verovatnoće razaranja u zavisnosti od radne izdržljivosti $P_R(\sigma_R)$. Ove funkcije raspodele verovatnoće razaranja neophodne su za određivanje (procenu) elementarne pouzdanosti u odnosu na lom zubaca zupčanika. Habanje zubaca zupčanika odvija se po drugačijim zakonitostima te će verovatnoća habanja biti definisana po drugačijim kriterijumima.

3. IDENTIFIKACIJA RAZARANJA

Centralni zupčanik je malog prečnika te je pri istom obrtnom momentu vrlo velika obimna sila. Usled malog broja zubaca i radijus krivine boka je mali što takodje doprinosi povećanju napona na boku zupca.



Sl. 4 Planetarni set sa označenim razaranjem centralnog zupčanika



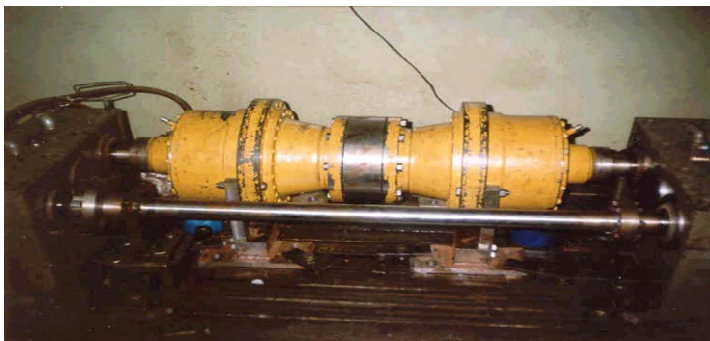
Sl. 5 Ispitivani prenosnik u rasklopljenom stanju

Povoljna okolnost je ta što se opterećenje ovog zupčanika deli na broj satelita, pa je sila po jednoj sprezi manja u poređenju sa zupčanikom istih dimenzija koji bi bio izložen celokupnim opterećenjem. Ipak ovaj efekat je umanjen neravnomernošću raspodele opterećenja na satelite i činjenicom da se isti zubac centralnog zupčanika spreže sa različitim zupcima zupčanika satelita. Na slici 4, prikazana je šema jednog planetarnog seta na kojoj je označeno mesto razaranja centralnog zupčanika. A na slici 5, ispitivani prenosnik u rasklopljenom stanju.

Planetarni prenosnik, koji je bio predmet istraživanja je dvostepeni sa ulaznim brojem obrtaja 1108 min^{-1} , ukupnim prenosnim odnosom 42 (prvi stepen 7, drugi 6), izlaznog obrtnog momenta 23000 Nm. Za prvi stepen brojevi zubaca centralnog zupčanika, satelita i venca su 12/30/72, modul 3,5 mm, a za drugi planetarni set, brojevi zubaca su 13/26/65 a modula 4 mm. Material centralnih zupčanika i zupčanika satelita je Č.4721, a venčanika Č.4732. Podmazivanje je uljem **S3 SAE90**. [1] Za ispitivanje navedenog planetarnog reduktora, pripremljen je odgovarajući probni sto. Koji čine dva istovetna prenosnika sa paralelnim vratilima istih prenosnih odnosa, spojeni u zatvoreni "back to back" sistem (sl. 6). [1] Opterećenje u sistemu se ostvaruje torzionim elastičnim deformisanjem vratila koja spajaju prenosnike.

4. METODA I POSTUPAK IZRAČUNAVANJA ELEMENTARNIH POUZDANOSTI PLANETARNOG PRENOSNIKA

Ispitivanje je izvedeno razvijenom metodom ubrzanog ispitivanja, primenom zatvorenog kola snage sl. 6. [1]. Spregnuti par istovetnih prenosnika, opterećen je momentom od 538 Nm na ulaznom vratilu.



Sl. 6 Ispitivani planetarni prenosnici u zatvorenom kolu snage

Na probnom stolu, slika 6, koji je predmet ovih analiza, mereno je opterećenje - obrtni moment, ugaona brzina, vibracije i buka. Kontrolisana je radna temperatura prenosnika, a habanja i druga razaranja utvrđena su rasklapanjem i kontrolom nakon izvršenih ispitivanja. Utvrđena su značajna oštećenja zubaca centralnih zupčanika, kod prenosnika u rasklopljenom stanju (sl.5)

Određivanje pouzdanosti zasniva se na upoređivanju radnih i kritičnih napona uključujući verovatnoću svih uticaja na ove veličine. U osnovi pouzdanost je verovatnoća da u eksploataciji neće doći do pojave neispravnosti. Svedeno na radne i kritične napone, to je verovatnoća da u toku radnog veka mešinskog dela, radni naponi neće biti veći od kritičnog. Ako je ova verovatnoća bliska jedinici, neispravnost, odnosno razaranja mašinskog dela u radu, neće nastupiti. Smanjenjem radnog napona, pouzdanost se ne može povećati iznad jedinice. To je područje sigurnosti za koje se izračunava stepen sigurnosti. Područje sigurnosti i pouzdanost se naslanjaju jedno na drugo. Razdvaja ih granica na kojoj je pouzdanost bliska jedinici. Opšti matematički model za izračunavanje ukupne pouzdanosti mašinskog sistema, koji je sastavljen od i -

komponentata, i brojem mogućih oštećenja k , koji se mogu pojaviti, je $R = \prod_{i=1}^k R_i$; gde je

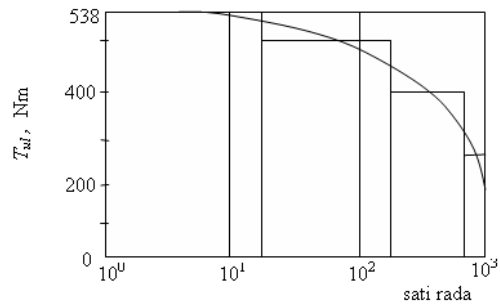
$R_i = 1 - F_{pi}$, F_{pi} - elementarna nepouzdanost (oštećenja i). Elementarna nepouzdanost $F_{pi} = 1 - R_i$ je funkcija složene verovatnoće od verovatnoće pojave radnog napona i od verovatnoće razaranja pri tom naponu, oštećenja i - te komponente.. Da bi nastupio lom usled zamora potrebno je da se u mašinskom delu pojavi napon i da postoji mogućnost zamora - loma, pri tom naponu. Lom nastupa ako su zadovoljena oba navedena uslova tj.

$$F_p = p(\sigma) \cdot P_R(\sigma); F_p = \sum_{i=1}^k p_i \cdot P_{Ri}; F_p = \sum_{i=1}^k f_i \cdot P_{Ri};$$

ako je mašinski deo izložen promenljivom naponu konstantne amplitude statistička težina odnosno mogućnost pojave tog napona je $p(\sigma) = n_{\Sigma i} / n_{\Sigma} = 1$ te je nepouzdanost jednaka verovatnoći razaranja $P_R(\sigma)$. Ako je mašinski deo izložen naporima različitih amplituda, statistička težina svake od njih je $p_i = n_{\Sigma i} / n_{\Sigma}$, n_{Σ} - ukupan broj ciklusa promene napona u radnom veku, $n_{\Sigma i}$ - ostvareni broj ciklusa radnog napona, ($n_{\Sigma} = \sum n_{\Sigma i}$). Planetarni prenosnik, koji je bio predmet istraživanja, je deklarisan za određene nominalne uslove rada tj. za određeni nominalni obrtni moment i za određenu nominalnu brzinu rotacije. U eksploataciji ovi uslovi se mogu pojaviti povremeno, a po pravilu najveći deo radnog veka ostvarivaće se lakši uslovi rada tj. manji obrtni moment ili manja brzina rotacije. Takođe su mogući i teži uslovi rada od nominalnih, dakle znatno veći obrtni moment ili brzina rotacije koji nastaju povremeno i u kraćim vremenskim intervalima. Odnos učešća velikih i malih opterećenja i brzine rotacije definiše se spektrom opterećenja odnosno radnim režimom prenosnika, tabela 1 i slika 7. Ako se predviđi da ovaj prenosnik služi samo za pokretanje bagera, njegovo korišćenje biće povremeno te će i ukupno vreme rada biti relativno malo, na primer 1000 sati. Ako se u toku ovog vremena koriste različite veličine obrtnih momenata, spektar opterećenja odnosno napona predstavljen je (tab.1). Grafička predstava ovog spektra prikazana je na slici 7.

Tabela 1 *Spektar opterećenja planetarnog prenosnika*

Nivo <i>i</i>	1	2	3	4
Nm	538	485	400	270
<i>t</i> , sati	20	180	600	200



Sl. 7 *Spektar opterećenja planetarnog prenosnika*

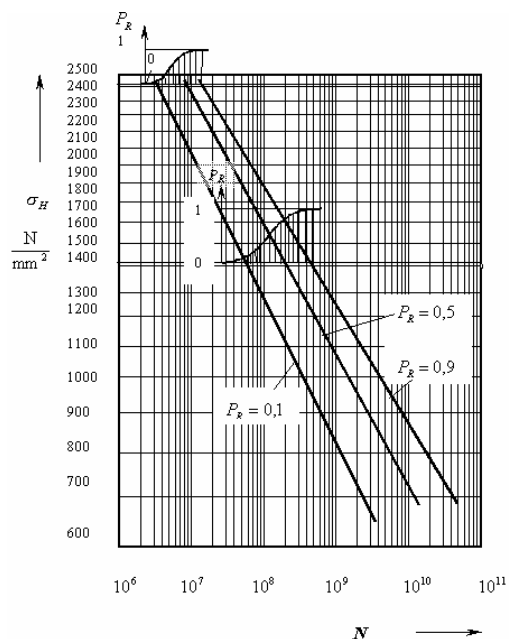
Za svako ulazno opterećenje ili napon nivoa (*i* = 1,2,4,,*k*, u ovom slučaju *k*=4). Statistička težina odnosno mogućnost pojave napona je $p_i = n_{\Sigma i} / n_{\Sigma}$, $n_{\Sigma} = n_{\Sigma 1} + n_{\Sigma 2} + \dots + n_{\Sigma k}$.

U toj proporciji utiču verovatnoća razaranja P_{Ri} na nepouzdanost F_p . Nepouzdanost je jednaka sumi proizvoda statističke težine *i* verovatnoće razaranja za svaku od veličine napona tj. $F_p = \sum_{i=1}^k p_i \cdot P_{Ri}$. Na isti način, za slučajnu promenljivu

radnog napona, proporcionalno čestanosti pojave napona f_i uključuje se verovatnoća razaranja P_{Ri} tj. nepouzdanost je jednaka zbiru proizvoda $f_i \cdot P_{Ri}$, odnosno pouzdanost $R = 1 - F_p$. Oštećenja bokova zubaca zupčanika su kompleksna i predstavljaju kombinaciju procesa površinskih razaranja. Ove kombinacije i procesi u značajnoj meri su slučajnog karaktera i mogu se definisati funkcijama verovatnoće. Za dati nivo napona, na primer za napon σ_{Hi} na boku zupca, razaranje se ostvaruje pri broju sprezanja zubaca N_i . Verovatnoća da će biti dostignuta kritična debljina pohabanog sloja može se predstaviti Weibulovom funkcijom

$$P_{Ri} = 1 - e^{-\left(\frac{N_i}{\eta_i}\right)^{\beta_i}}$$

gde su η_i N_i β_i parametri funkcije Weibulove raspodele. Nultoj debljini pohabanog sloja odgovara verovatnoća koja teži nuli. Pošto je proces površinskog razaranja bokova zubaca dugotrajan i postepen to je i Weibulova funkcija razvučena na velikom intervalu broja promena napona tj. broja



Slika 8. *Raspodela verovatnoće razaranja bokova zubaca centralnog zupčanika*

sprezanja zubaca zupčanika, slika 8. Za nivo napon $\sigma_H=1421 \text{ N/mm}^2$, i utvrđeni broj sprezanja zubaca $n_{\Sigma 1}=39,9 \times 10^6=N$, parametri Vejbulove raspodele su $\eta=2,5 \cdot 10^8$ i $\beta=1,5$, tj. funkcija Vejbulove raspodele je

$$P_R = 1 - e^{-\left(\frac{N}{2,5 \cdot 10^8}\right)^{1,5}} = 0,0617$$

Na slici 7, dat je prikaz funkcije za centralni zupčanike prvog planetarnog seta. Funkcija je nacrtane na nivoima napona koji odgovaraju naponima na bokovima zubaca pri ispitivanju.

U dvostrukom logaritamskom koordinatnom sistemu dinamička izdržljivost se pokorava pravoj liniji. Pravom linijom su spojene tačke sa istom verovatnoćom razaranja za obe veličine napona. Tako su dobijene prave linije koje odgovaraju verovatnoćama razaranja $P_R=0,1$ i $P_R=0,9$, kao i linija sa verovatnoćom 0,5. Područje rasipanja verovatnoće razaranja je dobijeno na osnovu ispitivanja za dva nivoa napona i može se koristiti za određivanje verovatnoće razaranja za bilo koju veličinu napona koja nastane u eksploataciji. To je osnovna ideja ubrzanih ispitivanja.

Rezultati se transformišu u radne uslove varijacijom verovatnoće napona ili verovatnoće broja sprezanja zubaca do razaranja.

5. ELEMENTARNA POUZDANOST CENTALNOG ZUPČANIKA PLANETARNOG PRENOSNIKA

Tabela 2. *Primer izračunavanja elementarne pouzdanosti protiv ostećenje centralnog zupčanika prvog planetarnog seta za 1108 min^{-1}*

<i>i</i>	1	2	3	4
T_{ul} , Nm	538	485	400	270
t_i , sati	20	180	600	200
σ_{Hi} , N/mm ²	1421	1352	1233	1024
$n_{\Sigma i}$	$3,99 \times 10^6$	$3,59 \times 10^7$	$1,19 \times 10^8$	$3,99 \times 10^7$
$N_{0,1}$	$5,5 \times 10^7$	7×10^7	$1,25 \times 10^8$	3×10^8
$N_{0,9}$	$4,35 \times 10^8$	$5,9 \times 10^8$	$1,1 \times 10^9$	$3,5 \times 10^9$
$\beta_{(N)}$	1,5	1,45	1,418	1,255
$\eta_{(N)}$	$2,5 \times 10^8$	$3,32 \times 10^8$	$6,2 \times 10^8$	$1,8 \times 10^8$
$p_{R(n_{\Sigma i})}$	0,00204	0,039	0,094	$8,334 \times 10^{-3}$
$p_i = n_{\Sigma} / n_{\Sigma}$	0,02	0,18	0,6	0,2
$p_i P_{Ri}$	$4,1 \times 10^{-5}$	$7,02 \times 10^{-3}$	$5,64 \times 10^{-2}$	$1,66 \times 10^{-3}$

Planetarni prenosnik koji se sastoji iz dva planetarna zupčanika (dvostepeni planetarni prenosik) [1], je izložen ulaznim obrtnim momentom sa spektra opterećenje predstavljenog na slici 7. Analiza je sprovedena pod pretpostavkom da je učestanost obrtanja centralnog zupčanika prvog planetarnog seta 1108 min^{-1} i da je maksimalni obrtni moment na ovom zupčaniku jednak onom pri ispitivanju od 538 Nm. Svaki od obrtnih iz spektra napona (tab.1), pri 1108 min^{-1} ulaznog zupčanika ostvari odgovarajuće napone σ_{Hi} sa odgovarajućim brojem promena $n_{\Sigma i}$ u tabeli 2, date su vrednosti ovih napona sa odgovarajućim brojevima promena napona centralnog zupčanika, za prvi planetarni red.

Pouzdanost centralnog zupčanika prvog planetarnog reda: -nepouzdanost ulaznog centralnog zupčanika:

$$F_{pa1} = p_{a1} \cdot P_{aR1} + p_{a2} \cdot P_{aR2} + p_{a3} \cdot P_{aR3} + p_{a4} \cdot P_{aR4} =$$
$$= 0,00004082 + 0,00702 + 0,0564 + 0,00166 = 0,065, \text{ odnosno pouzdanost je:}$$
$$R_{a1} = 1 - F_{pa1} = 1 - 0,065 = 0,935$$

6. ZAKLJUČAK

Razvijena je metoda za ubrzanu identifikaciju oštećenja zupčanika planetarnih prenosnika u zatvorenom kolu snage (back-to-back). Od značaja je što nije potreban veliki broj istovetnih prenosnika i dugotrajni proces praćenja oštećenja i pouzdanost u eksploataciji. Prikazano ispitivanje daje rezultate za verovatnoću razaranja bokova zubaca centralnih zupčanika. Koja je od opšteg značaja i omogućuje da se elementarna pouzdanost određuje za različite radne režime a uslovi ispitivanja se mogu svesti na radne uslove. Rezultati se mogu primeniti u industrijskim pogonima za poboljšanje konstrukcijskih rešenja i razvoja novih proizvoda planetarnih prenosnika snege i menjača.

Zahvalnost

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NOVI PRISTUP U MODELIRANJU KOTRLJAJNIH LEŽAJEVA

Radoslav Tomović ¹

Rezime: U ovom radu je predstavljen novi pristup u matematičkom modeliranju radijalnog kotrljajnog ležaja. Model razmatra dva granična položaja oslanjanja unutrašnjeg prstena - na paran i neparan broj kotrljajnih tijela. Novi pristup se odlikuje velikom jednostavnošću, što ga čini veoma pogodnim za praktičnu primjenu. Matematički model je uspješno provjeren ekperimentom. Rezultati eksperimentalne analize su prikazani u radu.

Ključne riječi: kotrljajni ležaj, radijalni zazor, defleksija ležaja, radijalno opterećenje, broj kotrljajnih tijela, vibracije rotora, frekvencija prolaska kuglica

NEW APPROACH TO THE MODELING OF ROLLING BEARINGS

Abstract: In this paper, a new approach in the mathematical modelling of radial rolling bearings is presented. The model considers two boundary positions of the inner ring supported - on an even or an odd number of rolling elements. A new approach is characterised by a great simplicity, what makes it very convenient for a practical application. The mathematical model is successfully checked in an experiment. The results of the experimental analyse are given in the paper.

Keywords: rolling bearing, radial clearance, bearing deflection, radial load, number of rolling elements, rotor vibrations, ball passage frequency

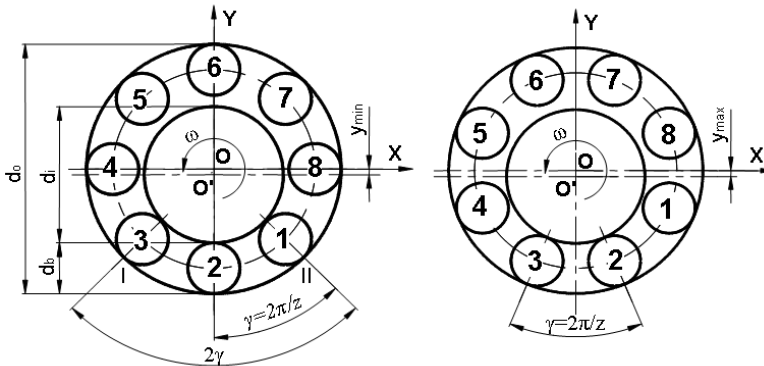
1. UVOD

Analiza rada rotacionih mašina predstavlja jedno od najvažnijih područja u inženjerskoj praksi. Veliki uticaj na ponašanje rotora imaju karakteristike uležištenja u koji su rotori oslonjeni. Kotrljajni ležajevi su najčešće korišteni elementi za oslanjanje rotacionih mašina. Konstrukcione karakteristike i kvalitet rada kotrljajnih ležajeva često imaju presudan uticaj na radnu sposobnost i radnu ispravnost cijelog rotacionog sistema. Svaka težnja za analizom i povećanjem performansi rotacionih sistema, kao osnov mora imati efikasan matematički model rotora oslonjenog u kotrljajnom ležaju. Matematički model mora što je moguće vjerodostojnije opisati ponašanje kotrljajnog ležaja u radu i uspostaviti što pouzdaniju i precizniju vezu između ulaznih i izlaznih parametara uležištenja, odnosno kompletnog rotacionog sistema.

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Međutim, iako na izgled jednostavne konstrukcije, koja se sastoji od samo četiri elementa, kotrljajni ležaj je veoma složen objekata za modeliranje. Razlog za to su statička neodređenost i nelinearnost međusobnih veza između elemenata ležaja, složene tribomehantičke pojave koje se javljaju pri radu ležaja, kao i teškoće u matematičkom opisivanju ponašanja elemenata uležištenja. Zbog toga se prilikom matematičkom modeliranja kotrljajnog ležaja usvajaju mnoga uprošćenja.

Jedno od najčešćih je, posmatraje kotrljajnog ležaja u samo jednom položaju, kada se centar jednog od kotrljajnih tijela poklapa sa pravcem dejstva spoljašnjeg radijalnog opterećenja (Sl.1.a). Iako je sa stanovišta raspodjele opterećenja, ovo najnepovoljniji položaj oslanjanja, razmatranje samo jednog položaja je nedovoljno i ne daje sve informacije o ponašanju ležaja u radu. Naime, u toku rada ležaja, komplet kotrljajnih tijela, u odnosu na pravac dejstva spoljašnjeg opterećenja, neprestano osciluje između dva krajnja položaja oslanjanja prikazana na Sl.1.. Jasno je da ako želimo što preciznije opisati ponašanje ležaja u radu, moramo u analizu uvesti i ovaj drugi granični položaj kompleta kotrljajnih tijela.



Sl.1 Granični položaji kompleta kotrljajnih tijela u radu [1]

Cilj ovoga rada je da pokaže opravdanost uvođenja i drugog graničnog položaja oslanjanja prilikom analize ponašanja kotrljajnog ležaja u radu. To je novi pristup u matematičkom modeliranju kotrljajnog ležaja, koji predstavlja rezultat višegodišnjih istraživanja autora. Dio rezultata tih istraživanja je već publikovan u radovima [1-5]. Ovaj rad kroz pregled tih istraživanja, treba da ukaže na razlike u raspodjeli opterećenja, dinamičkom ponašanju, nivou kontaktnih deformacija i karakteristikama krutosti ležaja u ova dva krajnja položaja oslanjanja.

2. GRANIČNI POLOŽAJI OSLANJANJA UNUTRAŠNJEG PRSTENA KOTRLJAJNOG LEŽAJA

Prenošenje opterećenja sa unutrašnjeg na spoljašnji prsten kotrljajnog ležaja se odvija preko određenog broja diskretnih kavezom odvojenih kotrljajnih tijela, čiji se ugaoni položaj u odnosu na pravac dejstva spoljašnjeg opterećenja, neprestano mijenja u toku rada ležaja. Promjene položaja kotrljajnih tijela izazivaju neprestanu promjenu međusobnog položaja unutrašnjeg i spoljašnjeg prstena, koja se sa rotacijom kaveza odvija periodično. Na slici Sl.1. su prikazana dva krajnja položaja oslanjanja za kotrljajni ležaj sa osam kotrljajnih tijela. U radovima [1-5] za ove krajnje položaje oslanjanja usvojeni su termini:

- Granični položaj oslanjanja na neparan broj kotrljajnih tijela (Sl. 1.a),
- Granični položaj oslanjanja na paran broj kotrljajnih tijela (Sl. 1.b).

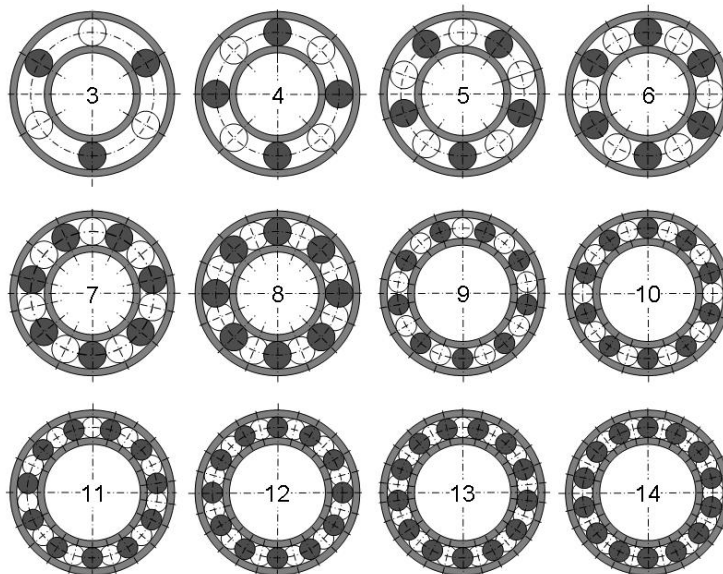
Prvi granični položaj oslanjanja se javlja, kada se centar jednog od kotrljajnih tijela poklapa sa pravcem dejstva spoljašnjeg radijalnog opterećenja, a drugi kada su kotrljajna tijela simetrično postavljena u odnosu na pravac dejstva spoljašnjeg radijalnog opterećenja. Sa slike se jasno vidi da se kod oslanjanja na neparan broj kotrljajnih tijela javlja minimalno radijalno rastojanje između prstenova ležaja, a kod oslanjanja na paran broj kotrljajnih tijela maksimalno.

Osa unutrašnjeg prstena, u odnosu na spoljašnji, će neprestano oscilovati u toku rada ležaja, između ova dva krajnja položaja oslanjanja. Ove oscilacije će se javiti kod svih ležajeva sa unutrašnjim radijalnim zazorom, bez obzira na broj kotrljajnih tijela i veličinu spoljašnjeg radijalnog opterećenja.

3. MAKSIMALAN MOGUĆ BROJ KOTRLJAJNIH TIJELA KOJI SE MOŽE NAĆI U OPTEREĆENOJ ZONI LEŽAJA

Kod kotrljajnog ležaja, spoljašnje radijalno opterećenje mogu prenositi samo kotrljajna tijela koja se nalaze ispod meridijanske ravni ležaja. Meridijanska ravan ležaja je upravna na pravac napadne linije spoljašnjeg opterećenja i dijeli ležaj na dvije polovine – u jednoj su neopterećena kotrljajna tela, a u drugoj opterećena. Kotrljajna tijela čiji centri pripadaju meridijanskoj ravni ne učestvuju u prenošenju opterećenja [2].

Broj kotrljajnih tijela koja se može naći ispod meridijanske ravni je različit za slučajeve kada se unutrašnji prsten ležaja oslanja na paran odnosno neparan broj kotrljajnih tijela. Pomoću slike Sl.2, je moguće odrediti ovaj broj za granične položaje oslanjanja, definisane u predhodnom poglavlju ovoga rada. Na slici su za slučaj oslanjanja na neparan broj, kotrljajana tijela tamno obojena, a za slučaja oslanjanja na paran broj, kotrljajana tijela su bijele boje.



Sl.2 Maksimalan mogući broj kotrljajnih tijela u opterećenoj zoni ležaja [2]

Na osnovu slike Sl.2. moguće je takođe odrediti i opšte obrasce za proračun maksimalno mogućeg broja kotrljajnih tijela u opterećenoj zoni ležaja [2].

- *Kod oslanjanja na neparan broj kotrljajnih tijela*

Za ukupan broj kotrljajnih tijela koji se kreće u granicama $z=[n-2, n+1]$, maksimalan moguć broj kotrljajnih tijela u opterećenoj zoni je:

$$z_{s,o} = \frac{n-1}{2} \quad (1)$$

- *Kod oslanjanja na paran broj kotrljajnih tijela*

Pri ukupnom broju kotrljajnih tijela koji se kreće u granicama $z=[n-1, n+2]$, maksimalan moguć broj kotrljajnih tijela u opterećenoj zoni je

$$z_{s,e} = \frac{n}{2} \quad (2)$$

4. RELATIVNO POMJERANJE IZMEĐU PRSTENOVA LEŽAJA

U zavisnosti od veličine spoljašnjeg radijalnog opterećenja i konstrukcije ležaja, broj kotrljajnih tijela koja učestvuju u prenošenju opterećenja se može kretati u intervalu od jednog do z_s . Ovdje z_s predstavlja maksimalno moguć broj kotrljajnih tijela koji se može naći u opterećenoj zoni ležaja.

Pri opterećenju relativno niskog nivoa, oslanjanje unutrašnjeg prstena se bazira naizmjenično sa jednog na dva kotrljajna tijela, tj. centar rotora će oscilovati između dva krajnja položaja prikazana na slici Sl.3.a) i b).. Za ovaj slučaj oslanjanja u radovima [1-3] je usvojen termin *sistema oslanjanja 1-2*. Kontaktne deformacije u ovom slučaju su veoma male, pa se sklop ležaja može posmatrati kao sistem krutih tijela. Kod sistema krutih tijela veze su geometrijske i sva kretanja se mogu analizirati na osnovu geometrijskih zakona.

Prema [2], veličinu relativnog pomjeranja prstenova ležaja u graničnim položajima oslanjanja na paran i neparan broj kotrljajnih tijela ležaja moguće je izračunati pomoću jednačina:

$$y_e = \frac{e}{2 \cdot \cos \gamma / 2} \quad (3)$$

$$y_o = e / 2 \quad (4)$$

Ovdje je: e – unutrašnji radijalni zazor, a γ – ugaono rastojanje između kotrljajnih tijela ležaja

Povećanjem opterećenja, u kontaktu između kotrljajnih tijela i prstenova ležaja će se pojaviti elastične kontaktne deformacije, što će usloviti dalje pomjeranje centra unutrašnjeg prstena u odnosu na spoljašnji i ulazak novih kotrljajnih tijela u zahvat sa prstenovima ležaja. Tako sistem postepeno prelazi sa *sistema oslanjanja 1-2*, na *sisteme oslanjanja 2-3, 3-4, 4-5*, itd. (Sl.3). Maksimalan broj kotrljajnih tijela koja mogu učestvovati u prenošenju opterećenja, jednak je maksimalnom broju kotrljajnih tijela koji se mogu javiti u opterećenoj zoni ležaja (z_s).

Da bi se ostvario odgovarajući sistem oslanjanja, kod ležaja sa unutrašnjim radijalnim zazorom, potrebno je ostvariti odgovarajuće međusobno (relativno) pomjeranje prstenova ležaja. To je moguće jedino ako se ostvari odgovarajući nivo kontaktnih deformacija elemenata ležaja. Usled kontaktnih deformacija dolazi do

međusobnog približavanja prstenova ležaja, što poništava negativan uticaj unutrašnjeg radijalnog zazora i omogućava ulazak novih kotrljajnih tijela u prenošenje opterećenja. Međutim, da bi se ostvario odgovarajući nivo kontaktnih deformacija potrebna je i odgovarajuća vrijednost spoljašnjeg radijalnog opterećenja.

Na slici Sl.3 su prikazani granični položaji oslanjanja unutrašnjeg prstena ležaja. Ovi granični položaji nastaju u graničnom trenutku, kada se unutrašnji prsten počinje oslanjati na q kotrljajnih tijela ležaja. Pri tome su kontaktnih deformacija na mjestu 1-vog i q -tog kotrljajnog tijela jednake nuli.

Pojedinim graničnim položajima oslanjanja, odgovaraju granične vrijednosti potrebnog pomjeranja prstenova ležaja usled kontaktnih deformacija. Njih je moguće proračunati prema jednačinama koje su detaljno izvedene i razjašnjene u literaturi pod rednim brojevima [1 i 2]:

- Granična vrijednost ukupnog pomjeranja centra rotora (y_q),

$$y_q = \frac{e}{2} \cdot \frac{1}{\cos \frac{q-1}{2} \gamma} = r_q \cdot \frac{e}{2} \quad (5)$$

- Granična vrijednost pomjeranje centra rotora usled kontaktnih deformacija (a_{1q}),

$$a_q = t_q \cdot \frac{e}{2} \quad (6)$$

Ovdje su: e – unutrašnji radijalni zazor, q - broj kotrljajnih tijela na koje se oslanja unutrašnji prsten ležaja, r_q – koeficijent ukupnog graničnog pomjeranja centra rotora i t_q – koeficijent granične defleksija ležaja koji je moguće dobiti prema jednačinama:

- Kod oslanjanja na neparan broj kotrljajnih tijela,

$$t_{q,o} = \frac{1}{\cos \frac{q-1}{2} \gamma} - 1 \quad (7)$$

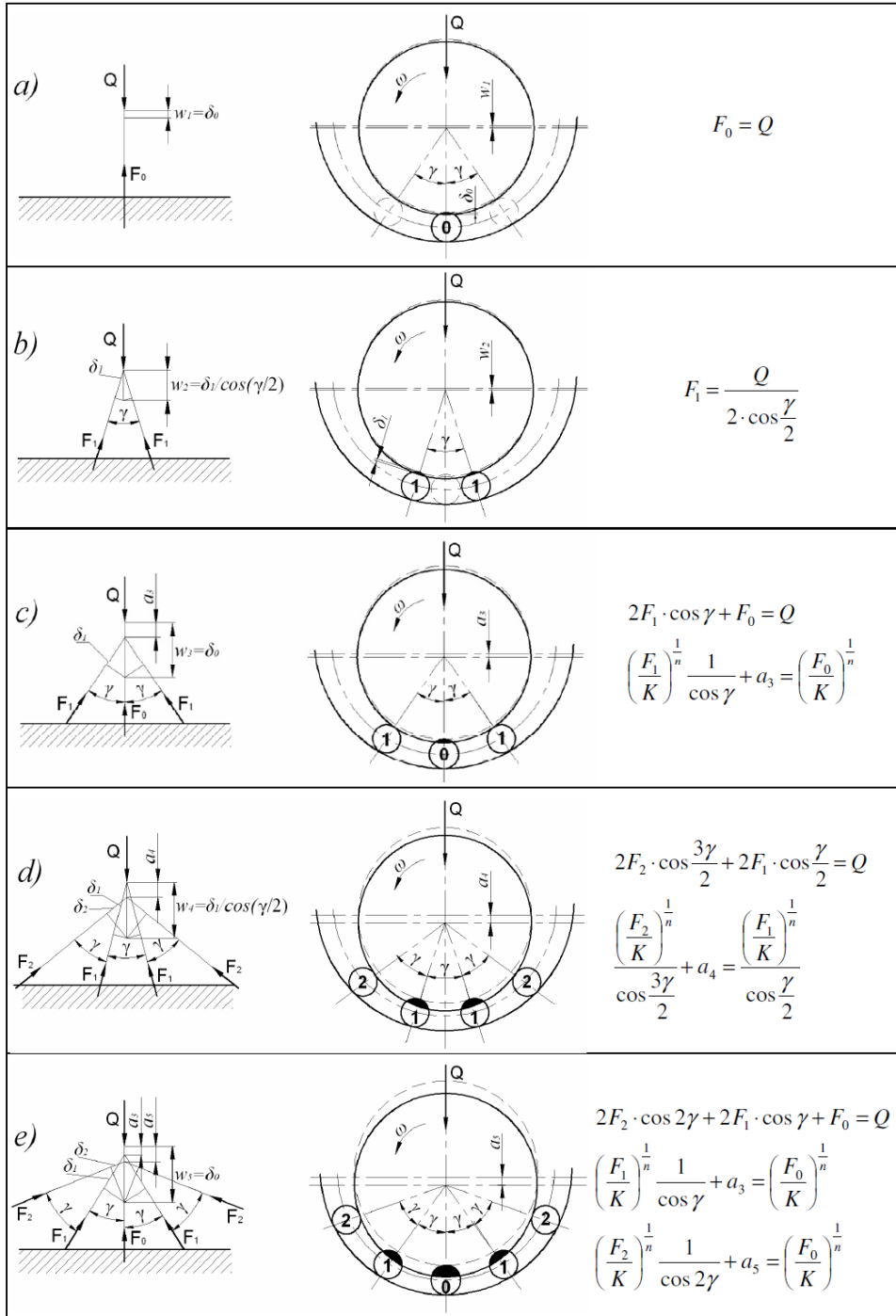
- Kod oslanjanja na paran broj kotrljajnih tijela

$$t_{q,e} = \frac{1}{\cos \frac{q-1}{2} \gamma} - \frac{1}{\cos \frac{\gamma}{2}} \quad (8)$$

Vrijednosti koeficijenata r_q i t_q lako se mogu očitati iz tabela i dijagrama, koji su razvijeni i prikazani u literaturi pod rednim brojem [1 i 2].

5. GRANIČNA VRIJEDNOST SPOLJAŠNJEG RADIJALNOG OPTEREĆENJA

Kao što je već navedeno, da bi se ostvario odgovarajući nivo pomjeranja unutrašnjeg prstenova ležaja, potrebna je i odgovarajuća vrijednost spoljašnjeg radijalnog opterećenja. Prema tome, graničnim vrijednostima pomjeranja unutrašnjeg prstena ležaja, koje su opisane pomoću jednačina (5) i (6), odgovaraju granične vrijednosti spoljašnjeg radijalnog opterećenja. Granično spoljašnje radijalno opterećenje, je ono opterećenje koje je potrebno ostvariti da bi se unutrašnji prsten počeo oslanjati na q kotrljajnih tijela ležaja.



Sl.3 Međusobni uticaj opterećenja i kontaktnih deformacija kod kotrljajnog ležaja [2]

Prema [3], granične vrijednosti spoljašnjeg radijalnog opterećenja za dati ležaj i za datu vrijednost unutrašnjeg radijalnog zazora se mogu izračunati pomoću jednačine:

$$Q_q = K \cdot s_q \cdot \left(\frac{e}{2}\right)^n \quad (9)$$

Ovdje je s_q – koeficijent graničnog spoljašnjeg radijalnog opterećenja. Koeficijenti s_q za slučaj oslanjanja na neparan i paran broj kotrljajnih tijela mogu se izračunati pomoću jednačina:

$$s_{q,o} = \left(\frac{1}{\cos \frac{q-1}{2} \gamma} - 1 \right)^n + 2 \cdot \sum_{i=1}^{\frac{q-1}{2}} \left(\frac{\cos(i\gamma)}{\cos \frac{q-1}{2} \gamma} - 1 \right)^n \cdot \cos(i\gamma) \quad (10)$$

$$s_{q,e} = 2 \cdot \sum_{i=1}^{\frac{q}{2}} \left(\frac{\cos(2i-1)\frac{\gamma}{2}}{\cos(q-1)\frac{\gamma}{2}} - 1 \right)^n \cdot \cos(2i-1)\frac{\gamma}{2} \quad (11)$$

Vrijednost koeficijenta s_q se mogu lako očitati iz tabela i dijagrama, koji su razvijeni i prikazani u literaturi pod rednim brojem [1 i 3].

6. VIBRACIJE KRUTOG ROTORA U KOTRLJAJNOM LEŽAJU

Već je rečeno da usled periodične promjene položaja kompleta kotrljajnih tijela, centar poprečnog presjeka rotora, u odnosu na centar otvora u kućištu ležaja, neprestano osciluje u toku rada. Kako se ove oscilacije dešavaju periodično sa rotacijom kaveza, njihova frekvencija će biti jednaka frekvenciji rotacije kaveza pomnoženoj ukupnim brojem kotrljajnih tijela. Ovu frekvenciju zovemo *prolaznom učestalošću kuglica (ball passage frequency - BPF)*. BPF predstavlja brzinu kojom kotrljajna tijela prelaze preko neke fiksne tačke na spoljašnjem prstenu ležaja. Prema [4], BPF se računa kao:

$$f_{bp} = \frac{z}{2} \cdot \omega \cdot \left(1 - \frac{d_b}{d_c} \cdot \cos \alpha \right) \quad (12)$$

Ovdje su: ω – frekvencija obrtanja rotora, d_b – prečnik kotrljajnih tijela, d_c – srednji prečnik kaveza, α – ugao kontakta ležaja.

Prema [5], veličina *pp*-amplitude (Δ) ovih vibracija je moguće dobiti kao razliku ekstremnih vrijednosti otklona rotora koji se javljaju u dva granična položaja oslanjanja prikazana na slici *Sl. 1.*, prema jednačini:

$$\Delta = y_e - y_o \quad (13)$$

Ovdje je:

- y_e – otklon rotora koji se javlja u graničnom položaju oslanjanja unutrašnjeg prstena na paran broj kotrljajnih tijela (*Sl. 1.b*)
- y_o – otklon rotora koji se javlja u graničnom položaju oslanjanja oslanjanja unutrašnjeg prstena na neparan broj kotrljajnih tijela (*Sl. 1.a*)

Otklon rotora je direktno zavisan od veličine relativnog pomjeranja između prstenova u dva granična položaja oslanjanja ležaja. Prema [1], na relativno pomjeranje prstenova ležaja direktno utiču: veličina unutrašnjeg radijalnog zazora, specifična konstrukcija ležaja, nivo kontaktnih deformacija usled spoljašnjeg radijalnog opterećenja i greške geometrije kotrljajnih staza i kotrljajnih tijela ležaja.

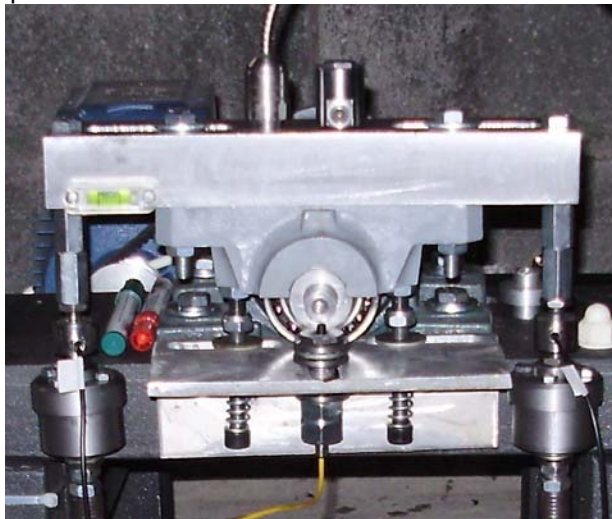
Oscilatorno kretanje rotora usloviće generisanje periodične poremećajne sile. Ova sila će se dalje preko spoljašnjeg prstena ležaja i kućišta prenosi na postolje mašine i pobuđuje vibracije elemenata konstrukcije na BPF i njenim harmonicima ($k \cdot f_{bp}$).

7. EKSPERIMENTALNA VERIFIKACIJA RAZVIJENOG MODELA

U cilju verifikacije razvijenog matematičkog modela izvršeno je eksperimentalno ispitivanje vibracija i napravljena frekventna analiza spektra vibracija kotrljajnog ležaja. Mjerenje vibracija je izvršeno na Uređaju za dinamičko ispitivanje kotrljajnih ležajeva, koji je razvijen na Mašinskom fakultetu u Podgorici. Izdgdled uređaja je prikazan na slici *Sl. 4.* Ležajevi koji su korišteni u ispitivanju su specijalno birani i sklapani za potrebe pojedinih eksperimenata u toku istraživanja.

Eksperimentalna aparatura

Osnovu ispitnog stola čini vratilo koje je oslonjena u dva kuglična ležaja i pogonjena elektromotorom snage 1,5 kW. Na prednjoj strani vratila se postavljaju ležajevi koji se ispituju (*Sl.4.*). U zavisnosti od potrebe, moguće je mijenjati broj obrtaja osovine. U eksperimentu je primjenjivana brzina obrtanja od $n=1476 \text{ min}^{-1}$, što odgovara frekvenciji obrtanja od $\omega=154,5 \text{ s}^{-1}$. Broj obrtaja je mjereno pomoću stroboskopske lampe.



Sl.4 Izgled ispitnog stola

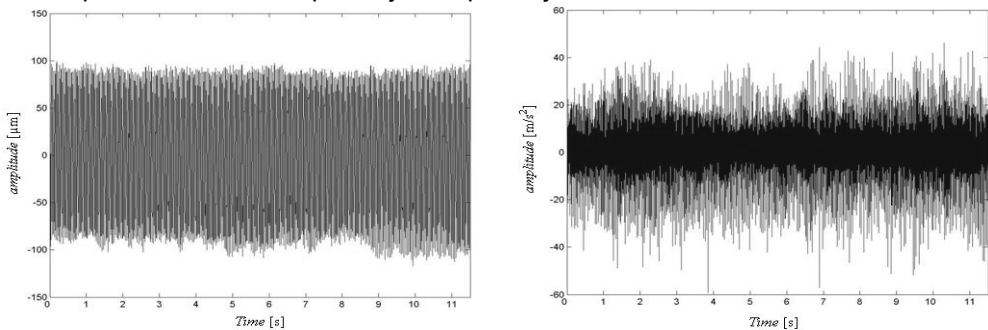
Uređaj omogućuje mjerenje relativnih vibracija (pomjeranje) između spoljašnjeg prstena ležaja i rotora i mjerenje apsolutnih vibracija spoljašnjeg prstena ležaja. Za ovaj eksperiment je korišteno mjerenje relativnih vibracija u radijalnom vertikalnom pravcu. Za mjerenje relativnih vibracija korišten je bezkontaktni davač koji radi na bazi

vrtožnih struja. Davač je montirana u izolovano kućište koje omogućava precizno podešavanje rastojanja vrha davača od površine osovine. Mjerni sistem za mjerenje relativnih vibracija omogućuje mjerenje vibracijskog pomjeranja u opsegu od $\pm 125 \mu\text{m}$ i opsega frekvencija od 5-3000 Hz. Za mjerenje apsolutnih vibracija spoljašnjeg prstena ležaja korišten je seizmički senzor. Senzor registruje vibracije u opsegu frekvencija od 0,5-10000 Hz. Osjetljivost senzora je 100 mV/g, što odgovara 10.2 mV/m/s^2 . Davač sistemu za akviziciju šalje signal opsega $\pm 5 \text{ V}$, što odgovara punoj skali vibracijskog ubrzanja od $\pm 490,5 \text{ m/s}^2$.

Mjerni signal se nakon propuštanja kroz odgovarajući filter u cilju eliminacije neželjenog šuma šalje na uređaj za akviziciju podataka. Uređaj ima šesnaestnositnu rezoluciju, sa brzinom uzorkovanja od 200 kHz i podržava rad u DMA modu. Upravljanje akvizicijom podataka je ostvareno pomoću softverskog paketa LabVIEW.

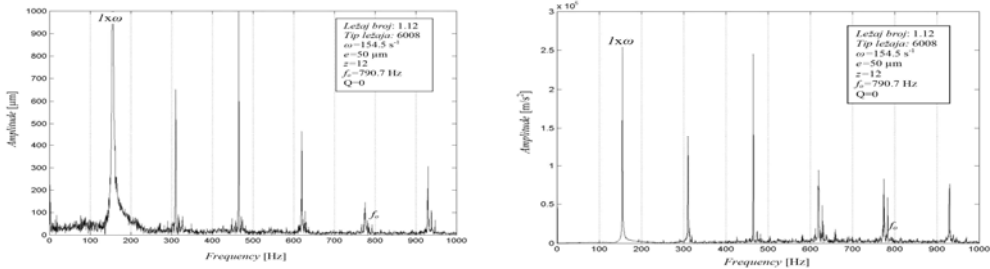
Ekperimentalna procedura

Kao rezultat svakog mjerenja na ispitivanim ležajevima dobija se vremenski zapis relativnih vibracija između rotora i spoljašnjeg prstena ležaja i apsolutnih vibracija spoljašnjeg prstena ležaja. Prikaz tih zapisa je prikazan na slici S1.5. Prilikom uzorkovanja vođeno je računa da budu zadovoljene preporuke da frekvencija uzorkovanja bude deset puta veća od maksimalne frekvencije od interesa, kako bi se izbjegao aliasing. Kako se maksimalna računaska vrijednost BPF ispitivanih ležajeva kretala u granicama do 800 Hz, usvojena vrijednost frekvencije uzorkovanja od 20 kHz je višestruko ispunjavala ovaj zahtjev. Sa svakog od ispitivanih ležajeva sniman je nivo relativnih vibracija u trajanju od 15 sekundi. Tako su dobijeni vibracioni zapisi od 300000 podataka za svako ponovljeno ispitivanje.



S1.5 Vremenski zapis vibracija ležaja a) relativne, b) apsolutne [1]

Rezultati mjerenja dalje su obrađivani FFT-tehnikom pomoću MATLAB-ove biblioteke funkcija za digitalnu obradu signala Signal Processing Toolbox. Frekventni spektar relativnih je prikazan na slici S1.6. Na ovim dijagramima su sa f_{bp} naznačeni prvi harmonici prolazne učestalosti kuglice i sa $1x\omega$ kružne frekvencije vratila. U spektru vibracija se javljaju pikovi i na višim harmonicima BPF. Međutim, za parametarsku analizu u razmatranje su uzete samo amplitude vibracija na primarnim frekvencijama, koje su u najvećem broju slučajeva i navažniji za ocjenu vibracionog ponašanja mašinskih konstrukcija. Napravljeno je šesnest vibracionih snimaka za svaki od ležajeva i za parametarsku analizu su uzete srednje vrijednosti.



Sl.6 Spektralni zapis vibracija ležaja a)relativne, b)apsolutne [1]

Na frekventnim dijagramima uočavaju se visoke vrijednosti amplituda vibracija na frekvenciji obrtanja rotora i njenim harmonicima, kao i na BPF. Visok nivo vibracija na frekvenciji obrtanja rotora je posledica zaostalog debalansa u sistemu, dok su vibracije na BPF posledica specifične konstrukcije i načina rada kotrljajnog ležaja. Ove vibracije se nazivaju strukturnim i ne mogu se izbjeći i javljaju kod svih kotrljajnih ležajeva, čak i onih idealne konstrukcije. Strukturne vibracije se mogu jedino značajnije smanjiti, smanjenjem radijalnog zazora ili odgovarajućom kombinacijom spoljašnjeg radijalnog opterećenja i radijalnog zazora u ležaju.

8. ZAKLJUČAK

U radu je predstavljen novi pristup u matematičkom modeliranju kotrljajnog ležaja. Kompletna matematička analiza, koja je napravljena, razmatra dva granična slučaja oslanjanja unutrašnjeg prstena ležaja: oslanjanje na paran i neparan broj kotrljajnih tijela. Granični položaj oslanjanja na neparan broj kotrljajnih tijela se javlja kada se centar jednog od kotrljajnih tijela poklapa sa pravcem dejstva spoljašnjeg radijalnog opterećenja, a kod oslanjanja na paran broj, kada su kotrljajna tijela simetrično postavljena u odnosu na pravac dejstva spoljašnjeg radijalnog opterećenja. Analiza prikazana u radu je pokazala opravdanost uvođenja i drugog graničnog položaja oslanjanja prilikom modeliranja i analize ponašanja kotrljajnog ležaja u radu i ukazala je na razlike u raspodjeli opterećenja, dinamičkom ponašanju, nivou kontaktnih deformacija i karakteristikama krutosti ležaja u ova dva krajnja položaja oslanjanja.

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PROGRAMSKI SISTEM ZA PRORAČUN MAŠINSKIH ELEMENATA - PROGRAMSKI MODUL ZA PRORAČUN FRIKCIONIH PRENOSNIKA

Dragan Milčić¹, Miroslav Mijajlović², Boban Anđelković³, Miodrag Milčić⁴

Rezime: Na Mašinskom fakultetu Univerziteta u Nišu već duže vreme se razvija programski sistema za proračun mašinskih elemenata i konstrukcija. U okviru programskog sistema PTD razvijeni su brojni programski moduli svrstani u tri celine: programski moduli za proračun elemenata za prenos snage, programski moduli za proračun elemenata za obrtno kretanje i programski moduli za proračun mašinskih spojeva. U radu je prezentiran aplikativni softver za proračun cilindričnih i konusnih frikcionih prenosnika. Za razvoj softvera korišćen je Visual Basic 6.

Ključne riječi: Programski sistem za proračun mašinskih elemenata, Frikcioni prenosnik

SOFTWARE SYSTEM FOR CALCULATIONS OF MACHINE PARTS – PROGRAM MODULE FOR FRICTION TRANSMISSION CALCULATIONS

Abstract: Faculty of mechanical engineering of University of Nis has been working for a long time period on development of the software system for calculations of machine parts and structures. Within software system PTD – Power Transmission Design many different program modules have been developed and they are grouped into three large groups: program modules for calculations of power transmission parts, program modules for calculations of rotation transmission and program modules for calculations of machine joints. Paper gives an overview on applicative software module for calculations of cylindrical and conical friction power transmissions. Software is developed within Visual Basic 6 environment.

Keywords: Software system for calculations of machine parts, Friction power transmission

1. UVOD

Tržište stalno postavlja sve složenije zahteve u pogledu produktivnosti, kvaliteta i brzine osvajanja novih proizvoda. Intenzivan tehnološki razvoj dovodi do porasta projektno - konstrukcijskih zadataka kao i do usložnjavanja sistema koji se

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razvijaju. Danas se u inženjerskoj praksi kao imperativ nameće primena računara u svim fazama procesa razvoja proizvoda.

Osnovni pravci primene računara u procesu razvoja proizvoda vezani su za zadatke:

- reprezentovanja i modeliranja,
- procesiranja i upravljanja podacima i informacijama,
- dokumentovanja,
- analiza i zaključivanja,
- proračuna i simulacija,
- pretraživanja,
- optimizacije,
- dijagnostike,
- procesiranja i upravljanja znanjem,
- sinteze, tj. generisanja koncepcije proizvoda.

Efekti primene računara u razvoju proizvoda su:

- kraće vreme ciklusa dizajniranja i smanjenje vremena do pojave proizvoda na tržište,
- smanjenje ukupnih troškova,
- poboljšanje kvaliteta,
- povećanje kompleksnosti proizvoda,
- povećanje broja dizajniranih varijanti,
- dislocirano konstruisanje, proizvodnja i održavanje.

Ovi efekti su mogući zahvaljujući: povećanju snage računara sa aspekta hardvera i komunikacija, povećanim sposobnostima softvera, povećanoj kompjuterskoj osposobljenosti dizajnera i inženjera, metodama koje omogućuju integrisanje CAX alata (Computer Aided X Tools), virtuelnom procesu razvoja proizvoda.

Iz svih ovih razloga, koji su napred navedeni, na Mašinskom fakultetu Univerziteta u Nišu se već duže vreme razvija programski sistem za proračun mašinskih elemenata i mašinskih konstrukcija - PTD.

2. PROGRAMSKI SISTEM ZA PRORAČUN MAŠINSKIH ELEMENATA

Ovaj programski sistem je, inače, deo inteligentnog integrisanog sistema za konstruisanje zupčastih prenosnika snage razvijenog na Mašinskom fakultetu u Nišu [1]-[3]. Programski sistem PTD je vrlo složene i heterogene strukture. Sistem je razvijen na modularnom principu koji omogućava izvršavanje, uz pomoć računara, pojedinih aktivnosti i zadataka konstruktora. Osnovni zadatak ovog sistema je da omogući integrisanu primenu različitih programskih modula i programskih sistema (CAD/CAE) razvijenih od strane autora i različitih softverskih kuća, a koji su namenjeni automatizaciji pojedinih aktivnosti u konstruisanju prenosnika snage. Zbog toga se softverska platforma razvijenog sistema, oslanja na maksimalnu primenu svih raspoloživih standarda u oblasti razmene podataka, komunikacija i računarstva.

Integrisani programski sistem PTD [4], [5] za proračun mašinskih elemenata, čija je arhitektura data na slici 1, čine tri celine:

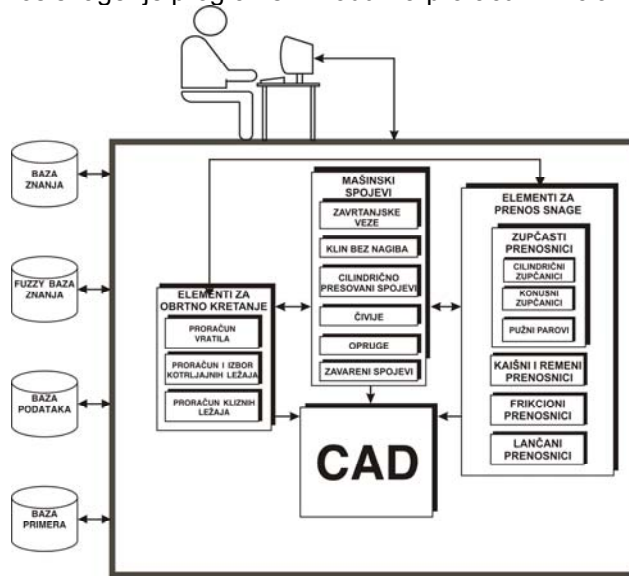
- programski moduli za proračun elemenata za prenos snage,
- programski moduli za proračun elemenata za obrtno kretanje,

- programski moduli za proračun mašinskih spojeva.

Prvom celinom programskog sistema PTD, koja se odnosi na proračun elemenata za prenos snage, obuhvaćeni su programski moduli za proračun cilindričnih, konusnih i pužnih zupčanika, frikcionih, lančanih, kaišnih i remenih prenosnika.

Drugom celinom obuhvaćeni su programski moduli za proračun vratila, proračun kliznih ležaja i proračun i izbor kotrljajnih ležaja, a trećom celinom obuhvaćeni su programski moduli za proračun klinova, žlebnih veza, cilindričnih presovanih spojeva, zavrtanjskih veza, opruga, čivije i zavarenih spojeva.

Nova verzija programskog modula u okviru programskog sistema PTD u delu „Elementi za prenos snage“ je programski modul za proračun frikcionih prenosnika.



Sl.1 Arhitektura programskog sistema PTD

3. PROGRAMSKI MODUL ZA PRORAČUN FRIKCIONIH PRENOSNIKA

Kod frikcionih prenosnika obrtni moment između pogonskog i gonjenog vratila prenosi se putem trenja i to njihovim neposrednim dodirivanjem. Da bi rad frikcionog prenosnika bio moguć potrebno je da sila trenja F_{μ} bude uvek veća ili, u graničnom slučaju, jednaka obimnoj sili F_t na frikcionim točkovima, odnosno $F_{\mu} \geq F_t$.

Potrebna sila trenja na dodirnim površinama frikcionih točkova dobija se pritiskom jednog frikcionog točka na drugi. Za prenos obimne sile F_t potrebna normalna sila između dodirnih površina iznosi:

$$F_n = \frac{F_t \cdot S_{\mu}}{\mu}, \quad (1)$$

gde je S_{μ} – stepen sigurnosti protiv klizanja, a μ – koeficijent trenja.

Na nosivost frikcionih prenosnika, pre svega, utiču: koeficijent trenja, dozvoljeni dodirni pritisak, otpornost u odnosu na habanje, odnosno radni vek i zagrevanje,

odnosno mogućnost odvođenja toplote. Nosivost frikcionog prenosnika zadovoljava ukoliko je radni površinski pritisak manji od dozvoljenog. Za linijski dodir Hercov površinski pritisak se određuje prema izrazu:

$$p = 0,418 \sqrt{\frac{K_A \cdot F_n \cdot E}{\rho_I \cdot b}} \leq p_{doz} \quad (2)$$

Za tačkasti dodir Hercov površinski pritisak iznosi:

$$p = 0,388 \sqrt{\frac{K_A \cdot F_n \cdot E^2}{(\rho_I / y)^2}} \leq p_{doz} \quad (3)$$

Stribekov površinski pritisak za linijski dodir iznosi:

$$k = \frac{K_A \cdot F_n}{2\rho_I \cdot b} \leq k_{doz} \quad (4)$$

gde je K_A – faktor radnih uslova, F_n – normalna sila, E – ekvivalentni modul elastičnosti, ρ_I – ekvivalentni radijus krivine, b – efektivna širina po kojoj se frikciono tačkovi dodiruju, p_{doz} – dozvoljeni površinski pritisak, k_{doz} – dozvoljeni Stribekov pritisak, y – faktor krivine.

The screenshot shows a software interface for calculating frictional transmission parameters. The window is titled "Frikcioni prenosnik" and contains several sections for input and output data.

IZBOR TIPRA PRENOSNIKA
 cilindrični frikcioni prenosnik

IZBOR MATERIJALA I LEZAJA
 Materijal točkova: E360(čaljeni čeli- podmazivanje mineralnim uljem)
 Tip lezaja: za ugrađena 4 koštajna lezaja
 μ = 0.03
 ε = 0.02
 f = 0.05 mm
 p_{doz} = 650 N/mm²
 E = 205000 N/mm²

ULAZNI PODACI
 P_1 = 10 kW
 n_1 = 1250 o/min
 S_μ = 1.5
 u = 2
 Ψ = 0.4
 Karakter promene obrtnog momenta radne masine: elektromotor-ravnomeran
 K_A = 1

IZLAZNI PODACI (GEOMETRIJA FRIKCIONOG PRENOSNIKA)
 Racunske vrednosti
 T_1 = 76.392 Nm
 D_1 = 169.718 mm
 D_2 = 339.437 mm
 b = 57.8874 mm
 i = 2
 Usvojene vrednosti
 D_1 = 180 mm
 D_2 = 360 mm
 b = 70 mm
 a = 270 mm

OSTALI IZLAZNI PODACI
 F_{t1} = 848.8 N
 F_n = 42440 N
 F_{t2} = 848.8 N
 n_2 = 625 o/min
 T_2 = 152.784 Nm
 V_1 = 11.7809 m/s
 P_2 = 9.39724 kW
 P_{GF} = 577.759 W
 P_{GL} = 25 W
 P_G = 602.759 W
 η = 0.99972
 η_F = 0.94222
 ρ_1 = 90 mm
 ρ_2 = 180 mm
 ρ = 60 mm
 p = 503.077 N/mm²

Sl.2 Unos neophodnih podataka za proračun frikcionih prenosnika

Frikcioni prenosnici se mogu podeliti u dve osnovne grupe: prenosnici sa konstantnim prenosnim odnosom i prenosnici sa (regulisanim) promenljivim prenosnim

odnosom ili varijatori. Svaka od napred navedenih grupa obuhvata veći broj prenosnika koji se međusobno razlikuju prema konstrukcionom izvođenju. Zavisno od položaja obrtanja vratila, frikcionni prenosnici mogu biti izvedeni kao cilindrični i konusni. Programskim modulom za proračun frikcionih prenosnika obuhvaćena su ova dva tipa konstrukcionih izvođenja frikcionih prenosnika.

Korisnik softvera opciono bira proračun cilindričnih ili konusnih frikcionih parova. U sledećem koraku se definiše materijal frikcionih točkova. Za izabrani materijal softver daje srednje vrednosti za koeficijent trenja μ , klizanje ε , krak trenja kotrljanja f , dozvoljeni površinski pritisak p_{doz} i ekvivalentni modul elastičnosti E . Naravno, korisnik softvera ove vrednosti može da promeni i unese neke druge.

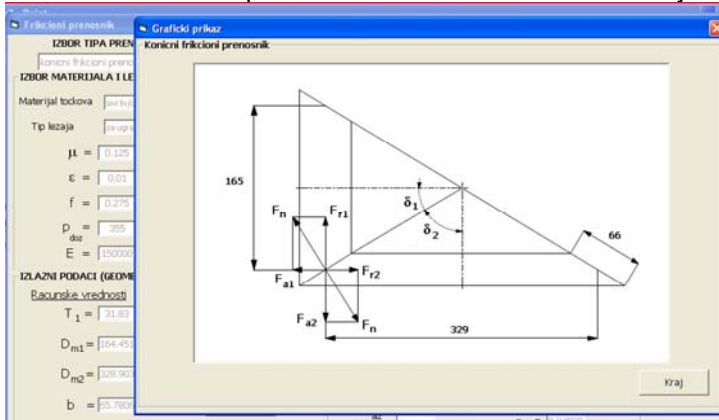
Sl.3 Rezultati prethodnog proračuna frikcionih točkova

Sl.4 Ostali rezultati proračuna

Da bi se izvršilo dimenzionisanje frikcionog prenosnika neophodno je uneti sledeće ulazne podatke: snagu na ulazu P_1 u kW, ulazni broj obrtaja n_1 u min^{-1} , Stepen sigurnosti protiv klizanja S_μ (u preporučenim granicama 1,4 do 2), prenosni odnos u , i odnos širine i prečnika ψ (za cilindrične frikционе točkove u granicama 0,2 do 0,8, a za konusne od 0,2 do 0,4). Faktor radnih uslova K_A se određuje na osnovu vrste pogonske mašine i karaktera promene obrtnog momenta radne mašine.

Na bazi unetih podataka i klikom na dugme PRORAČUN vrši se dimenzionisanje frikcionih točkova – određivanje prečnika D_1 , D_2 i širine b kod cilindričnih frikcionih točkova, odnosno prečnika u srednjem preseku D_{m1} , D_{m2} i širine b kod konusnih frikcionih točkova (sl. 3). Softver daje korisniku predlog usvojenih vrednosti prečnika, ali se pruža korisniku da usvoji vrednosti prečnika D_1 odnosno D_{m1} i zajedničke širine točkova b . Ostali podaci proračuna su dati na formi (sl. 4) odnosno mogu da se odštampaju u vidu Word dokumenta. Takođe korisnik softvera može u vidu

grafičkog prikaza da vidi frikcioni par sa sračunatim osnovnim dimenzijama (sl. 5).



Sl.5 Rezultati proračuna

4. ZAKLJUČAK

Na osnovu napred navedenog može se zaključiti sledeće:

- Na Mašinskom fakultetu Univerziteta u Nišu već duže vreme se razvija programski sistem PTD, koji je u početku bio namenjen za konstruisanje prenosnika snage, a danas prevazilazi prvobitnu ideju i obuhvata proračun gotovo svih mašinskih elemenata.
- Sastavni deo integrisanog programskog sistema za konstruisanje prenosnika snage-PTD, koji se razvija na Mašinskom fakultetu u Nišu, je programski modul za proračun frikcionih prenosnika, koji olakšava i ubrzava aktivnosti konstruisanja.

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ANALIZA HIDRAULIČKIH TRANSMISIJA TRAKTORA GUSENIČARA

Dragoslav Janošević¹, Nikola Petrović², Vesna Nikolić³, Jovan Pavlović⁴

Rezime: Rad sadrži uporednu analizu hidrodinamičkih i hidrostatičkih transmisija kretanja traktora guseničara. Kriterijami za ocenu transmisija se odnose na: efikasnost rada, ergonomiju upravljanja kretanjem, manevarske sposobnosti i mogućnosti regulacije vučnih karakteristika mašina

Ključne reči: traktori guseničari, transmisije kretanja

ANALYSIS OF HYDRAULIC CRAWLER TRACTORS TRANSMISSION

Abstract: *This paper shows a comparative analysis of hydrodynamic and hydrostatic transmissions of crawler tractors. Criteria for evaluation of transmissions related to: work efficiency, ergonomics, motion control, maneuverability and traction control capabilities of the machines.*

Key words: crawler tractors, motion transmissions

1. UVOD

Traktori guseničari pripadaju skupu savremenih mobilnih (građevinskih, rudarskih, transportnih, poljoprivrednih, komunalnih, ...) mašina koje svojim funkcijama obavljaju mnoštvo poslova u gotovo svim privrednim granama. Poslednjih dvadestak godina došlo je do značajnih promena u koncepciji strukturne građe mobilnih mašina. Kod traktora guseničara te promene su naročito izražene kod transmisijama kretanja i sistemima upravljanja kretanjem koje se, pre svega, ogledaju u mogućnostima prenosa energije od dizel motora do pogonskih lančanika u dva ili tri paralelna toka sa povećanim ukupnim stepenom korisnosti transmisije. Pored toga, novi sistemi upravljanja omogućuju traktoru poboljšane manevarske sposobnosti, ublažene prelazne procese u sistemu prenosa energije i ergonomsko rukovanje.

2. VARIJANTNA REŠENJA TRANSMISIJA

U cilju poboljšanja transmisija traktora guseničara IMK 14. Oktobar- Kruševac, izvršena je detaljna analiza izvedenih rešenja transmisija kretanja traktora guseničara vodećih svetskih proizvođača. Na osnovu sprovedene analize mogu se izdvojiti sledeće koncepcije transmisija kretanja traktora guseničara: a) hidrodinamička sa

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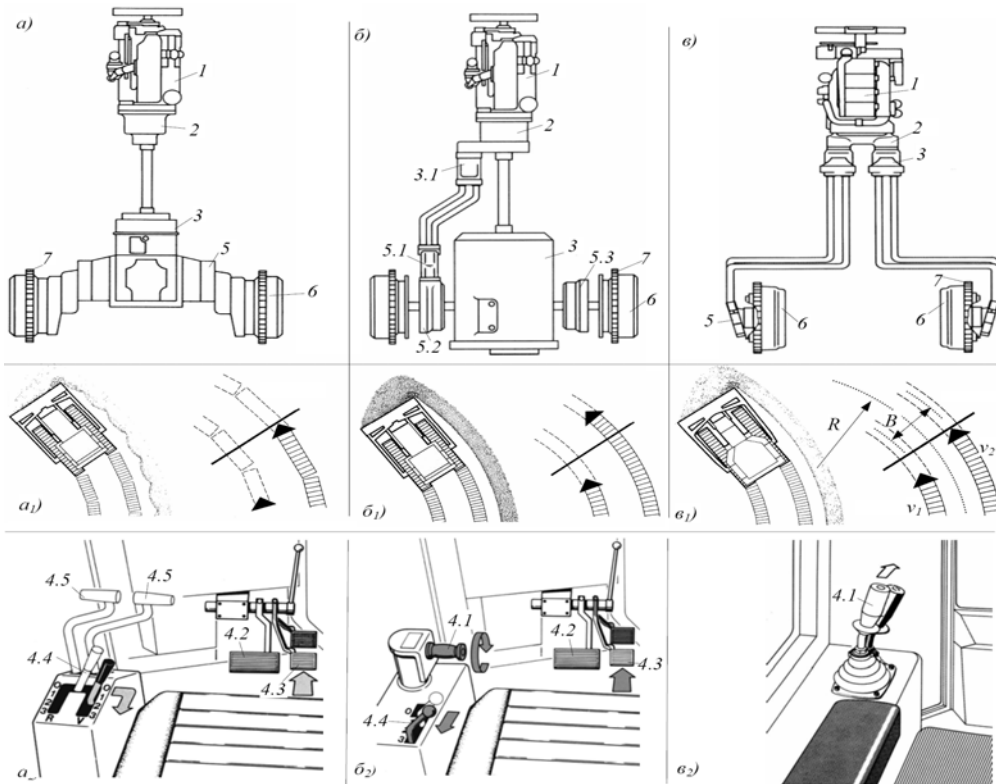
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frikcionim sistemom upravljanja, b) hidrodinamička sa diferencijalnim sistemom upravljanja, v) mehaničko-hidrostaticka i g) hidro-statička transmisija [1][2].

Varijanta I.- Hidrodinamička transmisija sa frikcionim sistemom upravljanja (sl.1a) i jednim tokom energije. Od dizel motora 1, energija se preko hidrodinamičkog pretvarača 2, menjača 3, koničnog para zupčanika, bočnih spojnica i kočnica 5 i bočnih reduktora 6 prenosi na lančanike 7.

Varijanta II. - Hidrodinamička transmisija sa diferencijalnim sistemom upravljanja (sl.1b) sa dva toka energije. Jedan tok ide kroz hidrodinamički deo transmisije koji je sličan prethodnoj varijanti transmisije. Razlika je u tome što su frikcioni članovi transmisije (bočne spojnice) zamenjeni diferencijalnim prenosnicima 5.2 5.3. Drugi tok energije ostvaruje zatvoreno hidrostaticko kolo sa dvosmernom hidropumpom 3.1 i hidromotorom 5.1 koji je povezan sa diferencijalnim prenosnikom 5.1 [2][3].



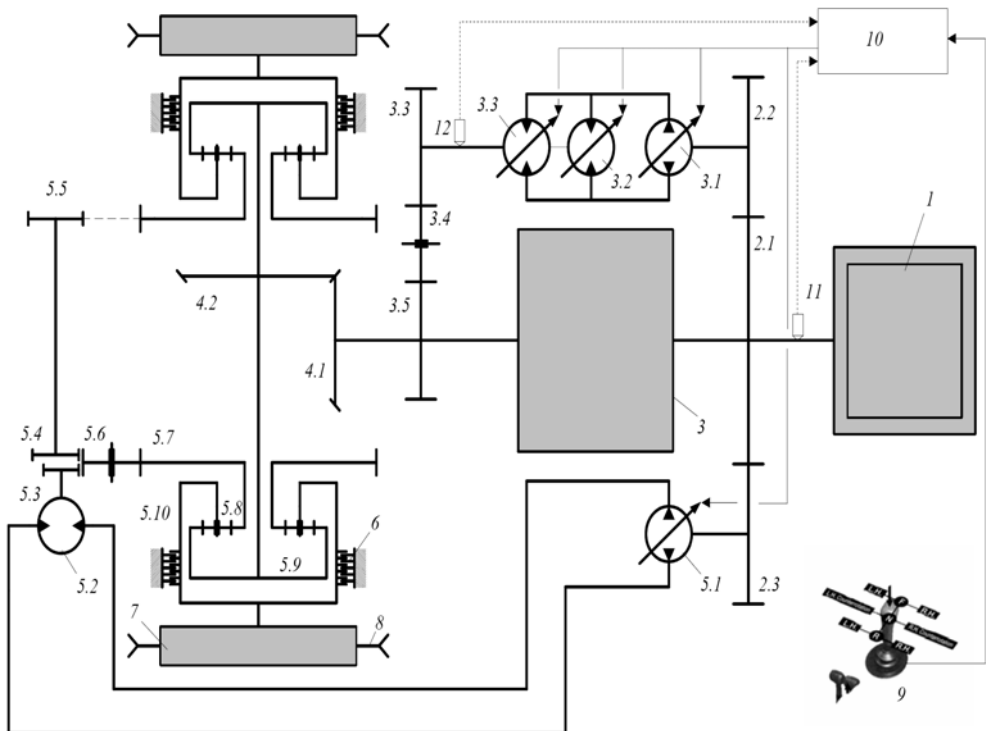
Sl.1 Poređenje transmisija kretanja traktora guseničara: a) hidrodinamička, b) hidrodinamička sa diferencijalnim upravljanjem, v) hidrostaticka [1] [6]

Varijanta III. - Hidrostaticka transmisija (sl.1v) sa dva toka energije kroz dva nezavisna zatvorena hidrostaticka kola - svako kolo za pogon jedne gusenice. Dizel motor 1 predaje svoju energiju preko elastične spojnice i razdelnog prenosnika 2, klipno-aksijalnim hidro-pumpama 3 koje napajaju klipno-aksijalne hidromotore 5 integralno ugrađene u bočne reduktore 6 za koje se vezuju lančanici 7 [4].

Varijanta IV. - Mehaničko-hidrostatička transmisija (sl.2) ima tri paralelna toka energije. Prva dva toka energije služe za pogon kretanja traktora a treći tok energije se koristi za diferencijalno upravljanje kretanjem traktora [5].

Prvi tok energije ide kroz mehanički deo trasmisije od dizel motora 1 kroz planetarni menjač 3 i dalje, preko koničnog para 4.1- 4.2 i bočnih prenosnika, sa jednim planetarnim setom i kočnicom 6, na bočne reduktore 7 za koje se vezuju pogonski lančanici 8. Drugi tok energije se može preneti od dizel motora do pogonskih lančanika, hidrostatičkim delom transmisije, preko zupčanika 2.1-2.2 i zatvorenog hidrostatičkog kola koje obrazuju klipno-aksijalna pumpa 3.1 i redno povezana dva klipno-aksijalna hidromotora 3.2 čija se kretanja, pomoću sabirnog prenosnika, koji čine zupčanici 3.3-3.4 -3.5, sprežu, na izlazu iz manjača, sa prvim tokom energije.

Kombinacijom prvog i drugog toka energije mogu se postići optimalne vučne karakteristike traktora. Tako se pri transportnim (povećanim) brzinama kretanja traktora energija prenosi kroz mehanički deo transmisije. Tada je bolje korišćenje snage dizel motora zbog većeg stepena korisnosti tog dela transmisije. Pri radnim (manjim) brzinama kretanja uključuje se hidrostatički deo transmisije traktora, koji pruža mogućnost lake automatske regulacije parametara kretanja, tako da se i u tom delu brzina postiže bolje korišćenje snage dizel motora u odnosu na klasične hidrodinamičke transmisije kretanja.



Sl. 2 Mehaničko-hidrostatička (hibridna) transmisija traktora guseničera

Automatizacija transmisije se postiže pomoću mikrokontrolera 10 koji na osnovu broja obrtaja dizel motora i hidromotora, merenih senzorima 11 i 12, uključuje i isključuje hidrostatički deo transmisije i vrši regulaciju kretanja promenom parametara hidropumpe 3.1 i hidromotora 3.2.

Treći tok energije se ostvaruje zatvorenim hidrostatičkim kolom sa pumpom 5.1 i hidromotorom 5.2. Vezom hidromotora preko zupčanika 5.6-5.4-5.5-5.7 sa planetarnim setom levog i desnog bočnog prenosnika postiže se uloga diferencijala transmisije. Željeno kretanje mašine se zadaje komandnom palicom 9 odakle se signal preko mikrokontrolera 10 prenosi na regulaciju pumpe 5.1, odnosno hidromotora 5.2, tako da se mogu ostvariti iste ili različite, istosmerne ili suprotnosmerne, brzine gusenica neophodne za pravolinisko ili krivoliniško kretanje traktora.

3. POREĐENJE TRANSMISIJA

Uporednom analizom su obuhvaćene: a) klasična hidrodinamička transmisija sa frikcionim sistemom upravljanja, b) hidrodinamička transmisija sa diferencijalnim upravljanjem i v) hidrostatička transmisija, kao moguće varijante transmisija kretanja traktora guseničara IMK 14. Oktobar - Kruševac. Poređenje se daje prema mogućnostima transmisija koje pružaju pri pravolinijskom i krivolinijskom kretanju kao i u pogledu vučnih karakteristika, od kojih bitno zavisi učinak traktora guseničara.

Poređenje transmisija pri pravolinijskom kretanju. - Kod hidrodinamičke transmisija sa frikcionim upravljanjem pri pravolinijskom kretanju su obe spojnice uključene i gusenice teorijski imaju iste brzine. Za upravljanje kretanjem mašine koristi se: poluga menjača 4.4 (sl.1a2), pedala kočnice 4.3, pedala za usporavanje 4.2, poluge 4.5 desne i leve upravljačke kočnice. Pri pravolinijskom kretanju ako se želi istovremena promena brzine kretanja mašine potrebno je pomoću poluge 4.4 izabrati odgovarajući stepen prenosa menjača.

Kod hidrodinamičke transmisije sa diferencijalnim upravljanjem pri pravolinijskom kretanju mašine energija dizel motora se prenosi samo kroz hidrodinamički deo transmisije. Za upravljanje kretanjem mašine koriste se: poluga za izbor stepena prenosa menjača 4.4 (sl.1b2), pedala kočnice 4.3, pedala za usporavanje 4.2 i komandna ručica 4.1 za izbor pravca i smera kretanja mašine. Pravolinisko kretanje se postiže okretanjem komandne ručice 4.1 napred ili nazad. Ako se želi istovremena promena brzine kretanja mašine potrebno je pomoću poluge 4.4 izabrati odgovarajući stepen prenosa menjača.

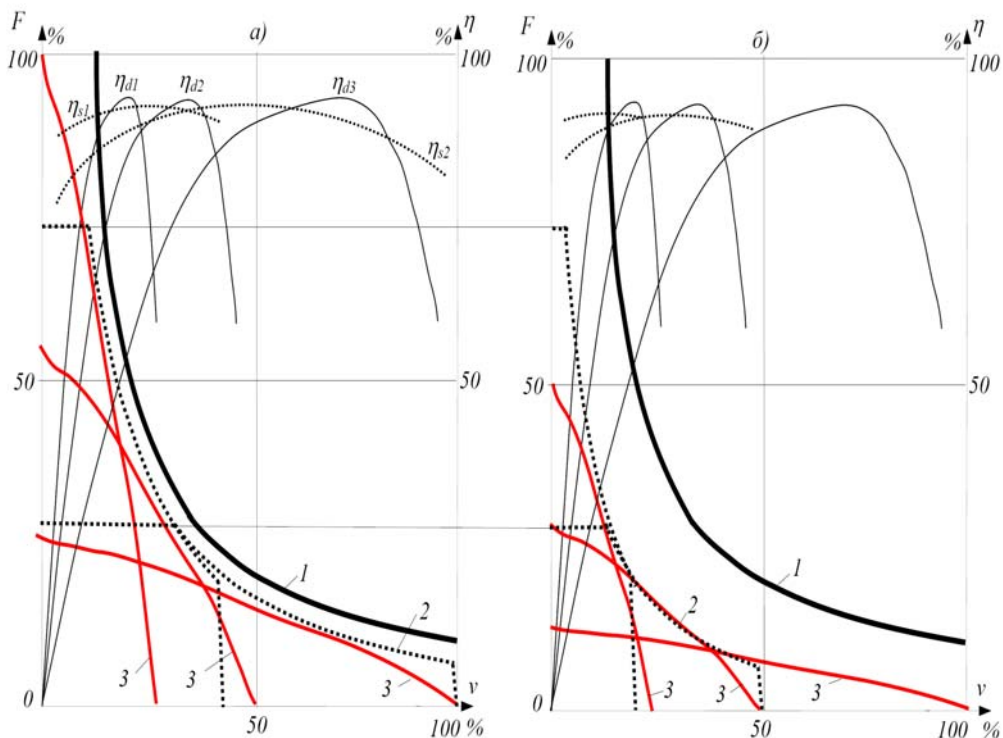
Kod hidrostatičke transmisije pomeranjem samo jedne komandne ručice 4.1 (sl. 1v2), napred ili nazad, ostvaruje se pravolinisko kretanje mašine u odgovarajućem pravcu. Zavisno od brzine i hoda pomeranja iste ručice menja se (ubrzava ili usporava) brzina kretanja mašine.

Poređenje transmisija pri krivolinijskom kretanju. - Zakretanje mašine sa hidrodinamičkom transmisijom i frikcionim upravljanjem se ostvaruje na taj način što se tok snage na jednu gusenicu delimično ili potpuno prekida. Gusenica se pri tome usporava ili je potpuno zaustavljena. Ovakav način upravljanja prouzrokuje nepravilno-isprekidano kretanje u krivini uz smanjenje ukupnih vučnih karakteristika mašine (sl.1a1). Kretanje mašine u krivini prouzrokuje habanje na upravljačkim spojnicama i kočnicama.

Kod hidrodinamičke transmisije sa diferencijalnim upravljanjem kada se želi krivolinijska putanja energija dizel motora 1 (sl.1b) se prenosi preko hidrodinamičkog i hidrostatičkog dela transmisije. U ovom slučaju deo energije koji dolazi iz menjača 3 se

prenosi u istom smeru sa istim brojem obrtaja na ulazna vratila bočnih reduktora. Međutim, energija koja dolazi od hidromotora zahvaljujući diferencijalnom prenosniku 5.2 se deli tako da su brojevi obrtaja vratila prema gusenicama isti ali suprotnih smerova. Na taj način kao rezultujuće kretanje me-njača i hidromotora dobija se ubrzano kretanje bežuće gusenice i isto toliko usporeno kretanje zaostajuće gusenice. Ako se energija dovodi samo preko hidromotora gusenice imaju iste suprotne brzine

Kod hidrostaticke transmisije jednostavnim pokretanjem komandne ručice 4.1 (sl. 1v2) napred ili nazad uz istovremeno njeno zakretanje levo ili desno postiže se krivolinijska putanja željenog pravca i smera. Bilo koji radijus krivine može biti odabran sa kontinualnom promenom inteziteta i smera brzina kretanja gusenica sve do potpunog okretanja mašine u mestu. Pri čemu obe gusenice nezavisno dobijaju pogon i svaka može biti odvojeno upravljana. Zavisno od brzine i veličine hoda zakretanja komandne ručice 4.1 menja se brzina kretanja traktora u krivini.



Sl. 3 Usporedne karakteristike hidrodinamičke i hidrostaticke transmisije traktora guseničara sa korišćenjem snage dizel motora: a) 100%, b) 50%

Poređenje transmisija prema vučnim karakteristikama. - Za ovu analizu posmatraju se dijagrami vuče hidrostaticke 2 (sl.3) i hidrodinamičke 3 transmisije u odnosu sa idealnu hiperboličku zavisnost 1 sile vuče F i brzine kretanja v i to: a) pri potpunom korišćenju snage dizel motora za kretanje mašine (sl.3a), b) pri korišćenju polovine snage dizel motora za kretanje mašine (sl.3b).

Dijagrami pokazuju da hidrostaticke transmisije imaju vučne karakteristike bliže idealnoj hipeboličkoj zavisnosti od hidrodinamičkih transmisija, zahvaljujući lakoj

regulaciji hidro-statičkih parametara snage (protoka i pritiska) transmisije. Osim toga, stepeni korisnosti η_{s1}, η_{s1} (sl.3a) hidrostatičke transmisije imaju veće vrednosti u odnosu na stepene korisnosti $\eta_{d1}, \eta_{d2}, \eta_{d3}$ hidrodinamičke transmisije u većem opsegu brzina kretanja mašine.

U slučaju kada se, na primer, za kretanje mašine koristi polovina snage dizel motora, a druga polovina za pogon manipulatora i pomoćnih sistema, hidrostatička transmisija može ostvariti maksimalnu silu vuče, sa manjim brzinama kretanja, kriva 2 (sl.3b). Pri tome hidropumpe hidrostatičke transmisije imaju maksimalni radni pritisak, ograničen ventilom sigurnosti sistema, a smanjeni protok. U istom slučaju opterećenja dizel motora, hidrodinamičke transmisije ne mogu da ostvare maksimalne sile vuče, kriva 3 (sl.3b), jer se sa smanjenjem snage za pogon kretanja mašine smanjuje i pogonski moment dizel motora koji se predaje hidrodinamičkom pretvaraču transmisije.

4. ZAKLJUČAK

Hidrodinamičke transmisije sa frikcionim upravljanjem kod traktora guseničara su u svom razvoju usmerne na usavršavanje komponenata mehaničkog dela transmisije, potpune automatizacije promene stepena prenosa menjača i povećanja stepena korisnosti. Hidrodinamičke transmisije sa diferencijalnim upravljanjem se javljaju kod traktora guseničara vodećih svetskih proizvođača koji su već imali razvijen koncept hidrodinamičkih transmisija. Hidrostatičke transmisije za traktore guseničare su se poslednjih dvadeset godina naglo razvile. Razlozi leže u tome što je glavni trend razvoja svih mobilnih mašina, pa i traktora guseničara, povećanje radnog učinka, smanjenje potrošnje energije i povećanje komfora rukovanja. Sve ove zahteve danas je nezamislivo ostvariti bez primene hidrostatičkih i elektornskih sistema na mobilnim mašinama. S druge strane opšta je svetska pojava brojnih specijalizovanih proizvođača određenih komponenata i sistema mobilnih mašina.

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ANALIZA KONTAKTNIH NAPONA KOD CIKLOREDUKTORA SA JEDNOSTRUKIM, DVOSTRUKIM I TROSTRUKIM KONTAKTOM

Marko Miletić¹, Mirko Blagojević², Snežana Vulović³, Ivan Miletić⁴

Rezime: Cikloreduktori nalaze primenu u mnogim industrijskim rešenjima i u zadnje vreme su popularni zbog svojih prednosti kao što su prenosni odnos, male dimenzije i veliki stepen iskorišćenja. U ovom radu je predstavljena analiza kontaktnih napona korišćenjem metode konačnih elemenata - MKE. Kontaktni naponi između ciklozupčanika i valjaka nepokretnog centralnog zupčanika su ispitani u tri slučaja (kada je ciklozupčanik u sprezi sa jednim, dva ili tri valjka). Rezultati pokazuju da povećan broj valjaka u sprezi smanjuje sile i napone na valjcima i zubima ciklozupčanika koji su u kontaktu.

Ključne reči: Cikloreduktori, Kontaktna analiza površina, Femap, 2D/3D model, Naponska analiza, Metoda konačnih elemenata

CONTACT SURFACE ANALYSIS ON CYCLOID DRIVES WITH SINGLE, DOUBLE AND TRIPLE MESHING

Abstract: *Cycloid drives have been popular gear reducers in many industry application due to its benefits as gear ratio, small size and great efficiency. In this paper numerical analysis of contact stresses in meshing is done by using FEM. Contact stresses between cycloid gear and output rollers and central gear rollers are investigated in three cases of meshing (single, double and triple meshing). Results show that increased number of meshing decrease forces and stress on teeth and cylinders in contact.*

Keywords: *Cycloid drive, Contact surface analysis, Femap, 2D/3D model, Stress analysis, Meshing characteristics*

1. UVOD

Botsiber i Kingston su 1956. prvi, analitički, opisali princip rada cikloidnih reduktora [1]. Malhotra i Parameswaran su ispitivali uticaj osnovnih parametara i veličina cikloreduktora na sile i opterećenja koji se tu javljaju, kao i teoretsku efikasnost ove vrste reduktora [2]. Chmurawa i John su dosta istraživali na ovom polju i dali veliki

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doprinos u ovoj oblasti. Vršili su analizu naponsko-deformacionog stanja cikloidnih zupčanika korišćenjem metode konačnih elemenata [3]. Takođe su ispitivali uticaj promene ekvidistantnog rastojanja na raspodelu opterećenja kod ciklozupčanika [4]. Koristili su metodu konačnih elemenata za ispitivanje pomeranja kod ciklozupčanika [5]. Chen i ostali su uporedili razlike u proračunima kod cikloreduktora kada je razlika u broju zuba ciklozupčanika i broja valjaka tačno 1 ili kada je veća od 1 [6]. Kwon i ostali su koristili genetske algoritme kako bi optimizovali dizajn i osnovne veličine hipotrohidalnog zupčanika, pri čemu se posebna pažnja odnosila na kontaktne napone [7]. Shin i Kwon su ispitali uticaj različitih profila i koncepcija cikloreduktora u svom radu [8].

2. OPIS CIKLOREDUKTORA, PRIMENJENE METODE I PROGRAMI

Osnovni podaci cikloreduktora

U samom radu je korišćen cikloreduktor koji ima 11 zuba i 12 valjaka na nepokretnom centralnom zupčaniku. Sam proračun ciklozupčanika i valjaka i njihovih osnovnih veličina se već nalazi u literaturi [9]. Osnovne veličine korišćenog cikloreduktora su date u tabeli 1.

Tabela 1 Osnovne karakteristike korišćenog cikloreduktora

	Oznaka	Vrednost
Snaga elektromotora	P_{em}	5.5 kW
Broj obrtaja elektromotora	n_{em}	1500 min ⁻¹
Prenosni odnos	u_{cr}	11
Poluprečnik podeonog kruga centralnog zupčanika	r	72 mm
Broj zuba ciklozupčanika	z_1	11
Broj valjaka nepokretnog centralnog zupčanika	z_2	12
Veličina ekscentriteta	e	4 mm
Ekvidistantno rastojanje	q	10 mm
Poluprečnik osnovne kružnice	R_a	6 mm
Poluprečnik kotrljajuće kružnice	R_b	66 mm

Primenjene metode i proračuni

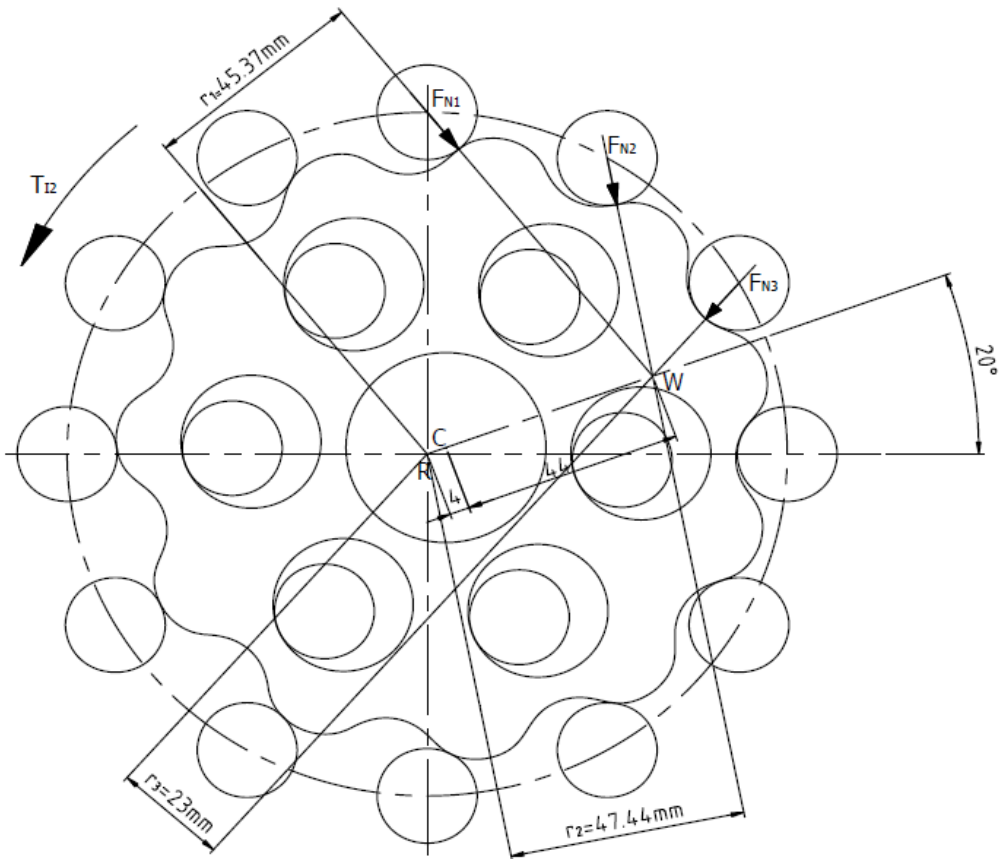
Metoda konačnih elemenata (MKE) je numerička metoda koja se koristi za nalaženje aproksimativnih rešenja parcijalnih diferencijalnih jednačina. Ovu metodu je razvio i prvi primenio Zijenkevič (Zienkiewicz) 1967. Godine, [10].

Po prethodnom proračunu za već pomenuti primer analitičkim putem su dobijene vrednosti sila u kontaktu [9]. Vrednosti sila u kontaktu valjaka i zuba su dati u tabeli 2.

Tabela 2 Vrednosti normalnih sila za I stepen prenosa [9]

U kontaktu	F_{N1}, N	F_{N2}, N	F_{N3}, N
1 zubac	4628,6	/	/
2 zubca	2211,1	2312	/
3 zubca	1969,3	2059,1	998,3

Na slici 1 je prikazano delovanje normalnih sila u kontaktu, osnovna rastojanja od pola i ugao zaokrenutosti ciklozupčanika.



Sl.1 Ciklozupčanik I stepena prenosa u kontaktu sa odgovarajućim valjcima [9]

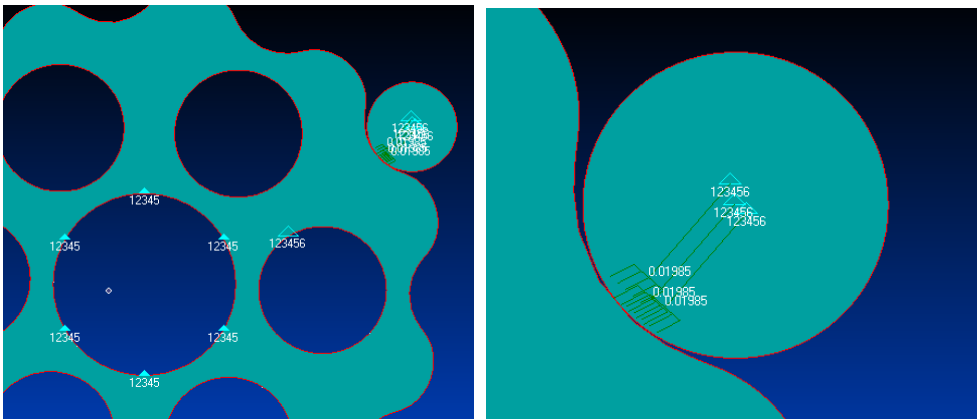
Softver korišćen za metodu konačnih elemenata - FEMAP

FEMAP je napredni program za inženjerske simulacije koji koristi metodu konačnih elemenata pri proračunima kompleksnih inženjerskih proizvoda i sistema i daje rezultate tih simulacija. Korišćenjem FEMAP-a moguće je modelirati pojedinačne delove, sklopove ili cele sisteme, a zatim odrediti njihovo ponašanje pri zadatim uslovima. Korišćenjem FEMAP-ovih simulacija moguće je:

- Predvideti i poboljšati performanse i pouzdanost proizvoda
- Smanjiti potrebno vreme i cenu za proizvodnju protopipa i njegovo testiranje
- Proceniti i oceniti različite varijacije proizvoda i korišćene materijale
- Optimizovati proizvod i smanjiti količinu potrebnog materijala

Način unosa opterećenja u FEMAP-u

U ovom radu biće obrađen 2D kontakt ciklozupčanika i valjaka. Kako još uvek ne postoji modul za unošenje sila u 2D kontaktu koji radi već se opterećenje zadaje preko pomeranja površina ako se koristi SLIDE LINE property opcija, neophodno je bilo fiksirati centar valjka u tri tačke. Kada se ovaj centar tako fiksirao usled pomeranja u zadatom pravcu, koji predstavlja normalan pravac na tangentu kružnice valjka u mestu kontakta, dolazi do pojave sila u fiksiranim tačkama. Zbir ovih sila predstavlja silu reakcije na valjku u kontaktu i valjak je pomeran dok se zbir sila nije poklopio sa vrednošću sila na kontaktima prikazanim u tabeli 2 i na slici 1. Na slici 2 je prikazano kako je vršeno ograničenje i zadavanje opterećenja u FEMAP-u za primer sa jednim valjkom, a isti princip je primenjen i za ostale primere kontakta (dvostruki i trostruki).



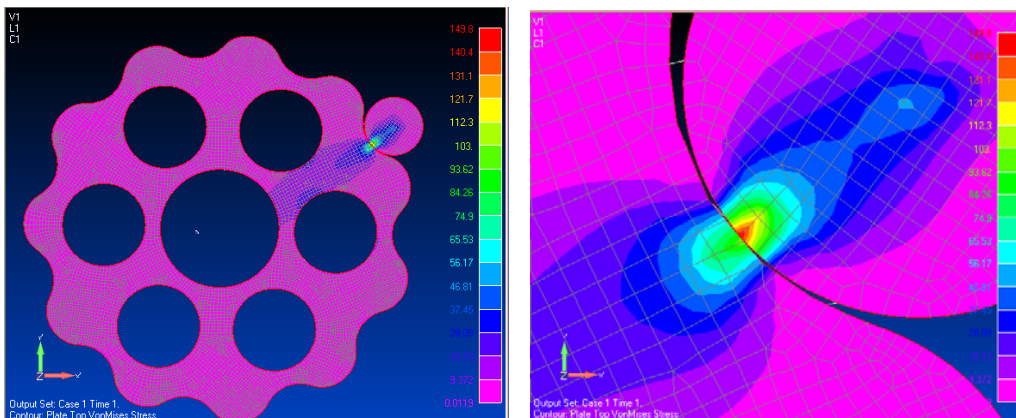
Sl.2 Zadavanje ograničenja i pomeranja kod ciklozupčanika i valjka I

3. REZULTATI I DISKUSIJA

Analiza kontaktnih napona je pokazala da se veći naponi javljaju kod valjaka u kontaktu nego kod ciklozupčanika. Takođe je dokazala da sa porastom broja zuba u kontaktu opada vrednost kontaktnih napona.

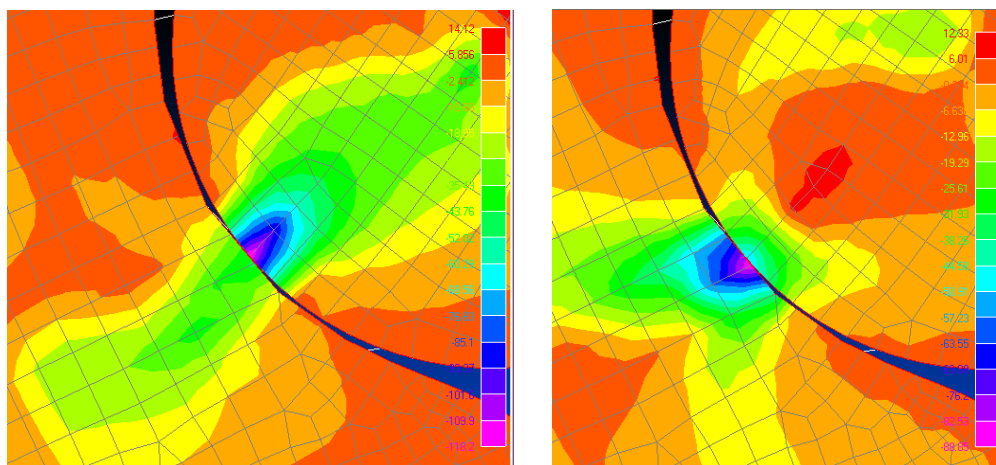
Analiza kontaktnih napona jednostruke sprege

Kod jednostruke veze primenjena je sila na prvom zupcu od 4628 N. Pri tome dolazi do pojave kontaktnih napona od 156.96 MPa na valjku i 104.19 MPa na ciklozupčaniku (sl. 3). Ovo je posledica razlike u obliku i krutosti samog ciklozupčanika i valjka u kontaktu.



Sl.3 VonMises-ovi naponi kod jednostruke sprege

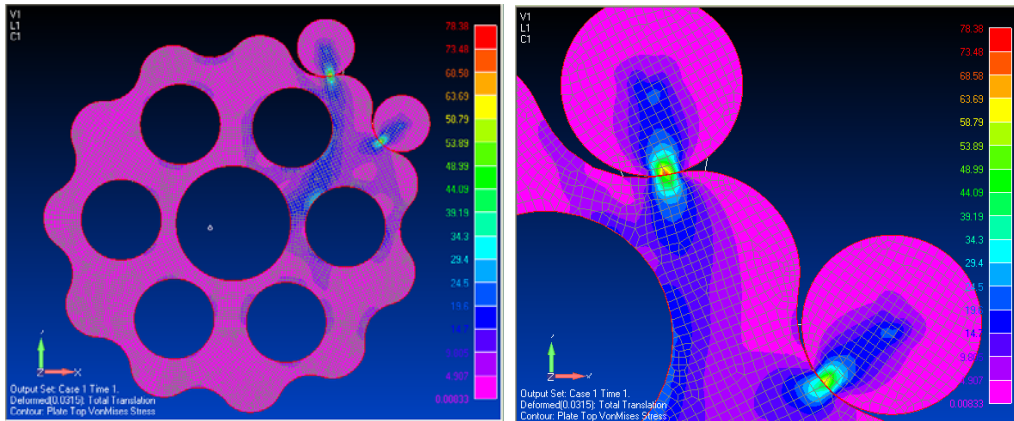
Na slici 4 levo su prikazani normalni naponi po X osi i tu se vidi da je kod valjka napon u kontaktu 124.07 MPa, dok je na ciklozupčaniku 57.01 MPa. Na slici 4 desno su prikazani normalni naponi po Y osi i tu se vidi da je kod valjka napon u kontaktu 59.08 MPa, dok je na ciklozupčaniku 98.03 MPa.



Sl.4 Normalni naponi po X (levo) i Y (desno) kod jednostruke sprege

Analiza kontaktnih napona dvostruke sprege

Kada se u kontaktu sa ciklozupčanikom nalaze dva valjka umesto samo jednog dolazi do opadanja vrednosti napona u kontaktu. U ovom slučaju veći naponi se usled veće sile u kontaktu javljaju na drugom valjku u kontaktu nego kod prvog (slika 5). Takođe je primetno da se naponi kreću duž najkraćeg pravca ka centru ciklozupčanika i valjka od mesta kontakta.

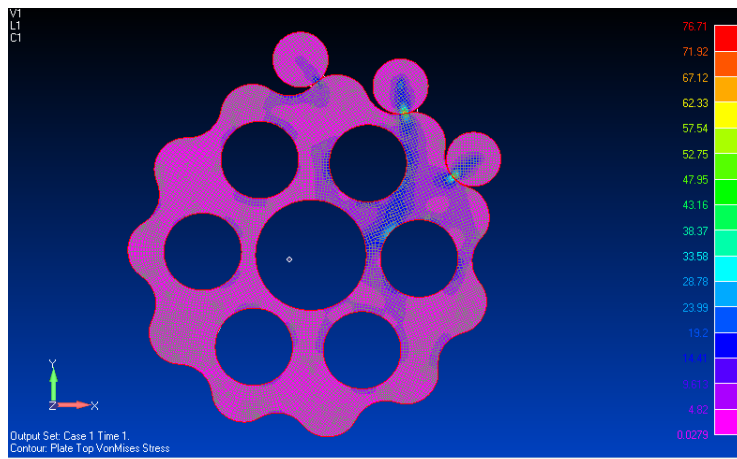


SI.5 VonMises-ovi naponi kod dvostruke sprege

VonMises-ovi naponi koji se javljaju na kontaktu prvog valjka i ciklozupčanika su 71.72 MPa na valjku i 46.499 MPa na ciklozupčaniku. VonMises-ovi naponi koji se javljaju na kontaktu drugog valjka i ciklozupčanika su 82.795 MPa na valjku i 58.045 MPa na ciklozupčaniku.

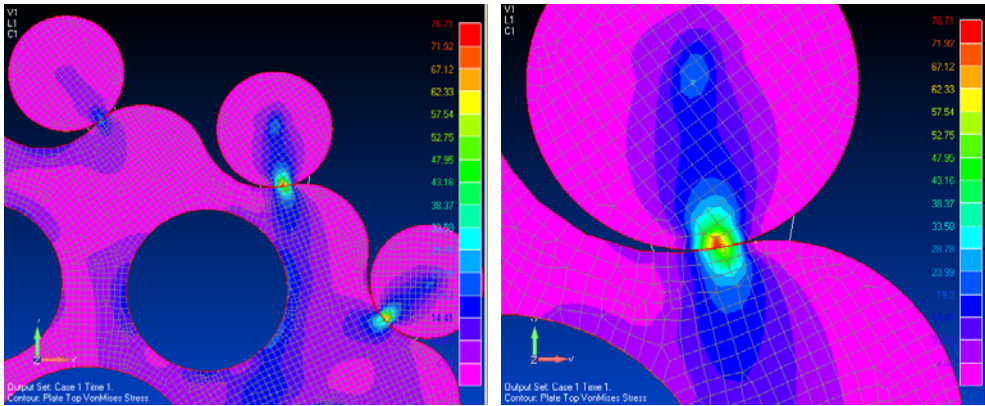
Analiza kontaktnih napona trostruke sprege

Kod analize sa tri valjka u kontaktu je primetno da je sila na trećem valjku dosta (duplo) manja nego kod kontakta sa prvim i drugim valjkom. Samim tim VonMises-ovi naponi su kod trećeg valjka dosta manji nego kod prva dva valjka (slika 6).



SI.6 VonMises-ovi naponi kod trostruke sprege

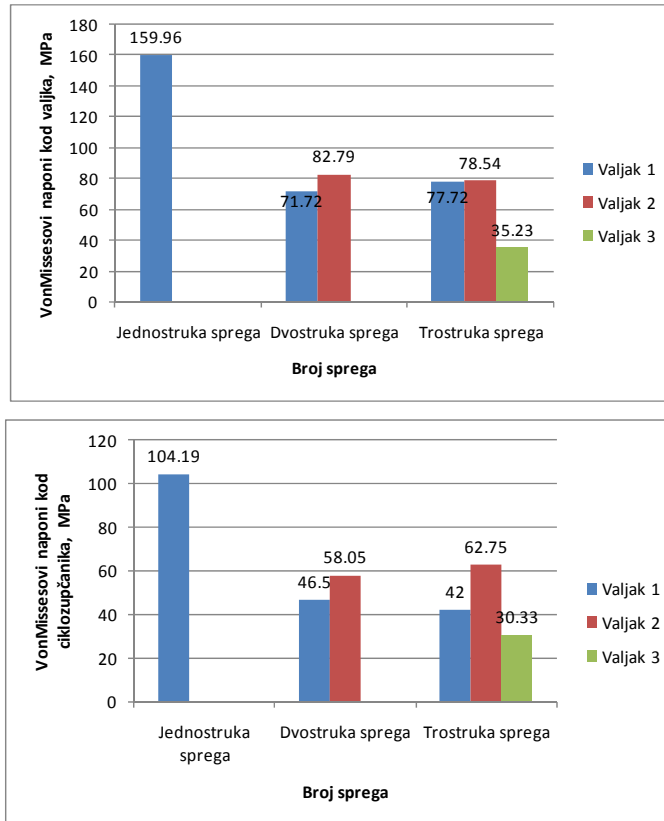
VonMises-ovi naponi na kontaktu kod prvog valjka su 77.27 MPa na valjku i 42 MPa na ciklozupčaniku. VonMises-ovi naponi na kontaktu kod drugog valjka su 78.537 MPa na valjku i 62.75 MPa na ciklozupčaniku. Sami naponi na drugom valjku su prikazani na slici 7 desno.



Sl.7 VonMises-ovi naponi kod trostruke sprege – detalj dole desno valjak 2

Na mestu kontakta trećeg valjka i ciklozupčanika se javljaju naponi od 35 MPa na valjku i 30 MPa na ciklozupčaniku.

Radi lakšeg pregleda rezultata na slici 8 su prikazane vrednosti VonMisesovih napona u zavisnosti od broja sprege i rednog broja valjka u kontaktu.



Sl.8 VonMises-ovi naponi na mestima kontakta (valjci-gore, ciklozupčanik-dole)

4. ZAKLJUČAK

Na osnovu dobijenih rezultata može se zaključiti da je analiza napona na mestu kontakta jako bitna. Takođe možemo zaključiti da su naponi na valjcima veći nego na ciklozupčaniku. Ovo je uslovljeno oblikom i pravcima kako se naponi prostiru kod valjka a kako kod ciklozupčanika. Bitno je primetiti da su naponi na valjku dva najveći u odnosu na druge valjka u kontaktu kada postoji dvostruka i trostruka veza. Ovo je uslovljeno samom silom u kontaktu, koja predstavlja obrtni moment koji se zadaje kretanjem ciklozupčanika i rastojanje od pola na mestu kontakta. Primetno je da sila, kao i naponi drastično opadaju na mestu kontakta trećeg valjka, dok se naponi na prvom i drugom valjku ne menjaju drastično kod prvog i drugog valjka kod trostruke veze u odnosu na dvostruku vezu. To znači da povećanje broja kontakta na više od tri ne bi imalo nekog velikog efekta i zato veći broj kontakta od 3 i nije tema istraživanja.

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ODREĐIVANJE KONSTRUKCIJSKIH PARAMETARA MJENJAČKOG PRENOSNIKA NA OSNOVU POTREBNE POUZDANOSTI

Miroslav Milutinović¹, Milosav Ognjanović², Spasoje Trifković³

Rezime: Razvoj ili usavršavanje postojeće konstrukcije podrazumijeva poznavanje uslova rada i opterećenja koja nastaju u toku eksploatacije prenosnika. U radu su dati rezultati istraživanja spektara opterećenja komponenata menjačkog prenosnika i razvijen model za određivanje konstrukcijskih parametara prenosnika. Kao ulazni podaci koriste se definisani spektri radnih opterećenja i željeni nivo pouzdanosti na kraju radnog vijeka prenosnika. Za tu svrhu razvijen je softver DRAG. Verifikacija razvijene procedure i softvera izvršena je na šestostepenom ZF-ovom manuelnom mjenjačkom prenosniku.

Ključne riječi: mjenjački prenosnik, zupčanici, pouzdanost, spektar opterećenja

DESIGN PARAMETERS IDENTIFICATION OF AUTOMOTIVE GEARBOX BASED ON DESIRED RELIABILITY

Abstract: Development and perfection of existing design structures implies knowledge about operating conditions and loads that occur in the course of gearbox exploitation. The paper contains results of gearbox components load spectrums research and developed model for determination of gearbox design parameters. As input data have used the defined load spectrums and desired level of gearbox reliability at the end of service life. For this purpose the software DRAG is developed. Verification of developed procedure and software is carried out on the manual six-speed ZF gear box.

Keywords: automotive gearbox, gear, reliability, load spectrum

1. UVOD

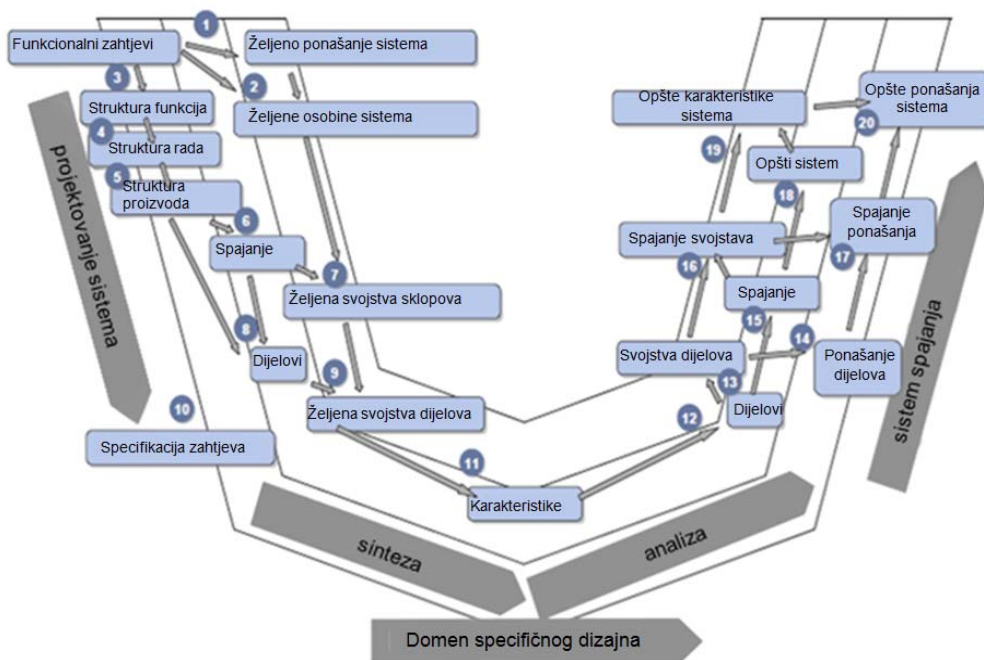
Mjenjački prenosnik ostvaruje funkciju u izrazito promjenjivim uslovima eksploatacije. Potrebno je da se pri određivanju konstrukcijskih parametara obezbijedi uslov da ovi parametri što manje zavise od varijacije uslova rada. Metodologija robustnog dizajna pruža mogućnost za realizaciju ovoga cilja. Osim toga za realizaciju postavljenog cilja u ovom radu biće iskorišćene i osnovne postavke aksiomatskog

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dizajna kao i postavke dizajna zasnovanog na svojstvima (property-based design) prikazanog na slici 1 [1]. Ovaj prikaz je zasnovan na V-modelu za razvoj proizvoda prema VDI-2206. Ravoj proizvda počinje sa funkcionalnim zahtjeva a završava se sa određivanjem pokazatelja ponašanja sistema u eksploataciji. Proces razvoja dat je u 20 koraka koji pokrivaju četiri logičke cjeline. U prvih deset koraka se željene vrijednosti funkcionalnih zahtjeva dekomponuju do nivoa svojstava dijelova i sklopova sistema. U okviru sinteze se na osnovu svojstava mašinskih dijelova, određuju njihovi konstrukcijski parametri. Cjelina koja obuhvata analizu podrazumijeva ponovno određivanje svojstava dijelova i sklopova na bazi izabranih konstrukcijskih parametara. Dalje slijedi integrisanje svojstava do nivoa kompletnog sistema gdje ona postaju pokazatelji kvaliteta sistema. Potrebno je da oni budu na nivou željenih funkcionalnih potreba od kojih se pošlo u razvoj. U ovom radu će pouzdanost mjenjačkog prenosnika biti funkcionalna potreba sistema, zatim svojstvo dijelova i sklopova mjenjača i na kraju pokazatelj njegovog kvaliteta u skladu sa V-modelom na slici 1.



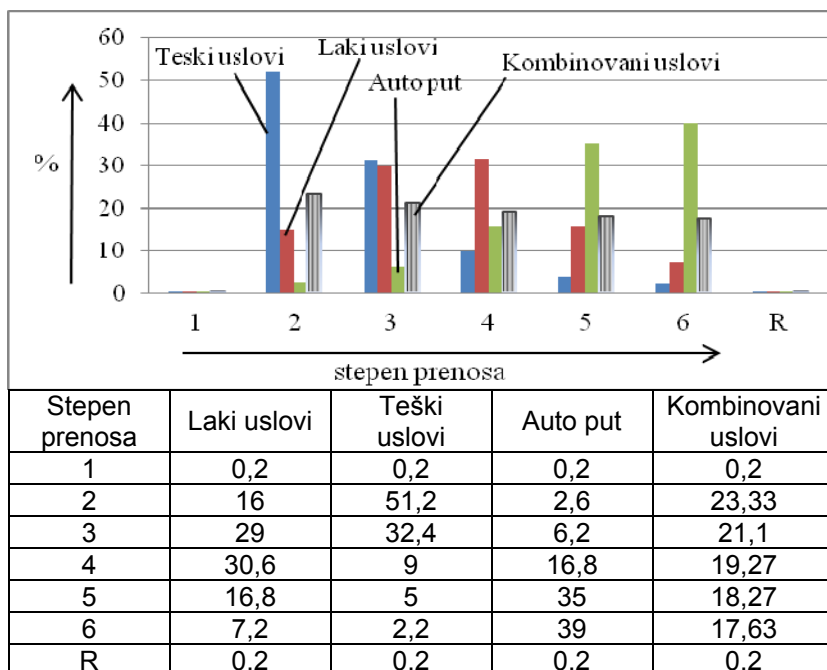
Slika 1. Model dizajna na bazi svojstva [1]

Cilj ovog rada jeste da se definišu optimalni konstrukcijski parametri ili definiše nosivost za date konstrukcijske parametre i za reprezentativne uslove eksploatacije. S druge strane potrebno je omogućiti provjeru dobijenih rezultata ili analizu postojećih rješenja. Za tu svrhu razvijen je softver koji omogućuje interaktivnu varijaciju ulaznih podataka i optimizovanje konstrukcijskih parametara i svojstava sistema i njegovih komponenata. Rad je takođe nastavak istraživanja započetih u radu [2] i koji obuhvata model pouzdanosti mjenjačkog prenosnika u radu [3] koji se odnose na specifičan način definisanja pouzdanosti zupčastih parova i ležaja u mjenjačkom prenosniku. Za definisanje pouzdanosti prenosnika ključna su potencijalna razaranja zupčanika (bokova zubaca) i ležaja. Razaranja bokova zubaca zupčanika zavise od materijala i termičke obrade zupčanika, obrađenih u radu [4]. Pouzdanost prenosnika zavisi od pouzdanosti komponenata ugrađenih u dati prenosnik. U skladu sa V-modelom na sl. 1, neophodno je izvršiti dekompoziciju prenosnika. Radovi [5]-[8] pored ostalog obraduju problematiku dekomponovanjem strukture, svojstava i parametara tehničkog sistema.

2. SPEKTRI OPTEREĆENJA KOMPONENATA PRENOSNIKA

Eksploatacija motornih vozila ostvaruje se u širokom spektru radnih uslova. Variraju karakteristike terena po kojima se vozilo kreće, različiti su vozači koji upravljaju vozilom, tako da isto vozilo može biti izloženo različitim uslovima rada na istoj deonici puta. Radna opterećenja su posledica radnih otpora koje vozilo savladava u uslovima eksploatacije, a koji su izrazito stohastički.

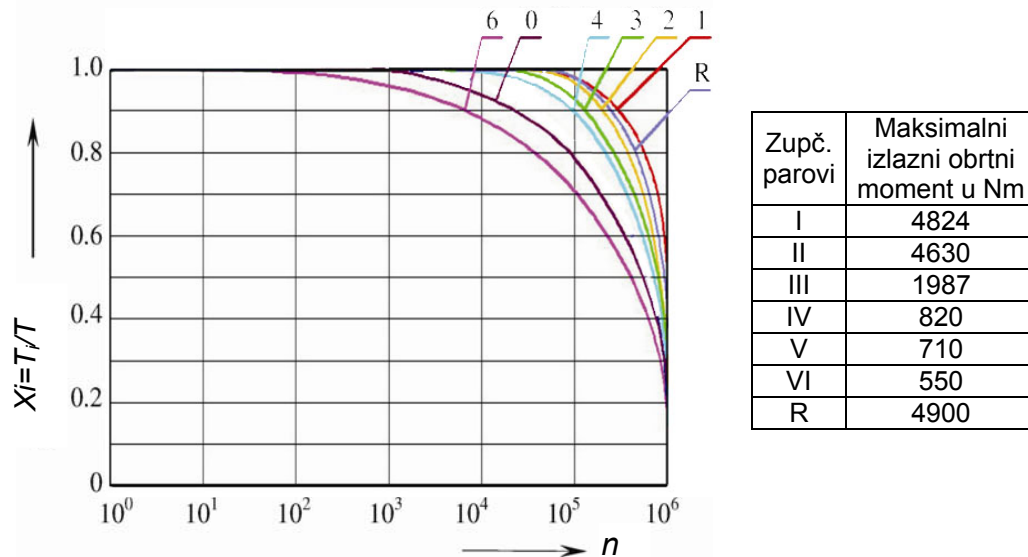
U cilju dobijanja reprezentativnih uslova rada pri korišćenju istog mjenjačkog prenosioca izvršena je analiza učešća (korišćenja) svakog od stepeni prenosa pri različitim putnim karakteristikama metodom intervjua. U pomenutoj metodi je učestvovalo 30 ispitanika, od kojih su polovina bili korisnici a druga polovina održavaoci teretnih motornih vozila u koja su ugrađeni određeni tipovi mjenjačkih prenosioca. Cilj ove metode jeste da se na osnovu dugogodišnjeg iskustva sakupe podaci o učešćima stepeni prenosa i oštećenjima koja nastaju na mjenjačkim prenosiocima. Na osnovu metode intervjua dobijeni su podaci o učešćima svakog od stepena prenosa za različite uslove rada (slika 2). Drugi korak u ovom istraživanju bio je mjerenje izlaznog obrtnog momenta iz mjenjačkog prenosioca u realnim uslovima rada za svaki stepen prenosa pri vožnji neopterećenog i opterećenog teretnog motornog vozila, u lakim i teškim uslovim rada.



Slika 2. Učešće stepeni prenosa pri vožnji u različitim uslovima

Mjerenja obrtnih momenata su izvršena na Kardanovom vratilu, koje je spojeno na izlazno vratilo iz mjenjačkog prenosioca. Na osnovu čega su dobijeni rezultati za vožnju po planinskim terenima kao reprezentima teških uslova rada i ravničarskim predjelima kao reprezentima lakih uslova rada. Kombinovanjem statističkih rezultata, rezultata mjerenja i procjenom učešća stepeni prenosa dobijaju se spektri opterećenja za svaki stepen prenosa. Spektar opterećenja pokazuje učešće obrtnog momenta pri svakom stepenu prenosa u milion promjena (obrta malog zupčanika u sprezi) (slika 3). Opterećenja na izlazu iz mjenjačkog prenosioca su odgovarajućim

transformacijama proračunate za svaki stepen prenosa i prikazane na slici 3. Prilikom rada svih stepeni prenosa, osim petog, učestvuje nulti par. Odnos $x_i=T_i/T_1$ je odnos od 0 do 1, gdje je T_1 je maksimalni obrtni moment malog zupčanika, odnosno T_{10} je za nulti par, T_{11} za prvi par zupčanika (za prvu brzinu), itd. Obrtni moment na odgovarajućem zupčastom paru dobija se proračunavanjem na osnovu odgovarajućih prenosnih odnosa.



Slika 3. Spektar opterećenja malog zupčanika za svaki stepen prenosa

3. POUZDANOST KOMPONENATA PRENOSNIKA

U skladu sa procedurom koja je data na slici 1, osnovna funkcionalna potreba mjenjačkog prenosnika je potrebna pouzdanost R posle potrebnog broja predjenih kilometara vozila tokom radnog vijeka. Dekomponovanje željene pouzdanosti može se ostvariti po raznim osnovama. Ako bi pouzdanosti komponenata bile jednake radni vijek svih komponenata bi se završio u isto vrijeme. Tom idealnom stanju može se samo težiti, ali i primeniti u ovom inverznom pristupu tj. dekomponovanju ukupne pouzdanosti u redno vezanom sistemu pouzdanosti. Ako je mjenjački prenosnik sačinjen od r komponenata, pouzdanost svake od njih je

$$R_j = \sqrt[r]{R} \quad (1)$$

gdje je: $r=x+y+z+p+m=7+3+6+1+2=18$

- x – broj parova zupčanika
- y – broj sinhro-spojnice
- z – broj ležaja
- p – broj upravljačkih sistema
- m – broj zaptivnih spojeva

U ovom modelu parcijalna pouzdanost zupčanika može se predstaviti modelom

$$R_x = R_{g0} R_{g1} R_{g2} R_{g3} R_{g4} R_{g6} R_{gR} \quad (2)$$

gdje je svaka od parcijalnih pouzdanosti nižeg nivoa $R_{g0}, R_{g1}, R_{g2}, R_{g3}, R_{g4}, R_{g6}, R_{gR}$ pouzdanost parova zupčanika ugrađenih u prenosniku, koji kada se oštete zamjenjuju se u paru. Broj ovih pouzdanosti odgovara broju parova zupčanika $x=7$ (videti šemu na slici 5). Elementarna pouzdanost svakog para zupčanika je $R_g=R_j$ prema jednačini 1.

Kao i za zupčanike, pouzdanosti sinhro-spojnika i pouzdanosti ležaja čine serijsku vezu elementarnih pouzdanosti

$$R_y = R_{c1}R_{c2}R_{c3}; \quad R_z = R_{b1}R_{b2}R_{b3}R_{b4}R_{b5}R_{b6} \quad (3)$$

Broj sinhrospojnika je $y=3$, a broj ležaja u ovom menjaču je $z=6$ (videti skicu na slici 5). Sistem upravljanja sa aspekta njegovih kvarova tretiran kao jedna komponenta $p=1$. Broj zaptivnih spojeva na ulaznom vratilu i na izlaznom vratilu je $m=2$. Pouzdanost jednog para zupčanika R_{gx} je komplement njegove nepouzdanosti F_{px}

$$R_{gx} = 1 - F_{px} \quad (4)$$

Zupci zupčanika mogu biti razoreni habanjem ili biti polomljeni. Lomovi su po pravilu rezultat akcidentnih stanja. Zupci se permanentno habaju te su za ovu i slične analize merodavna razaranja bokova zubaca. Nepouzdanost u odnosu na razaranja bokova jednog para zupčanika je

$$F_{px} = \sum_{i=1}^k p_i(\sigma_{Hi}) P_{Fi}(\sigma_{Hi}) \quad (5)$$

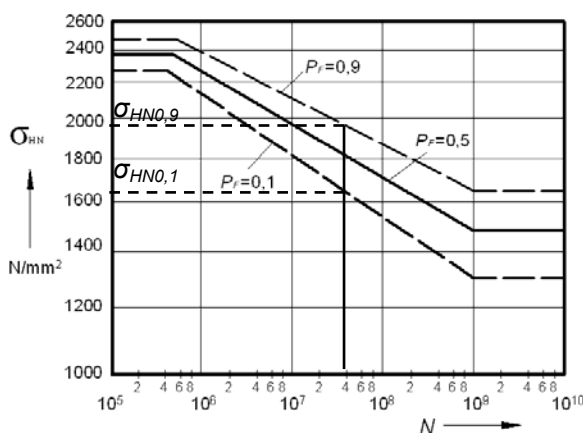
To je složena vjerovatnoća od vjerovatnoće pojave radnog napona $p(\sigma_{Hi})$ i vjerovatnoće razaranja pod dejstvom tog napona $P_F(\sigma_{Hi})$. Pošto je par zupčanika izložen spektru napona u skladu sa prikazom na slici 3, to je nepouzdanost integral odnosno suma vjerovatnoća za sve nivoe napona $i=k$.

Vjerovatnoća razara za odgovarajući napon σ_H definisan je Weibulovom raspodjelom

$$P_F = 1 - e^{-\left(\frac{\sigma_H}{\eta}\right)^\beta} \quad (6)$$

Parametri ove raspodjele mogu se dobiti na osnovu područja rasipanja vjerovatnoće razaranja dobijeno ispitivanjem i dato u DIN 3990 (sl.4). Za granične vrijednosti vjerovatnoće razaranja $P_F=0,1$ i $P_F=0,9$ sa ovog dijagrama, određuju se parametri η i β kao

$$\eta = \frac{\sigma_{HN}}{\sqrt[\beta]{-\ln(1 - P_R(\sigma_{HN}))}} \quad \beta = \frac{\log\left(\frac{-\ln 0,1}{-\ln 0,9}\right)}{\log\left(\frac{\sigma_{HN0,9}}{\sigma_{HN0,1}}\right)} \quad (7)$$



Slika 4. Područje rasipanja vjerovatnoće razaranja za cementirane zupčanike

4. KORELACIJA KONSTRUKCIJSKIH PARAMETARA USLOVA RADA I NOSIVOSTI

Na osnovu pouzdanosti para zupčanika R_{gx} dobijene dekomponovanjem ukupne željene pouzdanosti, uz korišćenje obrazca (5), izračunava se dozvoljeni napon za odgovarajući par zupčanika $(\sigma_{Hdoz})_x$

Iz uslova da radni napon na bokovima zubaca bude manji ili jednak dozvoljenom

$$Z \sqrt{\frac{T_{x1}}{2b_x d_{x1}^2} \frac{u_x + 1}{u_x}} K \leq (\sigma_{Hdoz})_x \quad (8)$$

Određuje se nosivost T_{x1} tog para zupčanika za date radne uslove i za date sve konstrukcijske parametre. Ako je potrebna nosivost definisana kao željena veličina i ako su svi konstrukcijski parametri definisani, iz jednačine (9) određuje se potrebna širina zupčanika.

$$T_{x1} = \frac{2(\sigma_{Hdoz})_x^2 b_x d_{x1}^2}{Z^2 K} \frac{u_x}{u_x + 1}; \quad b_x = \frac{T_{x1}}{2(\sigma_{Hdoz})^2 d_{x1}^2} \frac{u_x + 1}{u} Z^2 K \quad (9)$$

Uticaj parametara ozubljenja na naponsko stanje obuhvaćen koeficijentom Z , a uticaj karaktera raspodjele opterećenja obuhvaćen je koeficijentom K .

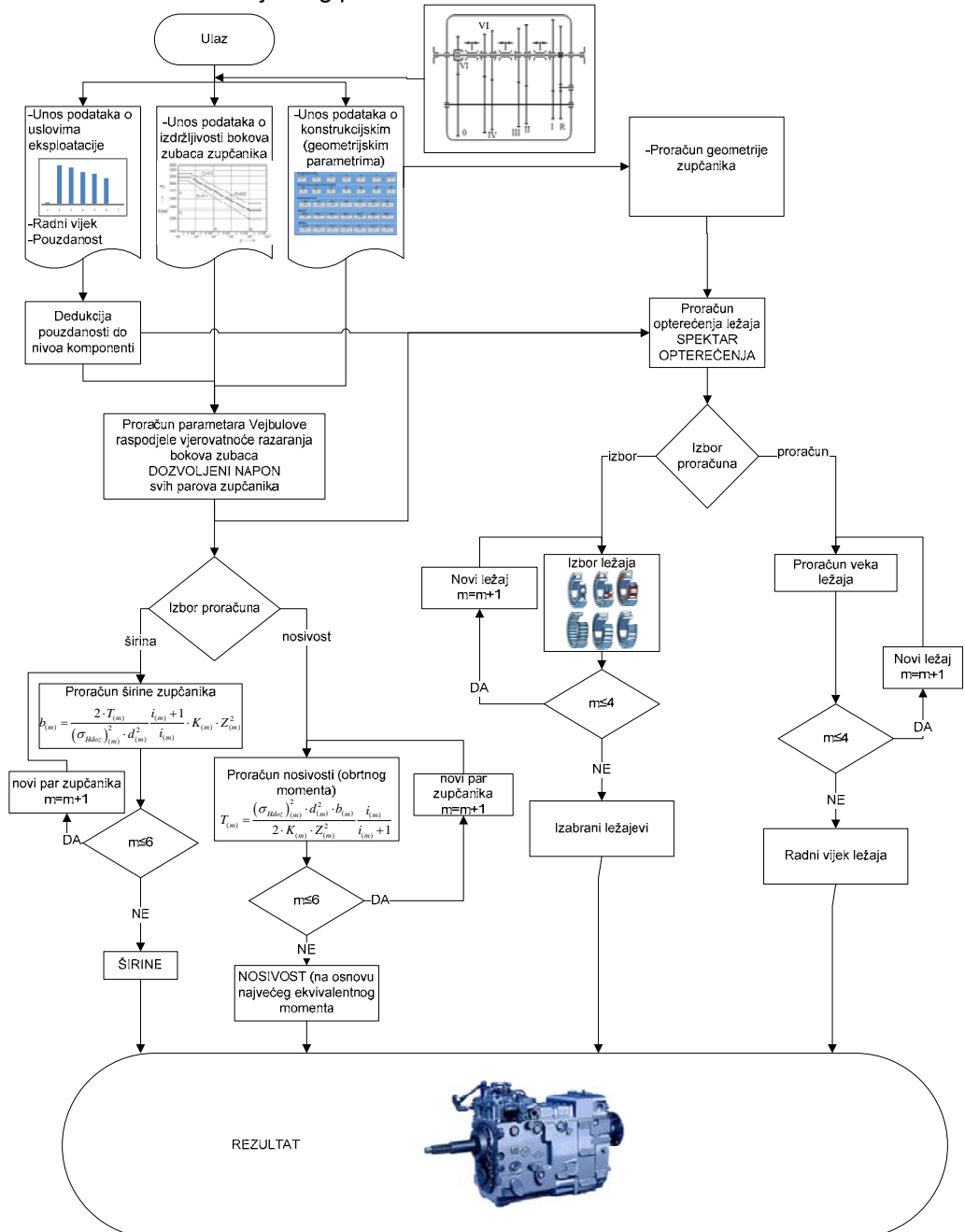
5. SOFTVER ZA ODREĐIVANJE KONSTRUKCIJSKIH PARAMETARA I NOSIVOSTI MENJAČKOG PRENOSNIKA

Prethodno razvijena procedura poslužila je za razvoj softvera podrške za određivanje nosivosti zupčanika na osnovu predviđene pouzdanosti i izabrane radne uslove prenosnika. Na bazi prethodno razvijenog modela, za proračun nosivosti zupčastih parova, razvijen je softver DRAG (slika 5). Korisnici softvera imaju mogućnost izbora varijante proračuna u kojima se u jednoj varijanti proračunavaju širine zupčanika na bazi opterećenja, dok u drugoj varijanti na bazi širina zupčanika kao izlazne vrijednosti dobijaju nosivost. U oba slučaja kao ograničenje jeste pouzdanost koju mjenjački prenosnik treba da zadovolji posle prelasku određenog broja kilometara. Za obe varijante postoji mogućnost varijacija radnog režima i pređenog puta, sa ograničenjem željene pouzdanosti na odgovarajućem broju pređenih kilometara. Kao još jedna mogućnost softvera jeste dobijanje pređenog broja kilometara pri svakom stepenu prenosa, kao i ukupnog broja pređenih kilometara za sve stepene prenosa zajedno. Lijeva strana blok dijagrama se odnosi na proračun zupčanika, dok se desna strana odnosi na ležaje. Softver se takođe sastoji od pet modula koji omogućuju rješavanje odgovarajućih zadataka. Prvi od njih jeste definisanje dozvoljenog napona i kao takav predstavlja kompleksan proračun zasnovan na pouzdanosti zupčanika za odgovarajuće spektre opterećenja. Drugi modul se odnosi na identifikaciju nosivosti mjenjačkog prenosnika poznatih konstrukcijskih parametara. U ovom modulu se određuje nosivost svih zupčastih parova u mjenjačkom prenosniku. Dobijene vrijednosti obrtnih momenata za pojedinačne zupčaste parove ne predstavljaju ukupno opterećenje koje koje može da prenese mjenjački prenosnik, nego služi kao osnova za proračun ukupnih vrijednosti ulaznih i izlaznih veličina obrtnih momenata za svaki stepen prenosa. Minimalna vrijednost ulaznog obrtnog momenta predstavlja nosivost mjenjačkog prenosnika.

Kao treći modul u radu softvera jeste inverzni proračun u odnosu na drugi modul. Na osnovu ulaznih obrtnih momenata vrši se proračun konstrukcijskih parametara za svaki stepen prenosa. Za poznato osno rastojanje i prečnike zupčanika

Određivanje konstrukcijskih parametara mjenjačkog prenosnika na osnovu potrebne pouzdanosti

dobijaju se širine zupčanika. Time se širine zupčanika usklađuju sa težinom radnog režima svakog od stepena prenosa za odgovarajuće uslove eksploatacije prenosnika. Softver je interaktivnog tipa što znači da korisnik u toku njegove primjene mora donijeti brojne odluke i unijeti određene podatke u iterativnom približavanju rješenju. U tom pogledu četvrti modul obezbeđuje iterativnu optimizaciju konstrukcijskih parametara odnosno nosivosti menjačkog prenosnika.



Slika 5. Blok dijagram softvera DRAG za identifikaciju konstrukcijskih parametara i nosivosti

Kao peti i posljednji modul jeste proračun ležaja prenosioca. To je lijevi dio blok dijagrama (slika 5). Kroz dati modul postoje dvije mogućnosti proračuna ležaja. U prvom dijelu za određene ležaje se može izračunati broj pređenih kilometara vozila do razaranja ležaja, dok se u drugom dijelu za dobijene vrijednosti dinamičke nosivosti može izvršiti izbor odgovarajućeg ležaja sa proračunom broja pređenih kilometara pri svakom stepenu prenosa

6. ZAKLJUČAK

Ovaj rad predstavlja prikaz razvijenog modela pouzdanosti mjenjačkog prenosioca koji je zasnovan na metodologiji Design based on properties na primjeni pristupa Design for Reliability. Pouzdanost je u ovom radu u funkciji pokazatelja kvaliteta, u funkciji svojstva komponenata mjenjača i u funkciji ograničenja na osnovu kojih se određuju konstrukcijski parametri i nosivost. Rad se bazira na rezultatima mjerenja opterećenja u različitim uslovima rada prenosioca koji su iskorišćeni za formiranje spektara opterećenja komponenata prenosioca. Na bazi razvijenog modela razvijen je softvera DRAG koji služi kao alat za brzo i jednostavno određivanje konstrukcijskih parametara i nosivosti uz varijaciju ulaznih podataka.

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ANALIZA PARAMETARA KOJI UTIČU NA STEPEN ISKORIŠĆENJA CIKLOREDUKTORA

Tihomir Mačkić¹, Mirko Blagojević², Živko Babić³

Rezime: U radu je izvršena analiza različitih parametara kako bi se pronašao njihov uticaj na stepen iskorišćenja cikloreduktora. Analitički izrazi za proračun sila i stepena iskorišćenja cikloreduktora su implementirani u programsku proceduru izrađenu u softverskom paketu MATLAB. U programu je vršeno mijenjanje vrijednosti svakog parametra posebno, bez promjene ostalih veličina. Analizom je utvrđeno da podioni prečnik ciklozupčanika i izlaznog mehanizma, prenosni odnos i broj valjaka izlaznog mehanizma utiču na stepen iskorišćenja cikloreduktora.

Ključne riječi: cikloreduktor, ciklozupčanik, stepen iskorišćenja, prenosni odnos.

ANALYSIS OF PARAMETERS THAT HAVE AN IMPACT ON CYCLO DRIVE EFFICIENCY

Abstract: The paper has been analyzed the influence of various parameters in order to find their impact on the efficiency of cyclo drive. Analytical expressions for the calculation of the force and efficiency of cyclo drive are implemented in the procedure made in the software package MATLAB. Within the program was carried out changing values of each parameter separately, without changing other parameters. The analysis shows that the pitch diameter of cyclo gear and output mechanism, gear ratio and the number of the roller of output mechanism have an impact on cyclo drive efficiency.

Keywords: cyclo drive, cyclo gear, efficiency, gear ratio.

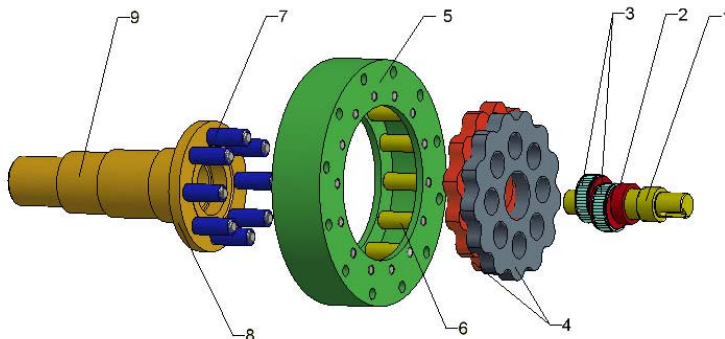
1. UVOD

U poređenju sa konvencionalnim reduktorima, koji koriste zupčanike sa evolventnim zupcima, cikloreduktori posjeduju niz prednosti kao što su: kompaktnost, veliki prenosni odnos, visok stepen iskorišćenja, miran rad bez vibracija, dug i pouzdan vijek, manja masa, itd. Rastavljeni sklop jednostepenog cikloreduktora prikazan je na slici 1 i sastoji se od sljedećih elemenata [1]: 1 - ulazno vratilo, 2 - ekscentar čaura, 3 - ležajevi ciklozupčanika, 4 - ciklozupčanici, 5 - tijelo centralnog zupčanika, 6 – valjci centralnog zupčanika, 7 – valjci izlaznog mehanizma, 8 – nosač izlaznog mehanizma i 9 – izlazno vratilo.

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Sl.1 Rastavljeni sklop jednostepenog cikloreduktora

Izvođenjem analitičkih izraza za proračun stepena iskorišćenja cikloreduktora bavilo se veoma malo autora. Malhotra [2] se bazira na proračunu ukupnog rada sila trenja, koji se ostvari za jedan elementarni obrtaj ciklozupčanika $d\theta$. Davoli, Gorla i drugi [3] su predstavili jedan inovativni model cikloreduktora, kod koga je cikloidni profil izrađen na centralnom zupčaniku.

2. ANALITIČKI IZRAZI ZA PRORAČUN STEPENA ISKORIŠĆENJA CIKLO-REDUKTORA

Stepen iskorišćenja cikloreduktora prvenstveno zavisi od otpora zbog trenja između elemenata cikloreduktora. Ova trenja su prisutna na sledećim mjestima [2]:

- trenje u ležaju ciklozupčanika,
- trenje kotrljanja valjaka izlaznog mehaniza i otvora na ciklozupčaniku,
- trenje kotrljanja između ciklozupčanika i valjaka centralnog zupčanika,
- trenje klizanja između valjaka i osovinica izlaznog mehanizma i
- trenje klizanja između valjaka i osovinica centralnog zupčanika.

Na slici 2 prikazane su sile, kao i obrtni momenti koji djeluju na elemente cikloreduktora [1]. Na drugom ciklozupčaniku, koji nije prikazan i zaokrenut je za 180° , djeluju potpuno iste sile.

Momenti koji djeluju na ciklozupčanik su:

- Pogonski obrtni moment ciklozupčanika - T_1 ;
- Obrtni moment na centralnom zupčaniku – T_2 ;
- Izlazni obrtni moment na jednom ciklozupčaniku – T_3 .

Izrazi za računanje sila, koji su predstavljeni u [1], su:

1) Normalna sila F_N , koja se razlaže na:

- vertikalnu komponentu na i-tom valjku:

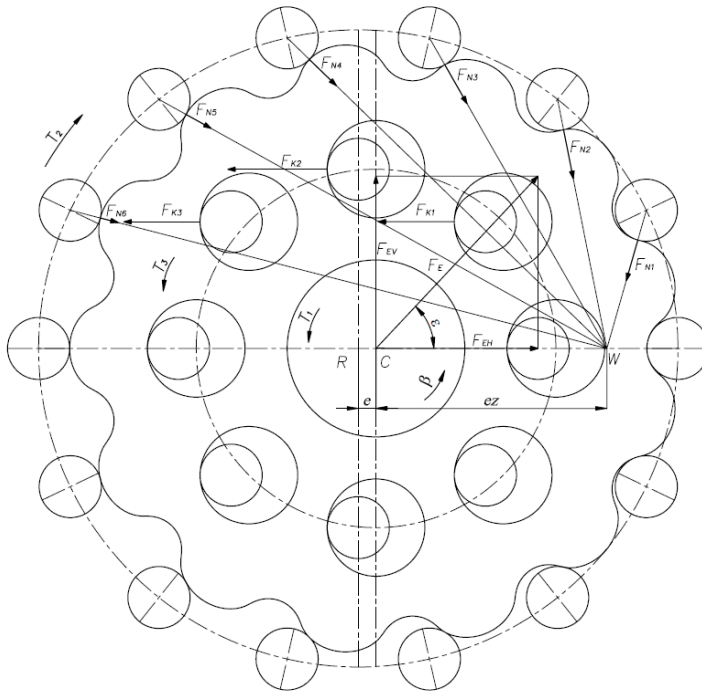
$$F_{NVi} = (c \cdot \Delta\beta) \cdot e \cdot z \cdot \sin^2(\delta_i + \gamma_i), \quad (1)$$

- horizontalnu komponentu na i-tom valjku:

$$F_{NH_i} = (c \cdot \Delta\beta) \cdot e \cdot z \cdot \sin(\delta_i + \gamma_i) \cdot \cos(\delta_i + \gamma_i), \quad (2)$$

gdje je:

- c - krutost valjka centralnog zupčanika,
- $\Delta\beta$ - malo ugaono pomjeranja ciklozupčanika,
- e - veličina ekscentriciteta,
- $z=z_1$ - broj zubaca ciklozupčanika,
- δ_i - pomoćni ugao i
- γ_i - ugao zahvata i-tog valjka centralnog zupčanika.



Sl.2 Raspored sila i momenata koji deluju na ciklozupčanik

- 2) Izlazna sila F_K , koja se računa na j -tom otvoru ciklozupčanika preko izraza:

$$F_{Kj} = (c_K \cdot \Delta\varphi) \cdot r_{Kj} \cdot \sin \psi_{Kj}, \quad (3)$$

gdje je:

- c_K - krutost valjka izlaznog mehanizma,
- $\Delta\varphi$ - malo ugaono pomjeranje ciklozupčanika,
- r_{Kj} - rastojanje između tačke kontakta j -tog valjka izlaznog mehanizma i ciklozupčanika P_j , i centra ciklozupčanika C ,
- ψ_{Kj} - ugao između izlazne sile na j -om valjku izlaznog mehanizma i pravca koji spaja tačku kontakta tog istog valjka izlaznog mehanizma i ciklozupčanika P_j sa centrom ciklozupčanika C .

- 3) Sila ekscentra F_E , koja se razlaže na:
- vertikalnu komponentu sile ekscentra:

$$F_{EV} = \sum_i F_{NVi} \quad (4)$$

- horizontalnu komponentu na i-tom valjku:

$$F_{EH} = \sum_i F_{NH_i} + \sum_j F_{K_j}. \quad (5)$$

Analiza uticaja parametara na stepen iskorišćenja cikloreduktora, bazirati će se na osnovu analitičkih izraza predstavljenih u radu Malhotre [2]. Kada se ciklozupčanik okrene za jedan elementarni obrtaj $d\theta$, tada će se ulazno vratilo, kao i valjci izlaznog mehanizma obrnuti $n \cdot d\theta$ puta, dok se valjci na centralnom zupčaniku obrnu za $(n+1) \cdot d\theta$, gde n predstavlja prenosni odnos ciklozupčanika. Ukupan rad sila trenja za jedan obrtaj ulaznog vratila se računa na osnovu izraza:

$$W = \int_0^{2\pi/n} dW = \frac{f_{r1} D_m n}{D_r} \int_0^{2\pi/n} F_E(\theta) d\theta + n \left(f_{r2} + \frac{f_{s1} D_q}{2} \right) \int_0^{2\pi/n} \sum_{j=1}^q F_{K_j}(\theta) d\theta + (n+1) \left(f_{r3} + \frac{f_{s2} D_p}{2} \right) \int_0^{2\pi/n} \sum_{i=1}^p F_{N_i}(\theta) d\theta. \quad (6)$$

Gdje su:

f_{r1}, f_{r2} i f_{r3} – koeficijenti trenja kotrljanja,

f_{s1}, f_{s2} – koeficijenti trenja klizanja,

F_E – trenutna sila ekscentra,

F_{N_i} – trenutna normalna sila na i-tom valjku,

F_{K_j} – trenutna izlazna sila na j-tom valjku izlaznog mehanizma,

p - broj valjaka centralnog zupčanika koji trenutno učestvuju u sprezanju,

q - broj valjaka izlaznog mehanizma koji u datom trenutku učestvuju u sprezi,

D_m - prečnik ležaja ciklozupčanika,

D_r - prečnik valjčića ili kuglica u ležaju ciklozupčanika.

D_q - prečnik osovinica na izlaznom mehanizmu,

D_p - prečnik osovinica na centralnom zupčaniku.

Izraz za ukupan stepen iskorišćenja cikloreduktora je:

$$\eta = \frac{M_a 2\pi - W}{M_a 2\pi}, \quad (7)$$

gdje je M_a – obrtni moment na ulaznom vratilu.

Iz izraza (6,7) je očigledno da određeni parametri (koeficijenti trenja, prečnici osovinica na centralnom zupčaniku i izlaznom mehanizmu itd.) direktno utiču na rad sila trenja, odnosno stepen iskorišćenja. Također, postoji dosta ulaznih parametara koji indirektno utiču na veličine sila u izrazima (1-5) i taj uticaj će dalje biti analiziran.

Geometrijski i kinematički parametri ciklozupčanika

Radi lakše analize uticaja pojedinih parametara, u tabeli 1, daju se izrazi za proračun svih geometrijskih i kinematičkih parametara ciklozupčanika [1].

Tabela 1 Geometrijski i kinematički parametri ciklozupčanika

Naziv veličine	Izraz
Prenosni odnos jednostepenog cikloreduktora u_{CR}	Usvojiti prema projektnom zadatku
Poluprečnik podeonog kruga centralnog zupčanika r	Usvojiti prema gabaritnim ograničenjima
Koeficijent korigovanja ξ	$\xi = 0,15 + 0,5$
Poluprečnik pokretne kružnice r_2	$r_2 = r \cdot (1 - \xi)$
Broj zubaca ciklozupčanika z_1 (Poglavlje 4.1)	$z_1 = u_{CR} $
Broj valjaka centralnog zupčanika z_2	$z_2 = z_1 + 1$
Veličina ekscentriciteta e	$e = \frac{r_2}{z_2}$
Poluprečnik nepokretne kružnice r_1	$r_1 = r_2 \cdot \frac{z_1}{z_2}$
Poluprečnik valjka centralnog zupčanika q	$q = 0,08 \cdot r$
Poluprečnik temenog kruga ciklozupčanika d_a	$d_a = 2 \cdot r + 2 \cdot e - 2 \cdot q$
Poluprečnik podnožnog kruga ciklozupčanika d_f	$d_f = 2 \cdot r - 2 \cdot e - 2 \cdot q$
Poluprečnik kotrljajuće kružnice R_a	$R_a = \frac{r}{u_{CR} + 1}$
Poluprečnik osnovne kružnice R_b	$R_b = r - R_a$
Pomoćni ugao ϕ	$\phi = \arctg \left(\frac{\sin \beta}{\frac{R_a}{e} + \cos \beta} \right)$
Ugao međusobnog položaja početne i trenutne tačke dodira osnovne i kotrljajuće kružnice u odnosu na centar osnovne kružnice α	$\alpha = \frac{R_a}{R_b} \cdot \beta$
Jednačine skraćene epitrohoide	$x = (R_b + R_a) \cdot \cos \alpha + e \cdot \cos(\alpha + \beta)$ $y = (R_b + R_a) \cdot \sin \alpha + e \cdot \sin(\alpha + \beta)$
Jednačine ekvidistante skraćene epitrohoide	$x = (R_b + R_a) \cdot \cos \alpha + e \cdot \cos(\alpha + \beta) - q \cdot \cos(\alpha + \phi)$ $y = (R_b + R_a) \cdot \sin \alpha + e \cdot \sin(\alpha + \beta) - q \cdot \sin(\alpha + \phi)$

3. ANALIZA DOBIJENIH REZULTATA

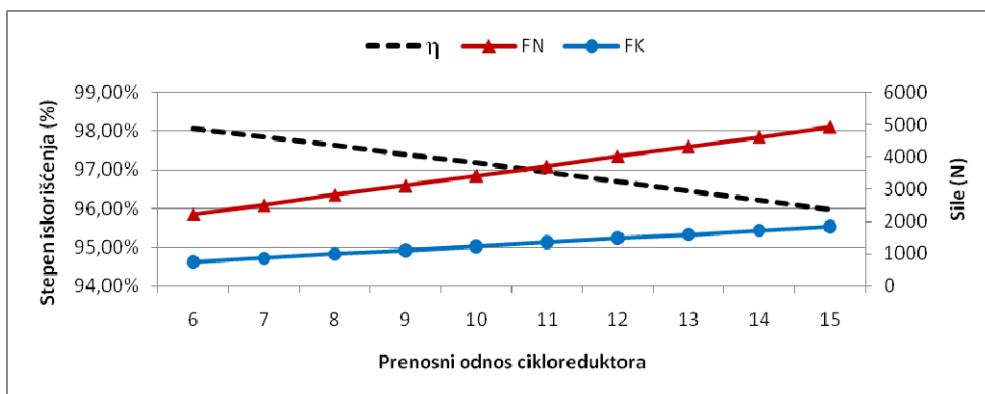
Analiza uticaja najvažnijih parametara na stepen iskorišćenja cikloreduktora je urađena za konkretan jednostepeni cikloreduktor, sa sljedećim osnovnim podacima:

- Snaga elektromotora: $P_{EM} = 4,0 \text{ kW}$;
- Broj obrtaja elektromotora: $n_{EM} = 1420 \text{ min}^{-1}$;
- Poluprečnik podionog kruga centralnog zupčanika: $r = 86 \text{ mm}$;
- Prenosni odnos: $n = 13$;

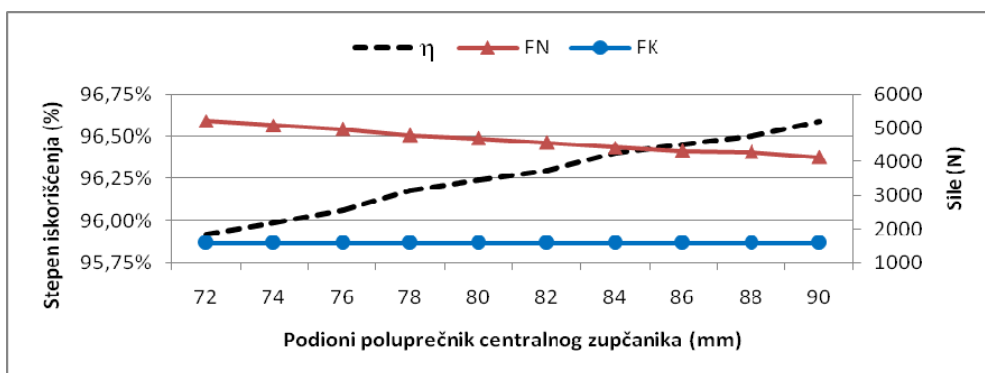
Ostale veličine su preuzete iz modela prikazanog u radu [1].

Izrazi za proračun sila i stepena iskorišćenja (1-7) i izrazi prikazani u tabeli 1, implementirani su u programsku proceduru izrađenu u softverskom paketu MATLAB. Vršeno je mijenjanje vrijednosti svakog parametra posebno, bez promjene ostalih veličina. Posmatran je uticaj promjene vrijednosti određenih parametara na sile, kao i ukupni uticaj na promjenu stepena iskorišćenja.

Povećanjem prenosnog odnosa (slika 3) rastu sile F_N i F_K , dok stepen iskorišćenja linearno opada. Karakter promjene stepena iskorišćenja i sila u zavisnosti od podionog prečnika centralnog zupčanika prikazan je na slici 4.

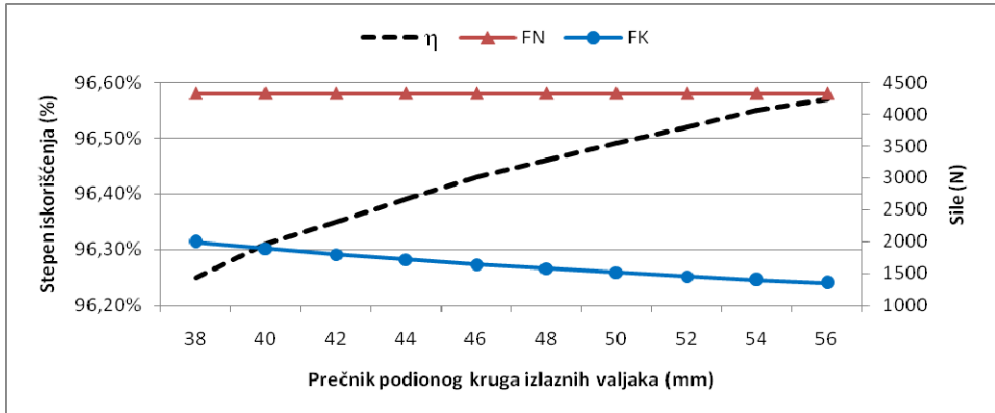


Sl.3 Promjena stepena iskorišćenja i sila u zavisnosti od prenosnog odnosa



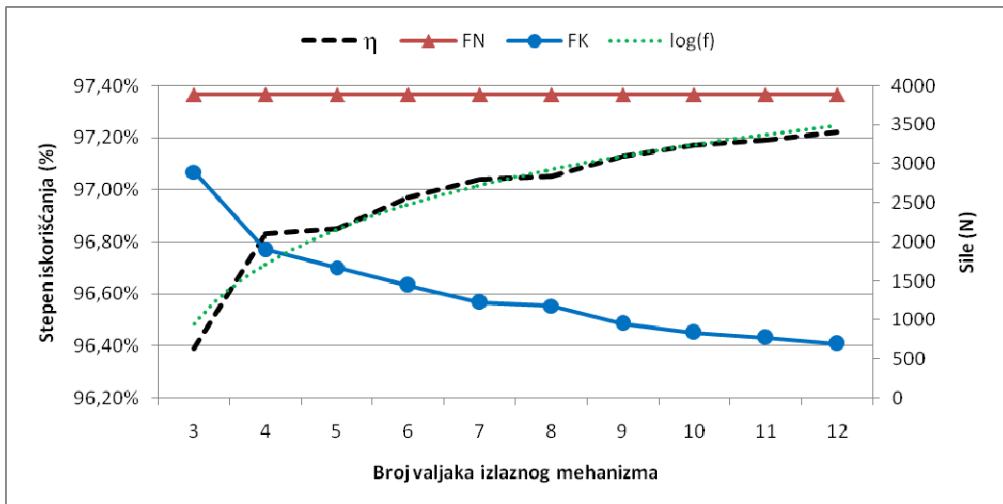
Sl.4 Promjena stepena iskorišćenja i sila u zavisnosti od prečnika podionog kruga centralnog zupčanika

Povećanje prečnika podionog kruga izlaznih valjaka ne utiče u velikoj mjeri na promjenu stepena iskorišćenja (slika 5), pri čemu dolazi do opadanja sile na izlaznim valjcima F_K , dok normalana sila sprežanja F_N ostaje konstantna. Ovaj rezultat je u saglasnosti sa vrijednostima koje su prikazane u radu [4].



Sl.5 Promjena stepena iskorišćenja u zavisnosti prečnika podionog kruga valjaka izlaznog mehanizma

Kako bi se uključio što veći broj valjaka izlaznog mehanizma u analizu, usvojene su veće vrijednosti podionog prečnika centralnog zupčanika i podionog prečnika kruga izlaznih valjaka. Može se uočiti da stepen iskorišćenja logaritamski raste sa povećanjem broja valjaka (slika 6), dok je pad vrijednosti izlaznih sila sličnog karaktera.



Sl.6 Promjena stepena iskorišćenja u zavisnosti od broja valjaka izlaznog mehanizma

4. ZAKLJUČAK

Veličine parametara cikloreduktora bitno utiče na stepen iskorišćenja. Taj uticaj je linearan kada je u pitanju izbor prenosnog odnosa, prečnika podionog kruga centralnog zupčanika i izlaznih valjaka. Povećanje broja valjaka izlaznog mehanizma dovodi do logaritamskog povećanja stepena iskorišćenja, pa treba izbjegavati odabir malog broja valjaka. Najveći uticaj na stepen iskorišćenja ima izbor prenosnog odnosa, gdje je povećanjem sa 6 na 15 promjenjen stepen iskorišćenja za 2%. Optimalnim izborom ovih parametara moguće je smanjiti gubitke i povećati stepen iskorišćenja cikloreduktora.

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UTICAJ KOREKCIJE PROFILA CIKLOZUPČANIKA NA BROJ OSTVARENIH KONTAKATA ELEMENATA CIKLOREDUKTORA

Nenad Kostić¹, Mirko Blagojević², Vesna Marjanović³,
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Rezime: U ovom radu razmatran je problem određivanja stvarnog broja kontakata između ciklozupčanika i valjaka nepokretnog centralnog zupčanika cikloreduktora, što je ključno za definisanje raspodele opterećenja na elementima prenosioca. Razvijen je analitički model za određivanje stvarnog položaja ciklozupčanika u odnosu na valjke centralnog zupčanika kao i za proračun rastojanja između ovih elemenata. Na osnovu izračunatih rastojanja, određuje se broj ostvarenih kontakata. Predstavljen je i način određivanja broja kontakata zubaca ciklozupčanika sa valjcima centralnog zupčanika u slučaju korigovanog profila ciklozupčanika. Na osnovu razvijenog softvera, ugrađen je i niz konkretnih primera. Na kraju rada su izneta zaključna razmatranja i smernice za dalji rad.

Ključne riječi: cikloreduktor, ciklozupčanik, kontakt, korekcija profila ciklozupčanika

INFLUENCE OF CYCLOIDAL GEAR PROFILE CORRECTION TO THE NUMBER OF CONTACTS BETWEEN THE ELEMENTS OF A CYCLOIDAL SPEED REDUCER

Abstract: *This paper presents the problem of determining the actual number of contacts between the cycloidal gear and the rollers of the stationary central gear of a cycloidal speed reducer, which is essential for the distribution of the load on the gear train elements. An analytical model for determining the actual position of cycloidal gear in relation to the rollers of the central gear, as well as for the calculation of distance between these elements, was developed. Based on the calculated distances, the number of contacts is determined. A method for determination of the number of contacts of the cycloidal gear teeth with the central gear rollers in the case of corrected profile of a cycloidal gear is presented. Based on the developed software, a series of concrete examples was made. The end of the paper gives concluding observations and directions for future work.*

Keywords: cycloidal gear reducer, cycloidal gear, contact, cycloidal gear profile correction

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1. UVOD

Analiza zazora između valjaka i ciklozupčanika kod cikloreduktora predstavlja problem koji daje prostora istraživačima. Ovaj problem je relativno mlad i nije razmatran u velikoj meri. Rešenje ovog problema predstavlja značajan korak u primeni prenosnika snage sa neevolventnim ozubljenjem, poboljšanjem njihovih performansi i smanjenjem proizvodnih troškova. To kao posledicu pruža mogućnost unapređenja karakteristika prenosnika koji će biti korišćeni u budućnosti.

Autori J.G Blanche i D.C.H Yang u radu [1] postavljaju osnovu kinematske analize cikloreduktora. Ovaj rad predstavlja početak razmatranja uticaja tehnoloških zazora na bitne parametre cikloreduktora. Izveli su potrebna matematička objašnjenja i uveli pojam ugla kašnjenja. Ovaj rad predstavlja prvi značajan doprinos u određivanju rastojanja između valjaka cikloreduktora i ciklozupčanika.

Razmatranje ovog problema predstavljeno je i u radu [2], autora D.C.H Yang, J.G Blanche. Ovaj rad predstavlja značajan doprinos u razmatranju problema zazora kod elemenata cikloreduktora. Autori koriste analitičke i numeričke – kompjuterske metode kako bi razmatrali problem zazora na nivou tolerancija.

Autori Lixing L., Jiaqing X., Tianmin G., Weidong H., Yuanmei Q. bavili su se načinom dobijanja krive pogodne za profil ciklozupčanika [4, 5, 6, 7]. Ova istraživanja predstavljaju bitan segmen u razvoju prenosnika snage sa cikloidnim ozubljenjem. Modifikacija profila i dobijanje odgovarajuće krive za profil ciklozupčanika neophodna je da bi se obezbedio normalan i pouzdan rad prenosnika.

U ovom radu predstavljen je način korigovanja elemenata cikloreduktora, način određivanja zazora između elemenata i uticaj korekcije na broj ostvarenih kontakata kod elemenata cikloreduktora.

2. ISTRAŽIVANJE

Teoretski model cikloreduktora nije moguće dobiti u praksi. Uvek postoje zazori između valjaka i ciklozupčanika. Ovaj zazor kompenzuje greške nastale pri izradi, omogućava podmazivanje elemenata u većoj meri i olakšava montažu i demontažu. Ovo ukazuje na potrebu za razmatranjem zazora među elementima cikloreduktora na nivou tolerancija.

Ovaj rad orijentisan je na razmatranje korigovanog profila ciklozupčanika kod cikloreduktora. Za definisanje profila krive ciklozupčanika korišćena je jednačina ekvidistanta skraćene epitrohoide[3] oblika:

$$x = (R_b + R_a) \cdot \cos \alpha + e \cdot \cos(\alpha + \beta) - q \cdot \cos(\alpha + \phi) \quad (1)$$

$$y = (R_b + R_a) \cdot \sin \alpha + e \cdot \sin(\alpha + \beta) - q \cdot \sin(\alpha + \phi) \quad (2)$$

gde su:

R_a – poluprečnik kotrljajuće kružnice,

R_b – poluprečnik osnovne kružnice,

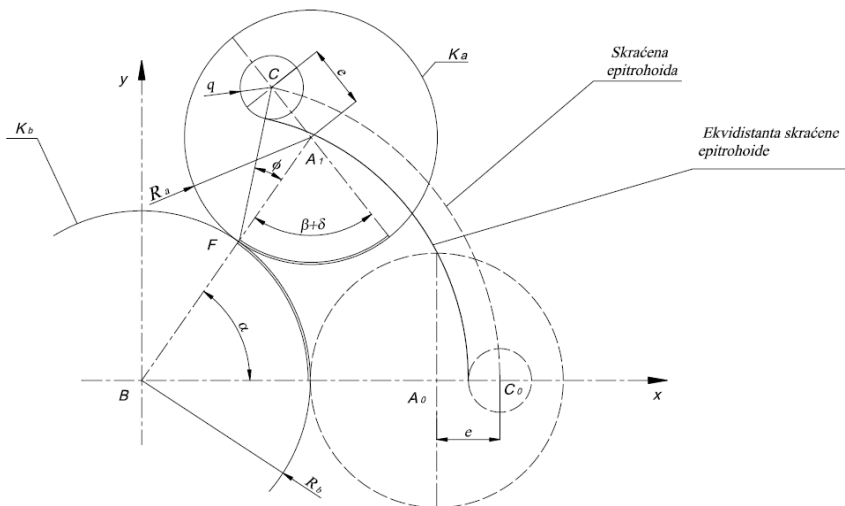
α – ugao međusobnog položaja početne i trenutne tačke dodira osnovne i kotrljajuće kružnice u odnosu na centar osnovne kružnice,

e – veličina ekscentriciteta,

q – poluprečnik valjka centralnog zupčanika,

ϕ – pomoćni ugao.

Veličine koje figurišu u jednačinama (1) i (2) prikazane su na slici 1 [3].



Sl. 1 Generisanje ekvidistante skraćene epitrochoida [3]

Jednačine (1) i (2) mogu biti zapisane u obliku:

$$x = (R_b + R_a) \cdot \cos \alpha + e \cdot \cos \left(\alpha + \frac{R_b}{R_a} \cdot \alpha \right) - q \cdot \cos \left(\alpha + \arctg \left(\frac{\sin \left(\frac{R_b}{R_a} \cdot \alpha \right)}{\frac{R_a}{e} + \cos \left(\frac{R_b}{R_a} \cdot \alpha \right)} \right) \right) \quad (3)$$

$$y = (R_b + R_a) \cdot \sin \alpha + e \cdot \sin \left(\alpha + \frac{R_b}{R_a} \cdot \alpha \right) - q \cdot \sin \left(\alpha + \arctg \left(\frac{\sin \left(\frac{R_b}{R_a} \cdot \alpha \right)}{\frac{R_a}{e} + \cos \left(\frac{R_b}{R_a} \cdot \alpha \right)} \right) \right) \quad (4)$$

znajući da su:

$$\beta = \frac{R_b}{R_a} \cdot \alpha,$$

$$\phi = \arctg \left(\frac{\sin \left(\frac{R_b}{R_a} \cdot \alpha \right)}{\frac{R_a}{e} + \cos \left(\frac{R_b}{R_a} \cdot \alpha \right)} \right).$$

Ovakav oblik jednačina interesantan je za razmatranja u ovom radu.

Metode postizanja zazora između valjaka i ciklozupčanika

U literaturi se sreće tri najčešća načina postizanja zazora između valjaka i ciklozupčanika[3]:

- korigovanjem profila ciklozupčanika,
- povećanje prečnika kružnice po kojoj su raspoređeni valjci,
- smanjenje prečnika valjaka.

Pomenutim metodama postiže se isti efekat, a za ovo razmatranje izvršeno je smanjenje prečnika valjaka centralnog zupčanika. U odnosu na početnu situaciju gde su svi valjci cikloreduktora na teoretskom modelu ne korigovanog profila bili u kontaktu sa ciklozupčanikom u ovom slučaju kontakt se ostvaruje samo između jednog valjka i ciklozupčanika. Korekciju profila ciklozupčanika treba razmatrati na nivou tolerancija bez obzira na koji način se ona izvodi.

Optimizacija

Radi određivanja tačnih rastojanja i kontakta valjaka cikloreduktora sa ciklozupčanikom razvijen je originalni optimizacioni softver u programskom jeziku Visual C++ kao MFC aplikacija. Metoda je numerička, a princip rada razvijenog softvera oslanja se na optimizacionu metodu genetskog algoritma. Primenjeni su principi selekcije, ukrštanja i mutacije prema već razvijenim modelima. Ovaj softver zahteva matematički model i na osnovu njega izračunava minimum zadate funkcije cilje.

3. MATEMATIČKI MODEL

Funkcija cilja postavljena je na osnovu jednačina ekvidistante skraćene epitrohoide i na osnovu jednačine koja definiše položaj centra kružnice valjka centralnog zupčanika. Problem je razmatran u dve dimenzije jer treća dimenzija nema nikakvog uticaja na samo rešenje. Oblik ekvidistante skraćene epitrohoide dat je u jednačinama (3) i (4).

Jednačine koje definišu centar jednog valjka cikloreduktora, a njihov oblik odgovara dozvoljenom unosu u razvijeni softver, imaju oblika:

$$x_v = (R_b + R_a) \cdot \cos \varphi \quad (5)$$

$$y_v = (R_b + R_a) \cdot \sin \varphi \quad (6)$$

gde je:

φ – ugao na kojem se nalazi centar valjka.

Funkcija cilja formirana je kao:

$$f = \sqrt{(x_v - x)^2 + (y_v - y)^2} \quad (7)$$

gde su sve veličine definisane u prethodnim jednačinama. Vrednost ove funkcije jeste rastojanje između valjka i ciklozupčanika.

Konačno funkcija cilja koja definiše problem u celini i na osnovu koje se izračunava minimalno rastojanje između valjka i ciklozupčanika, a na osnovu jednačine (7) ima oblik:

$$\begin{aligned}
 f = & \sqrt{((R_b + R_a) \cdot \cos(ugao + valjak \cdot \theta) - ((R_b + R_a) \cdot \\
 & \cos(\alpha) + e \cdot \cos\left(\alpha + \frac{R_b}{R_a} \cdot \alpha\right) - (q - \Delta q) \cdot \cos\left(\alpha + \arctg\left(\frac{\sin\left(\frac{R_b}{R_a} \cdot \alpha\right)}{\frac{R_a}{e} + \cos\left(\frac{R_b}{R_a} \cdot \alpha\right)}\right)\right) + \\
 & e \cdot \cos(\varepsilon))^2 + ((R_b + R_a) \cdot \sin(ugao + valjak \cdot \theta) - ((R_b + R_a) \cdot \\
 & \sin(\alpha) + e \cdot \sin\left(\alpha + \frac{R_b}{R_a} \cdot \alpha\right) - (q - \Delta q) \cdot \sin\left(\alpha + \arctg\left(\frac{\sin\left(\frac{R_b}{R_a} \cdot \alpha\right)}{\frac{R_a}{e} + \cos\left(\frac{R_b}{R_a} \cdot \alpha\right)}\right)\right) + \\
 & e \cdot \sin(\varepsilon))^2} \quad (8)
 \end{aligned}$$

gde su:

ugao – promenljiva koja figuriše u optimizaciji i definiše vrednost ugla na kojem se nalazi centar valjka koji se spreže sa ciklozupčanikom,

valjak – pomoćna veličina koja definiše redni broj valjka gde je valjak koji je u kontaktu jednak nuli,

$\theta = \frac{2 \cdot \pi}{z_2}$ – ugao za koji su zaokrenuti valjci redom – njihov položaj. z_2 predstavlja ukupan broj valjaka,

Δq – poluprečnik valjka nakon korekcije,

ε – ugao na kom je postavljen ciklozupčanik u odnosu na centar kruga po kome su raspoređeni valjci centralnog zupčanika.

Funkcija je predstavljena u ovom obliku zbog zahteva razvijenog softvera.

Matematički model je kreiran tako da funkcija cilja ima dve promenljive. Jedna promenljiva „*alfa*“ figuriše u jednačini skvidistante skraćene epitrohoide i kreće se u intervalu od 0 do 2π što predstavlja ograničenja ove promenljive. Druga promenljiva „*ugao*“ predstavlja poziciju centra valjka cikloreduktora, a ograničenja ova promenljive takođe se nalaze u intervalu od 0 do 2π . Sve ostale veličine zavise od konkretnog primera cikloreduktora i predstavljaju konstante.

4. REZULTATI

Da bi se utvrdila kompetentnost celokupne metode razvijeni matematički model i softver upotrebljeni su za razradu konkretnog cikloreduktora. Proračunom cikloreduktora dobijene su veličine profila ciklozupčanika bez korekcije (tabela1). Ove veličine predstavljaju teoretski model gde su svi valjci u kontaktu sa ciklozupčanikom.

Tabela 1 Vrednosti dobijene proračunom cikloreduktora potrebne za određivanje rastojanja između valjaka i ciklozupčanika

$R_a = 6,143 \text{ mm}$	Poluprečnik kotrljajuće kružnice
$R_b = 79,857 \text{ mm}$	Poluprečnik osnovne kružnice
$e = 4 \text{ mm}$	Veličina ekscentričnosti
$q = 7 \text{ mm}$	Poluprečnik valjka centralnog zupčanika
$z_1 = 13$	Broj zubaca ciklozupčanika
$z_2 = 14$	Broj valjaka
$R_a + R_b = 86 \text{ mm}$	Zbir poluprečnika potrebnih za optimizaciju
$\frac{R_b}{R_a} = 12,9997 \approx 13$	Odnos poluprečnika potrebnih za optimizaciju
$\frac{R_a}{e} = 1,53575$	Veličina koja figuriše u jednačini za optimizaciju
$\varepsilon = 0 \text{ rad}$	Ugao na kome je izvršeno pomeranje ciklozupčanika za veličinu ekscentričnosti u odnosu na centar cikloreduktora
$\Delta q = 6,9 \text{ mm}$	Veličina korigovanog prečnika valjka
$q - \Delta q = 0,1 \text{ mm}$	Pomoćna veličina
$\theta = 0,448798951 \text{ mm}$	Ugao koji definiše međusobni položaj valjaka

Na osnovu prethodnih vrednosti postavljena je funkcija cilja.

$$f = \text{sqrt}((86 \cdot \cos(\text{ugao} + 0 \cdot 0,448798951) - (86 \cdot \cos(\text{alfa}) + 4 \cdot \cos(14 \cdot \text{alfa}) - 0,1 \cdot \cos\left(\text{alfa} + \arctg\left(\frac{\sin(13 \cdot \text{alfa})}{1,53575 + \cos(13 \cdot \text{alfa})}\right)\right) + 4 \cdot \cos(0)))^2 + (86 \cdot \sin(\text{ugao} + 0 \cdot 0,448798951) - (86 \cdot \sin(\text{alfa}) + 4 \cdot \sin(14 \cdot \text{alfa}) - 0,1 \cdot \sin\left(\text{alfa} + \arctg\left(\frac{\sin(13 \cdot \text{alfa})}{1,53575 + \cos(13 \cdot \text{alfa})}\right)\right) + 4 \cdot \sin(0)))^2 \quad (9)$$

U ovom slučaju poluprečnik valjka korigovan je za 0,1 mm da bi se pokazala funkcionalnost metodologije. Veličinu koja je potrebna za rešavanje konkretnog problema moguće je menjati u zavisnosti od potrebe.

Pokretanjem simulacije dobijene su vrednosti ugla na kojem se nalazi centar valjka koji je u kontaktu sa ciklozupčanikom.

$$\text{ugao} = 0,67139524 \text{ rad}$$

Zapravo, kada funkcija cilja ima vrednost 0 valjak je u kontaktu sa ciklozupčanikom, a vrednost promenljive „ugao“ u tom slučaju definiše ugao na kom se nalazi centar valjka. Nakon toga moguće je odrediti i udaljenost ostalih valjaka u odnosu na ciklozupčanik. Vrednost dobijenog ugla u ovom slučaju zadaje se funkciji cilja kao konstanta, a promenljiva „valjak“ koja je za prethodni proračun bila 0 promenjena je u zavisnosti od rednog broja valjka za koji je potrebno izračunati rastojanje u odnosu na ciklozupčanik.

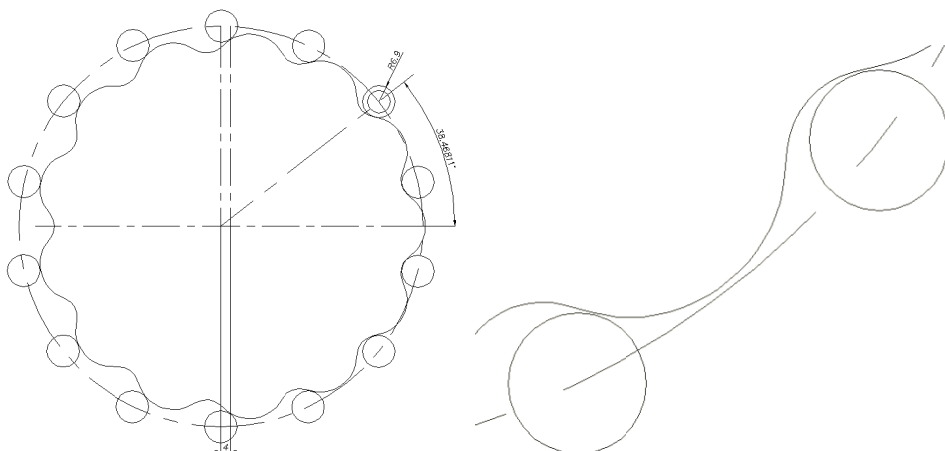
Rezultati rastojanja svih valjaka u odnosu na ciklozupčanik, kao i uglovi na kojima se valjvi nalaze predstavljeni su u tabeli 2.

Tabela2 Redni brojevi valjaka,uglovi na kojima se nalaze i rastojanja od ciklozupčanika

Redni broj valjka	Ugao valjka [rad]	Rastojanja od ciklozupčanika [mm]
0	0,671395240	0
1	1,120194191	0,000601774
2	1,568993142	0,013965444
3	2,017792093	0,034167148
4	2,466591044	0,058821151
5	2,915389995	0,086204957
6	3,364188946	0,114700215
7	3,812987897	0,142672673
8	4,261786848	0,168429273
9	4,710585799	0,190082953
10	5,159384750	0,204894835
11	5,608183701	0,205558399
12	6,056982652	0,154817602
13	6,505781603	0,032361203

Bitno je napomenuti da kada bi se vršilo izračunavanje vrednosti za valjak 14 ponovo bi bilo potrebno dobiti vrednosti kao za prvi valjak. Praktično primenom ove metode dobija se rastojanje $0,0000003mm$ zbog unosa ograničenog broja decimala. Takođe se za ugao ovog valjka dobija $0,671395247rad$. Ova greška je izuzetno mala i može biti zanemarena, ali je bitno napomenuti da rezultat zavisi od preciznosti proračuna cikloreduktora u unete tačnosti.

Izgled rasporeda korigovanih valjaka za ovaj konkretan slučaj predstavljen je na slici 2. Slika je kreirana prema proračunom dobijenim vrednostima. Na desnoj strani slike 2 predstavljen je detalj koji prikazuje zazor između valjaka 11 i 12 i ciklozupčanika.



Sl.2 Raspored korigovanih valjaka kod cikloreduktora za dobijene rezultatesa leve strane i detalj zazora sa desne strane

5. ZAKLJUČAK

Na osnovu celokupnog istraživanja izvedeni su zaključci da je korigovanje profila veoma bitno radi razmatranja i tumačenja realnih problema kod cikloreduktora. Samo kod teoriskog modela kontakt se ostvaruje između ciklozupčanika i svih valjaka cikloreduktora.

Razvijeni metod za korigovanje i izračunavanje rastojanja kod cikloreduktora daje dobre rezultate. Tačnost ovih rezultata zavisi od tačnosti osnovnog proračuna veličina cikloreduktora, tako da se u skladu sa tim može postići i zahtevana tačnost rezultata metode. Valjak koji se definiše kao nulti ostvaruje kontakt sa ciklozupčanikom, a svi ostali valjci se nalaze na nekom odstojanju od ciklozupčanika.

Veličina korekcije može biti podešena u zavisnosti od željenog efekta i konkretnog slučaja. Za ovaj primer izvršena je korekcija valjka za $0,1\text{ mm}$ kao pokazna veličina radi definisanja postupka rada. Ta vrednost je lako promenljiva i treba je usvojiti u zavisnosti od praktične situacije i razmatrati na nivou tolerancijskih mera.

Konačan zaključak je da se određivanjem rastojanja valjaka cikloreduktora od ciklozupčanika kod korigovanog profila realizuje samo prvi korak u metodologiji unapređenja cikloreduktora.

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ISTRAŽIVANJE TERMO-MEHANIČKIH KARAKTERISTIKA KLIZNIH LEŽAJA SA GRAFITOM

Nada Bojić¹, Dragan Milčić²

Rezime: Tendencije razvoja novih mašina danas, bazirane su na visokoj produktivnosti, uslovljavajući tako značajan porast: brzina, opterećenja, i radnih temperatura. Kao posledice toga javljaju se problemi sa povećanjem trenja i habanja. Ne treba zaboraviti činjenicu da svaki drugi klizni ležaj otkaže zbog neodgovarajućeg podmazivanja, što nameće pitanje opravdanosti upotrebe i unapređenja novih tehnologija u proizvodnji kliznih ležajeva. Cilj ovog rada je da ukaže na pravce koji bi se mogli koristiti u tehnologiji proizvodnje, izboru materijala posteljice, razvoju novih materijala posteljice, izboru sredstava za podmazivanje.

Ključne riječi: klizni ležaji, habanje, trenje, podmazivanje

EFFECTS OF VARIOUS PARAMETERS TO SLIDING BEARINGS

Abstract: Tendencies of development of new machines today are based on high productivity, thus causing a significant increase in speed, load, and operating temperatures. As a consequence there are problems with increased friction and wear. We should not forget the fact that every other plain bearing on them canceled due to inadequate lubrication, which raises the question of justification and promotion of the use of new technologies in production and in particular sliding bearings. The aim of this paper is to show the directions that could be used in the production technology, the choice of subgrade materials, new materials development placenta remedy choice for lubrication.

Keywords: sliding bearings, wear, friction, lubrication

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1. UVOD

Savremena saznanja nauke o konstruisanju još uvek u proces konstruisanja ne uključuju dovoljno i tribološke aspekte konstruisanja. Tribološki aspekti konstruisanja i tribologija u konstruisanju su neophodni uslov ispravnog konstruisanja. Sa tribološkog aspekta tokom procesa konstruisanja osnovno je izvršiti adekvatan izbor elementa MS (materijala, maziva i sistema podmazivanja) koji se želi konstruisati, a zatim utvrditi koje su mu radne i tribološke karakteristike (određivanje radnog veka sa gledišta habanja, proračun debljine mazivog sloja, temperature, protoka maziva, gubitaka usled trenja itd.). Svakako, klizni ležaj je najinteresantniji mašinski element sa tribološkog aspekta.

Klizni ležaji imaju veliku primenu u teškoj mašinogradnji, kod mlinova, turbina, drobilica, valjaoničkih i kovačkih mašina, presa, reduktora itd. Kod kliznih ležaja relativno kretanje delova uz istovremeno prenošenje opterećenja ostvaruje se posredstvom klizanja. Istraživanja izvršena poslednjih godina dovela su do značajnog usavršavanja kliznih ležaja. Osnovna prednost kliznih ležaja ogleda se u njihovoj nosivosti, odnosno radnom veku. Ako se kod kliznog ležaja obezbede uslovi hidrodinamičkog plivanja, onda on ima skoro neograničeni radni vek. Ovo je naročito bitno kod rada sa visokom učestanošću obrtanja, gde kotrljajni ležaji zbog ograničene nosivosti i ograničenog radnog veka ne mogu da se primene. Sa druge strane tendencija razvoja savremenih mašina ogleda se u stalnom poboljšanju njihovih performansi. To je mahom povezano sa uvećanjem opterećenja, brzine i brojeva obrtaja uz istovremeno smanjenje dimenzija i težine. Ovakav trend razvoja ukazuje da u budućnosti treba očekivati veću primenu kliznih ležaja.

Klizni ležaji mogu biti izrađeni kao jednodelni i dvodelni, dok kotrljajni mogu biti samo jednodelni. To im omogućuje primenu u slučajevima gde ležaji zbog montaže moraju da se rade iz dva dela, kao na primer kod kolenastih vratila. Prednost kliznih ležaja u odnosu na kotrljajne ogleda se u tome što su dimenzije kliznih ležaja za istu nosivost dosta manje u odnosu na kotrljajne.

Smanjenje trenja postiže se podmazivanjem dodirnih površina. U zavisnosti od debljine sloja maziva, stepena geometrijske sličnosti spregnutih površina, radnih uslova elemenata mehaničkog sistema moguće je ostvariti: granično, hidrostatičko, hidrodinamičko, mešovito i elastohidrodinamičko podmazivanje.

2. PREGLED ISTRAŽIVANJA

Moderno inženjstvo zavisi u velikoj meri od ležaja i progres u mašinogradnji je bitno povezan sa progresom u oblasti kliznih ležaja. Činjenica je takodje, da je ispravnost i pouzdanost rada mašina i uređaja funkcija ispravnosti pokretnih delova, od kojih su klizni ležaji svakako najvažniji elementi. Zbog toga, oštećenja i otkazi ovih vitalnih elemenata mogu da prouzrokuju znatne materijalne gubitke, pa i zakonsku odgovornost. To je i razlog da su istraživanja otkaza kliznih ležaja mnogobrojna i prikazana u literaturi kroz različite klasifikacije, istraživanja uzroka, manifestacija i korektivnih mera, istraživanja uticaja maziva, postupaka dijagnostike i ispitivanja. U današnje vreme čine se sve veći naponi u cilju otkrivanja zakonitosti u procesu dinamike habanja i trenja, kao i otkrivanju neželjenih pojava u radu kliznih ležaja kako bi se uzele u obzir pri proračunu i konstrukciji i po mogućstvu svele na minimum.

Izrada i remont sklopa kliznog ležaja i njihova montaža i demontaža često je jeftinija nego remont i montaža vratila. U tim slučajevima klizni ležaji moraju imati

dobra tehnološka svojstva za delove ležaja dobijene livenjem, nisku temperaturu topljenja, visoku tačnost, malo skupljanje, veliku čistoću površina pri livenju. U radu [1] izvršena su poređenje pojedinih elemenata važnih za ležaj koji su u vezi sa uticajem dve različite tehnologije izrade ležaja – nalivanje, odnosno navarivanje mekog kliznog sloja na osnovu visoke čvrstoće (čelik). Materijal posteljice mora da ima mogućnost odvođenja toplote, da veličina koeficijenta toplotnog širenja bude bliska sa koeficijentom toplotnog širenja vratila i kućišta ležaja i da pri zagrevanju u toku rada zadrži stabilnost fizičko-mehaničkih osobina. U radu [2] je pokazan uticaj temperature kliznih ležaja na stepen habanja (oštećenja) metalnih komponenti.

Izbor materijala za izradu kliznog ležaja zavisi od režima eksploatacije i to pre svega od veličine i karaktera specifičnog pritiska i brzine klizanja. U radu [3] su istraživani materijal za izradu posteljice, koji u osnovi sadrže kalaj. Istraživanja su rađena u uslovima suvog klizanja, jer uprkos prisustvu uljnog filma, pod teškim radnim uslovima suvog klizanja s' vremena na vreme može se pojaviti lokalno habanje.

Jedan od presudnih faktora koji određuju izbor antifrikcionog materijala je njegova čvrstoća i deficitarnost. Pred materijale za klizne ležaje se postavljaju zahtevi u smislu: visoke otpornosti na habanje ležaja, a sa njim i spregnutog vratila pri različitim brzinama klizanja i specifičnim pritiscima i dr. Zbog ovakvih zahteva koji se stavljaju pred klizni ležaj u radu [4] prikazana je razvijena nova grupa politetrafluoroetilena (PTFE) na bazi kompozitnih materijala za nanošenje na klizni ležaj.

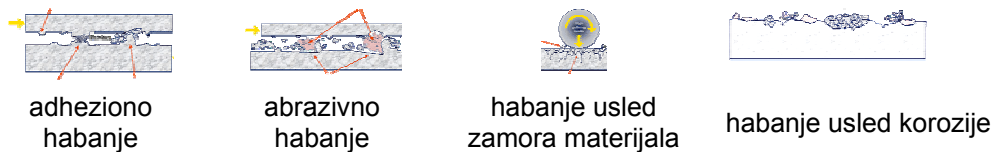
Idealan materijal za klizna ležaje bi bio onaj materijal koji lako apsorbuje abrazivne čestice, a pri narušavanju kontakata oslobađa se od njih. Univerzalne osobine u tom smislu imaju kompozitni materijali, elastomeri i polimeri. Samopodmazujući klizni ležaji ukazuju na niz prednosti i omogućavaju znatne uštede kako u održavanju, tako i u sredstvima za podmazivanje. Prilikom korišćenja bronzane čaure sa grafitom, grafit formira tanak film na obe dodirne površine koji je veoma otporan na udare i koji se zadržava i u poziciji mirovanja. U radu [5] je dato istraživanje u uslovima suvog trenja i ponašanje habanja dva abrazivna tela koja su napravljena od grafita i ojačana epoksi kompozitom. Primećeno je da se habanje ugljen-epoksi kompozitom redukuje dodavanjem grafitnog punila, u kojoj su dominirali mehanizmi habanja mikroprobijanja / mikrošećenja umesto mikroprrsline. U radu [6] data su istraživanja uticaja topografije površine PVD prevlake na tendenciju početnog prenosa materijala i frikcionu karakteristiku u kontaktnim uslovima suvog trenja. Rezultati pokazuju da rezultat topografije površine posteljice sa PVD prevlakom jako zavisi od topografije podloge materijala.

Zbog velikog broja uticajnih parametara neophodnih za proračun kao i važnosti i značaja uležištenja kod mašinskih sistema svrsishodna je primena računara pri konstruisanju radialnih i aksijalnih kliznih ležaja. Na Mašinskom fakultetu u Nišu [7] razvijeni programski paket za proračun i modeliranje hidrodinamičkih kliznih ležaja omogućuje u znatnoj meri automatizaciju procesa konstruisanja i dobijanje optimalnih konstrukcionih rešenja.

Proizvodnja i istraživanje samopodmazujućih kliznih ležaja su u stalnoj ekspanziji zbog svoje osobine da su pogodna za održavanje i imaju dug radni vek. Ovo je verovatno veoma važan razlog za njihovu uobičajenu upotrebu kod većine savremenih mašina i mehanizama, gde porozni klizni ležaji zauzimaju lidersku poziciju. Sa novim metodama simulacije i softverskim alatima moguće je sačiniti kvalitativne analize ponašanja kliznih ležaja, uzimajući u obzir njihove elastične deformacije. U

radu [8] predstavljena je strukturalna optimizacija radijalnih poroznih kliznih ležaja koji su složeno opterećeni. Kao opterećenje na unutrašnjoj površini poroznog kliznog ležaja uzeta je raspodelom pritiska izračunata po hidrodinamičkoj teoriji podmazivanja. Pored toga postoji i sila trenja klizanja, kao i neravnomerna raspodela temperatura po zapremini ležaja, koje takođe treba uzeti u obzir. Strukturalna analiza je urađena za svako od navedenih opterećenja pojedinačno, kao i za složeno opterećenje ovih ležaja. Analiza je obavljena metodom konačnih elemenata (MKE) u modulu za strukturalnu analizu softvera CATIA V5R11. Na osnovu rezultata ove analize u drugom delu rada je data parametarska optimizacija poroznog kliznog ležaja, uzimajući u obzir elastične deformacije čaure ležaja. Simulacije, analize i optimizacija, koje su realizovane pomoću CATIA V5R11 su u ovom radu predstavljene i ilustrovane odgovarajućim slikama i dijagramima.

Habanje kliznih ležaja predstavlja proces nepoželjnog postepenog progresivnog gubitka materijala posteljice kada na njega mehanički dejstvuje drugo telo (vratilo), koje se javlja kao rezultat trenja. Na slici 1 dati su primeri habanje kliznih ležaja.



Slika 1. Vidovi habanja

Veličina habanja je definisana: karakterom kretanja (klizanjem), opterećenjem (statičkim i dinamičkim), veličinom pritiska između kontaktnih površina, brzinom uzajamnog kretanja dodirnih površina, načinom dovoda, količinom, kvalitetom maziva kao i brzinom oscilovanja. Nivo habanja i koeficijent trenja povećavaju sa povećanjem brzine oscilovanja [9].

Danas se na tržištu može naći veliki broj mašina sa kliznim kontaktom u skoro svim granama industrije. Zahtevi kupaca ovakve opreme uglavnom su skoncentrisani na maksimalnu produktivnost i u najtežim radnim uslovima. Jak uticaj na performanse i ponašanje mehaničkih sistema imaju trenje, podmazivanje, i habanje [10]. Kao i brzine habanja, temperatura trenja, koeficijent trenja u suvim i uljem podmazanim uslovima [11].

Podmazivanje ležajeva odgovarajućim tipom i odgovarajućom količinom masti je osnovni preduslov rada bez problema. Pri izboru načina dovoda sredstava za podmazivanje neophodno je ustanoviti pravac dejstva opterećenja i karakter opterećenja. Ako se pri konstrukciji ležišta izvrši raspored kanala za podmazivanje ne vodeći računa o ovim faktorima, to narušava optimalnu raspodelu pritiska u uljnom klinu i snižava noseću sposobnost ležišta. Da bi se to izbeglo [12] urađeni su eksperimenti, koji su namenjeni za proučavanje efekata orijentacije žljebova na performanse trenja. Utvrđeno je da vertikalni ili paralelni žljebovi sa kliznim pravcem imaju snažan uticaj na performanse trenja kliznih površina, a dobra osobina normalne ili paralelne orijentacije može da zameni kontakt pod različitim uslovima.

U radu [13] je obrađen uticaj viskoznosti ulja za podmazivanje na radne uslove kod letećeg rukavca jednog dizel motora s predpritiskom namenjenog za ugradnju u

vozila. Analizirani su parametri: temperatura ulja u ležaju, promena maksimalne vrednosti srednjeg pritiska u ulju, minimalni nosivi sloj ulja i udeo mešovitog trenja, a sve u funkciji viskoznosti ulja na ulazu u ležaj, pri različitim zazorima sklopa ležaj – rukavac. Prikazani rezultati su dobijeni korišćenjem modela i vlastito razvijenih računskih programa za simulaciju uslova rada kliznih ležajeva uz eksperimentalnu potvrdu korišćenog modela.

Pošto je trenje danas neizostavni deo svakog procesa pa i kliznih ležajeva, bilo bi korisno imati uređaj koji bi merio trenje između pojedinih materijala. Upravo takav uređaj je tribometar. On meri trenje između dva materijala u različitim dinamičkim situacijama gde se može menjati temperatura ispitivanja, normalna sila na podlogu, relativna brzina između uzoraka, odnosno mogu se menjati svi parametri koji utiču na trenje u stvarnom procesu. Korišćenjem tribometra, u radu [14] vršeni su testovi habanja ležajeva da bi se okarakterisala konvencionalna legura koja će se koristiti za klizni ležaj. Daljim istraživanjima [15] triboloških karakteristika legure Al-25Zn-3Cu-3Si zapaža se da se koeficijent trenja povećava sa brzinom klizanja, ali se smanjuje sa povećanjem pritiska. Razvoj tehnologija prati razvoj i upotrebu novih materijala, posebno kompozitnih, koji se danas smatraju veoma značajnom klasom materijala koji zadovoljavaju visoke standarde moderne tehnologije. Kako su kompoziti dvo ili višefazni materijali koji u primeni pokazuju bolje osobine od sastavnih materijala posebno, to se nametnula potreba da se kroz teorijski model za izračunavanje triboloških sistema otpora pokažu dobre klizne osobine i visoka otpornost habanja kompozita [17].

Otkazi kliznih ležaja imaju najveći uticaj na vek i pouzdanost rada kod mnogih mašina i uređaja. Zbog toga je značaj ispitivanja otkaza dobro poznat, jer ukazuje na moguće uzročnike i na potrebne mere koje treba preduzeti za smanjenje i eliminaciju otkaza [18].

3. PLANIRANA ISTRAŽIVANJA KLIZNIH LEŽAJA SA GRAFITOM

Osnovno svojstvo samopodmazujućih ležaja jeste da ne zahtevaju posebno podmazivanje i održavanje tokom rada. To određuje oblasti primene: na mestima gde su maziva neefikasna, odnosno na mestima izloženim niskim ili visokim temperaturama ili u reaktivnoj sredini, gde se fluidi za podmazivanje ne mogu koristiti zbog mogućnosti kontaminacije proizvoda ili sredine, gde je primena uobičajenih maziva nepogodna zbog nemogućnosti održavanja. S'obzirom da se klizni ležajevi sa lamelama grafita (Sl. 2) primenjuju pri malim brzinama kretanja i visokim opterećenjima, kod teških građevinskih mašina i rudarske mehanizacije to su više izloženi velikom trenju i aktuelniji su za dalja istraživanja.



Sl.2 Samopodmazujući klizni ležaj sa grafitom

Planira se ispitivanje samopodmazujućeg kliznog ležaja, čija je posteljica izrađena od osnovnog materijala – bronz (hemijski sastav dat u tabeli 1) visokog kvaliteta sa ulošcima (lamelama) od grafita, koji homogeno prijanjaju na površinu zauzimajući 20 % i 30 % čaure. Navedeni ulošci urađeni su pod visokim pritiskom i sastavljeni od grafita i formaldehidne smole.

Tabela 1. Hemijski sastav CuSn 10

Zn 0.82%	Pb 1.56%	Sn 10,09%	P 0 %	Mn 0%	Fe 0%	Ni 0.36%	Si 0%	Mg 0%
Cr 0%	Te 0%	As 0%	Sb 0%	Cd 0%	Bi 0%	Ag 0%	Co 0%	Al 0%
S 0%	Be 0%	Zr 0%	Au 0%	B 0%	C 0%	Ti 0%	Cu 87.03%	

Karakteristike CAD/CAE softvera za inženjersku analizu konstrukcija omogućavaju da se izvrši detaljna analiza termo-mehaničkih karakteristika kliznog ležaja sa grafitom, koji su posebni zbog svoje konstrukcije. Ovo istraživanje je usmereno na identifikaciju termo-mehaničkih karakteristika i mogućih uzroka pojave neželjenog habanja u eksploataciji kliznih ležaja sa grafitom. U pravcu izvođenja numeričkih simulacija koje odgovaraju realnim eksploatacionim uslovima rada, vršiće se eksperimentalna istraživanja konstrukciono-triboloških karakteristika kliznih ležaja sa grafitom. U tom pravcu razviće se tribometar za eksperimentalna istraživanja kliznih ležaja sa grafitom.

Primenom eksperimentalnih istraživanja, izvršiće se identifikacija parcijalnih uticaja pojedinih konstrukcionih parametara kliznih ležaja sa grafitom, kao i njihove korelacione zavisnosti. Putem eksperimentalnih metoda biće određeni i parametri realnih eksploatacionih opterećenja i biće izvršena validacija metodologije razvoja.

4. ZAKLJUČAK

Na Mašinskom fakultetu u Nišu vršiće se istraživanja konstrukciono – triboloških parametara radijalnih kliznih ležaja sa grafitom sa aspekta optimalne osnovne funkcije.

U okviru prve faze istraživanja biće izvršena analiza tehničko-eksploatacionih karakteristika kliznog ležaja sa grafitom i identifikacija uticajnih parametara koji definišu konstrukcione karakteristike kliznog ležaja sa grafitom.

U okviru druge faze istraživanja definisaće se numeričke, optimizacione i eksperimentalne procedure istraživanja i razvoja kliznih ležaja sa grafitom.

U trećoj fazi istraživanja formiraće se originalni eksperimentalni sto i vršiti eksperimentalna istraživanja na radijalnim kliznim ležajima sa grafitom,

U četvrtoj fazi istraživanja vršiće se termo-mehanička analiza sa optimizacijom konstrukcije ležaja sa aspekta optimalne funkcije.

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THERMAL ANALYSIS OF HIGH POWER REDUCTION GEARBOX

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Abstract: This paper presents thermal analysis of high power reduction gearbox used for transferring power to surface mining conveyor belts. Gearbox is designed for continuous operation at high speeds, which results in generation of large amount of heat. Analysis is used to determine proper way of fan cooling which drains the entire amount of generated heat from casing. Thermal analysis of gearbox is performed for various convection coefficients out of which in this paper we presented two cases, one that satisfy and other that does not satisfy required conditions.

Keywords: gearbox, heat transfer, finite element method

1. INTRODUCTION

In industrial production gearboxes are required to transfer power from drive to working machines. High power gearboxes transfer a lot of power, so unavoidable power losses generate significant amount of heat which is absorbed by oil and casing. Depending on working conditions cooling of gearbox casing is done by passive or active convection. When passive convection is insufficient, active (fan) convection is applied.

The goal of analysis, presented in this paper, is to determine proper way of fan cooling which drains the entire amount of generated heat. Analysis is done using PAK-T [1] software package, which is based on finite element method (FEM) and heat conduction laws [2-3].

2. EQUILIBRIUM EQUATION OF HEAT CONDUCTION

Derivation and solving Matrix form of equilibrium equation (1) is described in [2]

$$CT+KT=Q \quad (1)$$

where **C** represents capacity matrix and components of matrix **K** and vector **Q** are determined as:

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$$K_{ll} = K_{ll}^k + K_{ll}^h + K_{ll}^r \quad (2)$$

$$Q_l = Q_l^q + Q_l^{q_n} + Q_l^h + Q_l^r \quad (3)$$

Indexes k , h and r are notation for conduction, convection and radiation respectively. Exponent q indicates volume source while exponent q_n indicates surface flux.

Calculation of convection coefficient for active cooling

The amount of heat per unit of time that is exchanged from fluid to the wall (or vice versa):

$$Q = Ah(T_f - T_z) \quad (4)$$

where: T_f fluid temperature, T_z wall temperature, h heat convection coefficient, A the surface of heat exchange. Value of convection coefficient between wall and fluid can be calculated using:

$$h = \lambda N_u / L \quad (5)$$

where: λ thermal conductivity of fluid, N_u Nusselt number and L characteristic length of the flow. Nusselt number for active convection can be calculated using equation:

$$N_u = CR_e^n P_r^m G_r^r \left(\frac{P_r}{P_{rz}} \right)^{0.25} \quad (6)$$

where: R_e Reynolds number, C, n, m, γ are coefficients depending on Reynolds number and position of convection surface, P_r i P_{rz} are Prandtl numbers that depend on fluid and wall temperatures, G_r is Grashof number. Reynolds, Prandtl and Grashof number can be calculated using following expressions.

$$R_e = \frac{v_f L}{\nu}, \quad P_r = \frac{\nu}{a} = \frac{\nu \rho C_p}{\lambda}, \quad G_r = \frac{g \beta \Delta T L^3}{\nu^2} \quad (7)$$

where: v_f fluid velocity, ν kinematic viscosity, ρ density of fluid, C_p specific heat capacity, a thermal diffusivity of fluid, β volumetric coefficient of thermal expansion of the fluid and $\Delta T = T_z - T_f$ difference between the wall and fluid temperature.

3. ANALYSIS OF GEARBOX THERMAL CAPACITY

Analised gearbox have power transfer capacity of 1000 kW, and it is designed for continuous power transfer to conveyor belts used in coal surface mines. Gearbox power losses are 40 kW, and those losses are converted to heat which is absorbed by oil and casing. To protect bearings from overheating and damage, the condition is set that the temperature of the oil in the housing should not exceed 90 °C at an ambient temperature of 40 °C. The goal of the analysis is to determine the needed airflow rate when active cooling is applied to gearbox, which is required for total amount of heat

generated by the power losses in gearbox to be exchanged with the environment.

Due to symmetry of geometry and loads, half of the gearbox casing is modeled. Finite element mesh is generated automatically in FEMAP software. Default element size is 12.5 mm. Generated mesh contains 310382 nodes and 1357714 tetrahedral 3D elements, Figure 1.

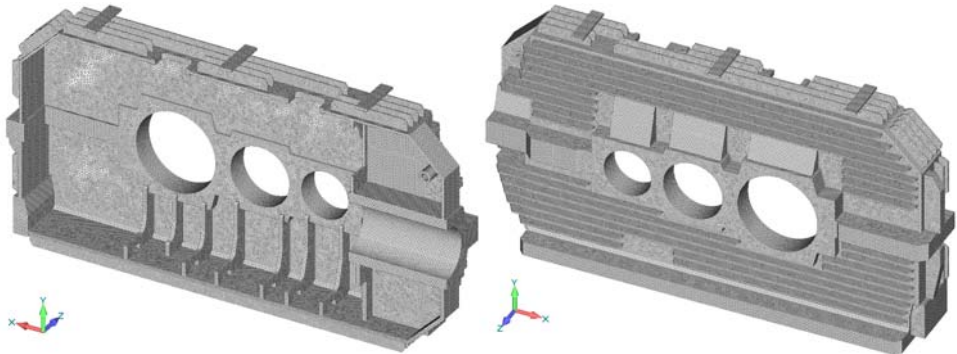


Fig.1 Finite element mesh

Heat conduction coefficient of gearbox casing is $k = 40 \text{ W/mK}$. On the inside of the gearbox oil temperature of 90°C is specified. Heat transfer coefficient between oil and casing is $h=1000 \text{ W/m}^2\text{K}$. The ambient temperature is 40°C . Two cases are considered for fan cooling (active cooling), with different heat transfer coefficients between casing and surrounding air ($h = 30 \text{ W/m}^2\text{K}$, and $h = 40 \text{ W/m}^2\text{K}$), corresponding to different speeds of air flow around the casing. As a result of the analysis we get temperature field, thermal flux field, total thermal flux of outer surface of gearbox casing. As a proof that designed fan cooling system meets the requirements, condition that total heat flux exchanged is greater than total power loss in the gearbox was used.

Analysis results for convection coefficient on outer surface $30 \text{ W/m}^2\text{K}$

Results show that gearbox casing in this operation mode exchange thermal flux of 17.2 kW , which is less than required 20 kW on half of the model. Figure 2 shows temperature field on inner and outer surface of gearbox casing. It also shows that maximum temperatures occur in bearings zones.

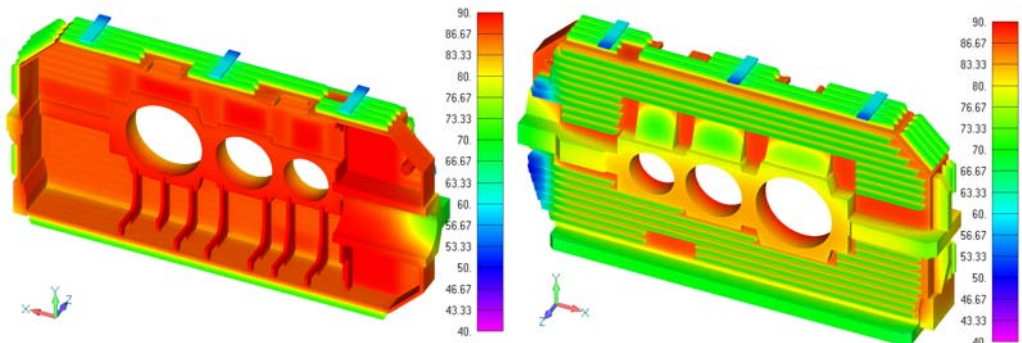


Fig.2 Temperature field on inner and outer surfaces

Analysis results for convection coefficient on outer surface 40 W/m²K

Gearbox casing analysis results show that in this operation mode exchange thermal flux of 21.5 kW, which is greater than required 20 kW on half of the model. Figure 3 shows temperature field on inner and outer surface of gearbox casing. It also shows that maximum temperatures occur in bearings zones. At high speed of convection air flow it comes to increased cooling of fan case as can be seen by comparing Figures 2 and 3.

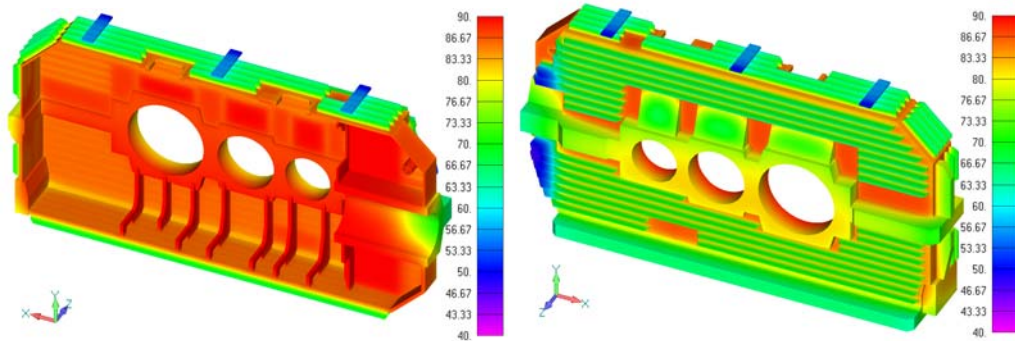


Fig.3 Temperature field on inner and outer surfaces

4. CONCLUSION

Thermal analysis of gearbox casing presented in this paper demonstrates procedure for determination of required airflow speed generated by active fan cooling system. Based on calculated required airflow speed, proper fan was selected, which meets condition that oil temperature in gearbox casing does not exceed 90°C. Based on analysis that we performed, we can conclude that in case of active convection with heat transfer coefficient ($h = 30 \text{ W/m}^2\text{K}$), heat capacity of gearbox does not meet the requirements. In case of active convection with heat transfer coefficient ($h = 40 \text{ W/m}^2\text{K}$), heat capacity of gearbox meets the requirements. Also, paper presents successful solution problem of heat transfer in software PAK-T.

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ZAHTEVI EDUKACIJE ZA INŽENJERE RAZVOJA – KAKO SARADIVATI U MEĐUNARODNIM PROJEKTIMA?

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Rezime: Shvatanje važnosti zahteva u edukaciji mašinskih inženjera na svakom nivou njihove obuke, predstavlja ključni element pripreme za uključivanje u praktičan rad. Posedovanje znanja iz različitih oblasti koje se stiču edukacijom je osnov učešće u međunarodnim projektima, pogotovo za inženjere početnike. Specifičnosti inženjerske obuke podrazumevaju objedinjavanje soft i hard veština, razumevanje socijalnog i kulturološkog konteksta za izvođenje projekata, potrebe za timski radom i korišćenje dostupnih tehnika i metoda razvoja proizvoda, podržanih savremenim komunikacionim sredstvima i CAD/CAM alatima. Ovaj rad se bavi problemima edukacije razvojnih inženjera kod nas, u poređenju sa efikasnim primerima dobre prakse u svetu.

Ključne riječi: edukacija, mašinsko inženjerstvo, razvoj, dizajn, međunarodni projekti

REQUIREMENTS FOR DEVELOPING ENGINEERS EDUCATION – HOW TO PARTICIPATE IN INTERNATIONAL PROJECTS?

Abstract: Understanding of importance of requirements at every level of mechanical engineering education represents the key element of preparing engineers for being involved in practical work. Knowledge in different fields of mechanical engineering education is base for participation in international projects, especially for engineers novice. Specificity of engineering education implies integration of soft and hard skills, understanding of social and cultural context for project execution, necessity for team work and usage of accessible product development techniques and methods, supported by modern communication means and CAD/CAM tools. This paper deals with problems in engineering education in our surrounding (Bosnia and Herzegovina, former YU republics) in comparison to efficient examples of good practice in the world.

Keywords: education, mechanical engineering, development, design, international projects

1. UVOD

Integrisani pristup razvoju proizvoda, kao odgovor na savremene uslove privređivanja, odnosno zahteve tržišta, je, pre svega, humano orjentisan pristup optimizaciji procesa razvoja proizvoda, gde odlučujuću uloga u pogledu uspešnosti i

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pozitivnog ishoda ovog procesa „igra“ znanje, kao rezultat istraživanja u nauci i tehnologiji. Naravno, brz razvoj nauke i tehnike pretpostavlja enormno uvećanje znanja, tzv. „eksploziju znanja“, te ono postaje važan resurs u razvoju svake zemlje, sa većim potencijalom nego prirodna bogastva i preduslov visoko kvalitetne, produktivne i efikasne proizvodnje [5].

Konstrukcioni inženjer ili „onaj koji razvija projekat“ je centralni dizajner i onaj koji je sposoban da kreira proizvod. Zahtevi ove pozicije su duboko tehničko razumevanje kao i visoke kompetence u pogledu komunikacije i razumevanja procesa. Šta više, dizajneri se moraju međusobno razlikovati sa metodološkim znanjem, uparenim sa socijalnim kompetencama i potencijalom da realizuju ideje. Industrija traga za inženjerima koji su u stanju kontinuirano savladavati problematične situacije, koje se dešavaju tokom razvoja novog proizvoda i pored njihovog dobro postavljenog osnovnog treninga za sticanje metodičkih veština i njihove mogućnosti za apstrakovanjem i dizajnom modela. Ono što je važno je razumevanje kompetenci upravljanja komplikovanim izazovima razvoja proizvoda.

2. ZAHTEVI EDUKACIJE, REZULTAT ZAHTEVA PRAKSE

Budućnost naučno zasnovane edukacije inženjera na univerzitetu mora imati za cilj prenošenje kompetenci u rešavanju problema nove inženjerske prakse, tj. »usađivanje« kompetenci za razvoj. Ovo se postiže kroz nezavisnu praćenje učenja u naučnoj istraživačkoj radnoj sredini, koja podražava ili stimuliše uslove realne radne sredine. Zašto? Istraživanja iz prakse pokazuju da bi osnovni cilj i zahtev edukacije inženjera trebao biti poboljšanje ključnih kompetenci ličnosti.

Kroz studiju koju je napravila VDI [6] (asocijacija njemačkih inženjera), u kojoj je učestvovalo nekoliko domaćih kompanija, trebalo je da se odgovori na pitanja o tome koji su nedostaci i koji su razlozi za neuklapanje mašinskih inženjera tokom perioda njihovog probnog rada. Rezultati pokazuju da je najveći deficit u socijalnim kompetencama (preko 50%), personalnim kompetencama (preko 45%), a nizak procenat (oko 10%) u profesionalnim kompetencama, koje pominju učesnici studije.

Ovo znači da je potrebno definisati položaj studenata kao korisnika usluga (kupaca, klijenata) ili partnera, na polju distribucije znanja i učenja, na savremeno postavljenim i podešenim osnovama, koje odgovaraju sadašnjem trenutku vremena. Cilj svih učesnika u procesu edukacije mora biti jedno posvećeno vođenje, radi davanja individualne pomoći studentima na njihovom izabranom putu, kroz promovisanje i podržavanje studentske predanosti i potencijala za postizanje ciljeva.

Budući inženjeri moraju biti „timski igrači“, obučeni u tehničkom, „now-how“ i biznis menadžmentu i trebaju biti osposobljeni da donose odluke i da ih implementiraju.

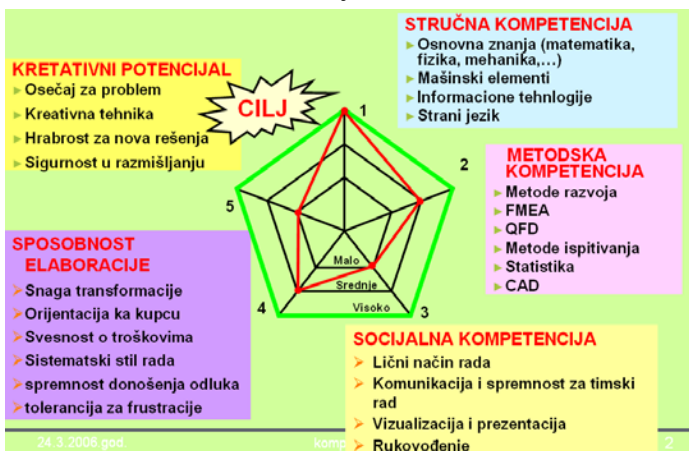
Bitno je naglasiti da problem potrebe „zatvaranja prostora“ između inženjerske edukacije i zahteva prakse nije samo evidentan u neposrednom okruženju (zemlje bivše Jugoslavije), već rešenje ovog problema predstavlja izazov većini razvijenih zemalja i njihovim sistemima edukacije inženjerskog kadra uopšte. Osnovni razlog za pojavljivanje ovog prostora je odsutnost „racionalnog“ i „detaljnog“. Zato savremeni pristup obrazovanju inženjera danas mora obezbediti sledeće sposobnosti:

Razumevanja, dizajniranja (konstruisanja), primenjivanja (implementacije) i korištenja.

2.1. »Good practice« - KaLeP model edukacije

Primer dobre prakse u edukaciji inženjera, koja se razvija već duži niz godina na Institutu za integrisani razvoj proizvoda IPEK Karlsruhe, je model edukacije KaLeP [1]. Sledeći tradiciju, razvijen je didaktički pristup koji dozvoljava da neophodno znanje bude prenešeno inženjerima na visokim standardima, čak i pod ograničenjima sve razvijenije globalizacije i promenjenih uslova. Karlsruhe model učenja za razvoj proizvoda KaLeP je univerzalni sistem obuke, orjentisan prema praktičnim procesima razvoja. Za cilj ima prenošenje veština u razvoju proizvoda koji se obezbeđuju na sledeći način:

1. Intenzivna umrežena primena lekcija, podrške timskom radu i slobodnih projekata u smislu »učenje kroz rad«. Ovo potvrđuje filozofiju edukacije koja odgovara modernom konstruktivizmu, što podrazumeva da najbolji rezultat edukacije ne dolazi iz visoko vrednovanih lekcija u odnosu na neaktivno slušanje, već kroz aktivno učenje, koje se vežba kroz timske workshop-ove tokom izrade projekta.
2. Obuka studenata nije samo (iako veoma važno) u području sticanja »tehničkih veština«, već takođe i na polju »mekih« veština, kao što su socijalne veštine, kreativni potencijal, potencijal za elaboriranje i methodske veštine.
3. Osnovni novi didaktički pristup prenošenja razumevanja funkcije elemenata i mašina, poznat kao Contact&Channel Model (C&CM) [2].
4. Univerzalni način prenošenja znanja podržan multimedijalnim sredstvima, kroz obezbeđenje poslednje IT tehnologije, radi efikasnog učenja i pripreme za razvoj nove radne sredine u industriji.



SI.1 Vrednovanje kompetenci profila inženjera

KaLeP model se bazira na tri pristupa, koja su uključena u sticanje znanja, u praktičnoj formi:

- Lekcije za učenje, koje su podeljene na tri dela;
- Praktični deo/radionice, (workshop-ovi);
- Projekat (praktičan rad).

KARLSRUHE MODEL EDUKACIJE KaLeP		
Edukacija	Sredina	Ključne kvalifikacije
Predavanja Kursevi vežbi Projektni zadatak	Stvaranje realne sredine	Integrirani projektni zadatak

Sl. 2 Model edukacije KaLeP

Važan aspekt je taj što su ove tri kolone veoma bliske jedna drugoj. Edukacija je podeljena u tri dela, teorijsko znanje se prenosi lekcijama, u jednoj posebnoj formi, tokom tutorijala se studenti uče kako da praktično primene znanja u rešavanju različitih zadataka, analiziranjem tehničkih sistema ili sl., a primena zauzima mesto na workshop-ovima. Timovi studenata rade zajedno na kompleksnom projektnom zadatku. Na taj način je KaLeP model baziran na konstruktivnom procesu učenja – studenti moraju postaviti svoje znanje na pravi način i razumeti problem ispravno.

Uspeh ovako postavljenog metoda edukacije je već dokazan tokom nekoliko godina izvođenja projekata razvoja, gde je pokazan studentski odgovor kroz promenjen smisao učenja prema instrukcijama KaLeP modela i taj postignuti uspeh u učenju je značajno veći nego pri korištenju »konvencionalnog« modela, isključivo kroz lekcije i vežbe pred većim auditorijumom.

2.2. Nova vizija edukacije inženjera - CDIO (Conceive–Design–Implement–Operate) inicijativa

Inženjerska edukacija i zahtevi realnog sveta za inženjera su poslednjih godina tekli odvojeno. Shvatajući činjenicu da ova velika razlika mora biti zatvorena, vodeće obrazovne inženjerske ustanove u SAD, Evropi, Kanadi, Velikoj Britaniji, Africi, Aziji i Novom Zelandu su formirale CDIO inicijativu, novu viziju inženjerske edukacije.

CDIO (Conceive–Design–Implement–Operate) ili «Shvatanje, kreiranje, primena i korištenje», je jedan inovativan obrazovni okvir, koji omogućava obrazovanje mašinskih inženjera nove generacije. On predstavlja osnov, u okviru organizovanog sistema edukacije, koji uvodi mlade inženjere u jedan stvarni, realni svet sistema i proizvoda [3].

CDIO inicijativa je razvijena na osnovu "ulaza" koji su dobijeni iz akademskih, industrijskih, inženjerskih i studenstkih izvora. CDIO inicijativa okuplja saradnike iz celog sveta, koji žele da implementiraju ovakav okvir za rad, kao i metode vrednovanja rezultata rada [4]. CDIO inicijativa je:

- Bogata studentskom projektima, dopunjena stažiranjem u industriji;
- Organizovana kroz aktivne grupe za učenje, putem lekcija i modernih radionica/laboratorija, sa rigoroznim sistemom procene i evaluiranja procesa;

Ciljevi CDIO inicijative su:

- Edukacija studenata radi ovladavanja dubljim znanjima tehničkih osnova;
- Edukacija inženjera u izvođenju konstruisanja i primene novih sistema i

proizvoda;

- Edukacija budućih istraživača u razumevanju važnosti i strategijske vrednosti njihovog rada;

CDIO inicijativa je specifično razvijena kao šablon koji može biti prihvaćen i prilagođen od strane različitih univerziteta. Radi se otvorenom modelu koji je dostupan svim obrazovnim inženjerskim programima i njihovim specifičnim potrebama. Uključeni univerziteti (saradnici) redovno razvijaju svoje materijale i pristupe i dele ih sa drugim saradnicima.

Od januara 2004. god. CDIO inicijativa je prilagodila 12 standarda, koji opisuju CDIO program. Ovi vodeći principi su razvijeni kao odgovor na pitanje vođa projekata, diplomiranih inženjera i partnera iz industrije, koji su željeli znati kako prepoznati inženjere koji su diplomirali na ovakvom programu. CDIO standardi definišu različite oblike CDIO programa, koji služe kao uputstvo za program edukativne reforme i vrednovanja, za korištenje i postizanje ciljeva širom sveta i obezbeđuju okvir za kontinuirano poboljšanje [3] Ti standardi su sledeći:

Standard 1.- CDIO, kao kontekst (sadržaj)

Standard 2.- CDIO Syllabus, rezultati

Standard 3.- Integrisani Nastavni plan i program

Standard 4.- Uvođenje u inženjerstvo

Standard 5. - Iskustvo u izradi konstrukcije (generisanje konstruktivnih rešenja)

Standard 6. – CDIO Radni prostor

Standard 7. – Iskustvo u integrisanom učenju

Standard 8. – Aktivno učenje

Standard 9. – Povećanje fakultetskih CDIO veština

Standard 10. – Povećanje fakultetskih nastavnih veština

Standard 11. – CDIO procena veština

Standard 12. – CDIO program vrednovanja (evaluiranja)

Velike kompanije kreirale su listu sposobnosti koje žele da poseduju inženjeri koji rade za njih (Boeing, napr.). U cilju ohrabrenja i podstreka univerzitetima da idu u susret potrebama realne sredine i da promene vlastitu obrazovnu strategiju, ABET (akreditaciono telo za inženjerstvo i tehnologiju) [8] formiralo je listu očekivanja od diplomiranih inženjera, te je kao rezultat toga nastao CDIO Syllabus (verzija 1.0., upravo se uvodi verzija 2.0.)

CDIO Nastavni plan i program (Syllabus), verzija 1.0., obuhvata:

1. Tehničko znanje i rasuđivanje

- 1.1. Znanje fundamentalnih nauka,
- 1.2. Znanje jezgra osnovnih inženjerskih nauka
- 1.3. Unapređeno znanje osnovnih inženjerskih nauka

2. Lična i profesionalna znanja i osobine

- 2.1. Inženjersko rasuđivanje i rešavanje problema (problem solving)
- 2.2. Eksperimentisanje i otkrivanje znanja
- 2.3. Sistemsko razmišljanje
- 2.4. Lične veštine i osobine

3. Profesionalne veštine i stav

- 3.1. Međuljudske veštine: timski rad i komunikacija

3.2. Timski rad

3.3. Komunikacija

3.4. Komunikacija stranim jezicima

4. Shvatanje, kreiranje, primenjivanje i korištenje sistema u okruženju i socijalnom kontekstu

4.1. Međuljudski i socijalni kontekst

4.2. Kontekst posla i preduzeća

4.3. Shvatanje i inženjerski sistem

4.4. Konstruisanje

4.5. Primena

4.6. Delovanje (rad)

3. MEĐUNARODNI KOOPERATIVNI PROJEKTI

Analizirajući stanje istraživanja u Svetu i kod nas, kada su u pitanju međunarodni kooperativni projekti, uključujući i međunarodne projekte u konstruisanju (dizajnu), može se reći sledeće:

- Timska ograničenost i geografska odvojenost prouzrokuje komunikacione probleme, poznate kao “siromašna komunikacija” ili “čekanje na odgovore”;
- Upravljanje projektom na daljinu uključuje “raspored odlaganja” i “potcenjivanje veličine projekta i kompleksnosti”;
- Kulturološke i jezičke razlike stvaraju određen oblik komunikacionog problema koji je moguće prevazići dobrom organizacijom i pravilnim izborom učesnika.
- Važnost velikih multinacionalnih, konzorcijum projekata je prepoznata, sa stanovišta upravljanja i organizacije, ali vođenje manjih konstrukcionih projekata nije egzaktno objašnjeno;
- Nivoi pojavljivanja komunikacionih problema, način pojave i vrsta komunikacionih medija, odnosno problemi tokom projekta konstrukcije i korišteni alati za prevazilaženje nisu precizno obelodanjeni;
- Naglašena je važnost koordinacije u globalnim dislociranim projektima, ali je ograničena količina informacije o uspešnoj koordinacionoj praksi.

S toga, iako je jasno pokazana internacionalna podijeljenost sa stanovišta nivoa i kompleksnosti u projektima, koji zahtevaju dodatne veštine i saglasnost svih nivoa ili svih članova tima ka postizanju ciljeva projekta, to ne obezbeđuje dovoljno jasan “putokaz” kako da se problemi raspoznaju ili kako da se rešavaju ili prevazilaze.

S toga se nameće zaključak da način obrazovanja inženjera ne obuhvata potrebe realne radne sredine, kao što su i pokazali rezultati različitih istraživanje, te da je neophodno prihvatiti primere dobre prakse razvijenih zemalja i omogućiti prilagođavanje nastavnih planova i programa međunarodnim inicijativama, kao što je CDIO.

3.1. Zašto su »soft« veštine posebno važne danas?

Poslednjih 10 godine su promene u svetskim tokovima doprinele promenama i u ovoj sferi, i reflektovale se na to da su profesionalne sposobnosti u kritičnoj fazi, danas više nego pre.

Tome su doprinele rapidne promene u tehnologijama, posebno informacionim, vanjski izvori, globalizacija tržišta, što je napravilo veliki uticaj na profesionalne veštine.

Sledeća četiri glavna megatrenda imaju presudan uticaj na tehničku praksu i sticanje znanja u veštinama koje su mnogo više od tehničkih:

- Promena odnosa snaga (vodećih sila) u svetskoj osetljivoj ekonomiji;
- Mobilnost profesora i studenata;
- Korišćenje komunikacionih i nastavnih tehnologija,
- Jačanje uticaja socijalnog imperativa.

Prethodno pomenute „soft“ (meke) veštine, koje su mnogo više od sposobnosti javnog izražavanja, rukovodećih veština, sposobnosti rada u timu, su potrebe razumevanja kako rast socijalnih konsekvenci širom sveta čine imperativ za studente tehnike, što im pomaže da razumeju implikacije njihovog rada.

Globalizacija podrazumeva takođe globalizaciju profesije inženjera, tera na razmatranje buduće uloge inženjera i edukacija mora ići u susret toj ulozi. Danas je jasno, napr, da mnoge kompanije iz SAD traže talentovane inženjere bilo gde, širom sveta, gde je to moguće. Kvalitet u dizajnu, konstruisanju, niska cena inženjerskih usluga i proizvodne mogućnosti, određuju mesto gde se takav kadar može nalaziti i tražiti. Tako, kompanije iz SAD koje se bave konstrukcijama, traže građevinske inženjere iz Koreje, automobilske kompanije traže talente iz Evrope, kompanije za software angažuju inženjere iz Indije [10].

Da bi se razmotrile »soft« veštine, moguće ih je podeliti u dve grupe:

- Procesne veštine: sposobnost komunikacije, timski rad, mogućnost prepoznavanja i rešavanja etičkih dilema,
- Svesne veštine: razumevanje uticaja globalnog i socijalnog faktora, znanje iz savremenih izvora i sposobnost učenja za čitav život.

4. VAŽNOST ULOGE TIMA I TIMSKOG RADA

Veličina i kompleksnost većine razvojnih projekata (malih i velikih, internacionalnih) danas, zahteva timski rad, pre no individualan, pa je, prema tome, neophodnost timskog rada u razvoju proizvoda opšte prihvaćena. Rezultati timskog rada zavise od više faktora, kvalifikacija članova tima, dobro struktuisanog procesa razvoja, metoda za podršku procesu razvoja. Rad u timu zahteva obraćanje pažnje na različite stilove rešavanja problema, svih članova tima.

Savremeni dizajnerski problem zahteva konstruktorski tim – relativno mali broj ljudi, sa komplementarnim veštinama, koji su ujedinjeni u zajedničkoj svrsi, zajedničkom postizanju cilja i zajedničkom pristupu, u meri u kojoj oni međusobno mogu da računaju. Efektivan tim, međutim je mnogo više od prethodno nabrojanog. Osim cilja, za rešenjem dizajnerskog problema, timovi imaju još jedan set ciljeva, koji zahtevaju pažnju:

- I. Članovi tima moraju učiti kako da sarađuju jedan sa drugim, saradnja znači mnogo više od pojma raditi zajedno.
- II. Timovi su, opšte gledano, osposobljeni za donošenje odluka.
- III. Članovi tima moraju uspostaviti komunikaciju, koja će podražati rešenje problema u realnom vremenu.
- IV. Veoma je važno da članovi tima i rukovodstvo budu ujedinjeni, za dobiti

tima. Ako to nije slučaj, veoma je teško postići ostale ciljeve tima.

- V. Timski rad mora biti baziran na modernim strategijama upravljanja, [TQM (Total Quality Management), Keizen, Lean–Production, Lean–Management, KVP2 (kontinualno poboljšanje procesa), Re-engineering].

5. ZAKLJUČAK

Primeri generisani u dostupnoj literaturi su pokazali da evidentno postoje primeri „dobre prakse“ u izvođenju globalnih, inter-organizacionih projekata, ali su oni sporadični, nisu univerzalnog karaktera, menjaju se od slučaja do slučaja, što daje prostor za dalja i dublja istraživanja, svaki put kada su granični uslovi izvođenja projekata makar i za nijansu drugačiji. Zato su svi konkretni primeri saradnje na međunarodnom nivou, uz učešće inženjera različitog „backgrounda“, bazirani na drugačijim istraživačkim aspektima, dobrodošli u sakupljanju novih saznanja za kriranje i sprovođenje novih eksperimenata i buduća istraživanja.

Osim toga, primeri dobre prakse u edukaciji pokazuju da su indutrija i ABET identifikovali destinaciju, vreme je da edukatori (univerziteti) menaju plan puta. Suočeni sa razlikom između naučnih i praktičnih inženjerskih zahteva i potreba, neophodno je prihvatiti izazov reforme inženjerske edukacije. Rezultat tog nastojanja je i prihvatanje širom sveta rasprostranjenje CDIO inicijative, kojoj je neophodno pridružiti sisteme edukacije zemalja u okruženju.

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STRESS AND STRAIN STATE OF CYCLOID DISC

Mirko Blagojević¹, Zorica Đorđević², Vesna Marjanović³, Nenad Marjanović⁴,
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Abstract: *This paper deals with stress and strain state analysis for cycloid disk, as a vital element at cycloidal speed reducer, for a case when machining tolerances exist. Three cases of the most critical meshing have been analysed: single, double and triple meshing. Values of forces between the rollers of the stationary central gear and cycloid gear were analytically calculated. Stress and strain state analysis were numerically realised by application of FEM. The whole range of models with different cases of load distribution has been made. Obtained results are showed in a form of figures, diagrams and tables. Finally, conclusions were made, based on realised analysis.*

Keywords: *cycloidal speed reducer, cycloid disc, stress state, strain state*

1. INTRODUCTION

The most important application of the cycloid profile gears (cycloid gears) is their use at cycloidal speed reducers. Due to a range of good characteristics they possess, and firstly due to a big gear ratio and low losses, cycloidal speed reducers are very much used within modern industrial machines. Considering the fact that they possess very compact design, they can be readily applied for devices with space limitations. Model of the single-stage cycloidal speed reducer is shown in Figure 1.

The most important element of the cycloidal speed reducer is certainly cycloid gear. As a teeth profile of the cycloid gear, equidistant of the shortened epitrochoid is the most frequently used. Cycloidal gear teeth are meshed with rollers of the stationary central disk. For theoretical case, when machining tolerances are not considered, half

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of cycloidal gear teeth participate at the load transmission process. The most frequently, for each transmission rate, two identical cycloid disks are used, rotated 180° relative to each other. This way, good dynamical equilibrium of cycloidal speed reducer elements is obtained and also the ability to accept even the significantly high short-time overloads (up to 500%) without failures.

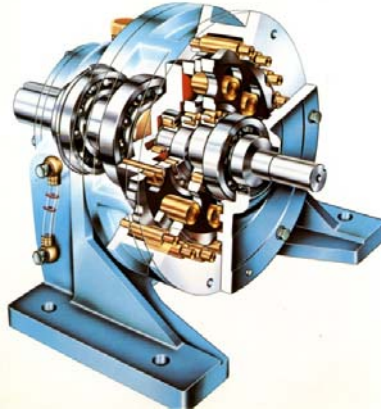


Fig. 1. Single-stage cycloidal speed reducer

The way of cycloidal gearing generation is defined by Kudrijavcev [1], and after that, in more details by Lehmann [2]. Litvin and Feng [3] derived parametric equations of the trochoid and its equidistant. Blanche and Yang [4] defined inter-dependencies between machining tolerances, drive parameters (namely, gear ratio, pitch diameter and normalized tooth heights) and drive performance (namely, backlash and torque ripple), by using equations in vector form.

Analysis of loads that appear at cycloidal speed reducer, for a case when machining tolerances do not exist, is represented in papers [5] and [6]. Papers [7] and [8] describe the procedure for force calculation of cycloidal speed reducer elements, for the case of modified tooth profile of cycloid disk. Yunhong, Changlin and Liping have taken into account friction force during load analysis [9], whilst in paper [10], experimental analysis of efficiency coefficient of cycloidal speed reducer is done. Chmurawa and John [11] have done analysis of stress state and strain state of cycloid gears when machining tolerances do not exist and when all teeth of cycloid disks are in contact with appropriate housing rollers. Static and dynamic forces act upon elements of the cycloidal speed reducer. Dynamical models of involute gear pair and cycloidal speed reducer are represented in papers [12].

This paper deals with analysis of stress state and strain state of cycloid gears for the case when machining tolerances exist in the presence of static forces.

2. CYCLOID DISC LOADS

Cycloid disk is the most significant element of the cycloidal speed reducer due to its complex geometry, but also due to a complex stress state occurring within it. In order to realise analysis of the stress and strain state, it is necessary to define forces which act upon it. Cycloid disk in contact with housing rollers and output rollers, [5] is shown in Figure 2.

Forces on cycloid disc are:

F_E – bearing reaction,

F_{Ni} – force between housing roller i and cycloid disc,

F_{Kj} – force between output roller j and cycloid disc,
 T_1 – input torque.

The following equations can be expressed, based on Figure 2:

$$T_1 = F_E \cdot e \cdot \cos(\beta + \varepsilon) \quad (1)$$

$$T_1 = \frac{r_i}{z} \cdot \sum_{j=1}^q F_{Kj} \cdot \sin(\beta_j + \beta) \quad (2)$$

$$\sum_{i=1}^p F_{Ni} \cdot \cos \alpha_i - \sum_{j=1}^q F_{Kj} \cdot \cos \beta - F_E \cdot \sin \varepsilon = 0 \quad (3)$$

$$F_E \cdot \cos \varepsilon - \sum_{i=1}^p F_{Ni} \cdot \sin \alpha_i + \sum_{j=1}^q F_{Kj} \cdot \sin \beta = 0 \quad (4)$$

$$\sum_{i=1}^p F_{Ni} \cdot l_i - \sum_{j=1}^q F_{Kj} \cdot r_i \cdot \sin(\beta_j + \beta) = 0 \quad (5)$$

where:

e – eccentricity,

β – swivel angle of the input shaft,

ε – angle betce F_E and eccentricity e direction,

r_i – radius of output rollers pitch circle,

z – number of teeth of cycloid disc (gearing ratio of the cycloidal speed reducer),

β_j – angular position of the output roller j ,

α_i – angle which force F_{Ni} makes with vertical,

l_i – lever arm of force F_{Ni} ,

p – number of housing rollers that carry the load,

q – number of output rollers that carry the load.

Values α_i and l_i are calculated according to Figure 2, based on the following expressions:

$$\alpha_i = \arctg \frac{\sin \beta + \frac{r}{r_2} \cdot \sin \gamma_i}{\cos \beta - \frac{r}{r_2} \cdot \cos \gamma_i} \quad (6)$$

$$l_i = r_i \cdot \sin(\alpha_i - \beta) \quad (7)$$

Angle γ_i (angular position of the housing rollers) is calculated based on the following expression:

$$\gamma_i = \frac{360 \cdot (2 \cdot i - 1)}{2 \cdot (z + 1)} \quad (8)$$

where:

r – radius of housing rollers pitch circle,

r_1 – base circle radius of the cycloid disc,

r_2 – base circle radius of the housing rollers.

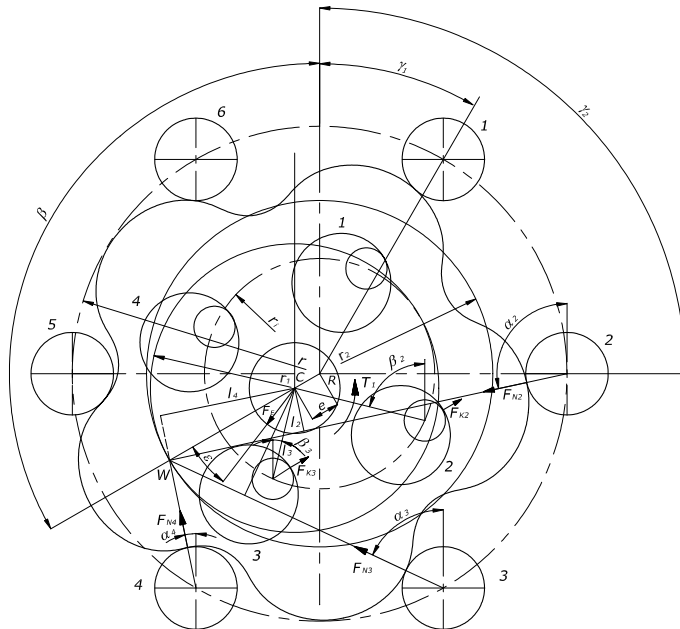


Fig. 2. Cycloid disc in contact with housing rollers and output rollers

Forces F_{Ni} and F_{Kj} are proportional to their respective distances from the centre of rotation:

$$\frac{F_{Ni}}{l_i} = const. \quad (9)$$

$$\frac{F_{Kj}}{\sin(\beta_j + \beta)} = const. \quad (10)$$

Only for ideal (theoretical) case all cycloid disc teeth are in contact with appropriate rollers and half of them carry load. In reality, cycloidal speed reducer has machining tolerances due to which number of teeth in contact is lower than in ideal case, that is, the load per one tooth is increased.

This paper deals with three the most critical cases (single, double and triple meshing). For observed single-stage cycloidal speed reducer ($P = 5,5 \text{ kW}$, $n = 1500 \text{ min}^{-1}$, $z = 11$, $e = 4 \text{ mm}$, $r_1 = 44 \text{ mm}$, $r_2 = 48 \text{ mm}$, $r = 72 \text{ mm}$) values of forces F_{Ni} are calculated, based on expressions (1) – (10) and results are given in Table 1.

Table 1. Values of forces between housing rollers and cycloid disc

Meshing:	F_{N1}, N	F_{N2}, N	F_{N3}, N
Single	4628,5	-	-
Double	2211,1	2312	-
Triple	1969,3	2059,1	998,3

3. ANALYSIS OF STRESS – STRAIN STATE OF CYCLOID DISC USING FEM

Analysis of stress and strain state of cycloid disc is realised using FEM. For this purpose, the whole range of numerical models has been made. Cycloid disc is considered to be deformable elastic body. Three the most critical cases (single, double and triple meshing) are analysed, for the value of the swivel angle of the input shaft $\beta = 20^\circ$. It is considered that at one instant two output rollers are in contact with cycloid disc, for all numerical models. Supports have been set up at these points. Bearing reaction is decomposed into nine components and supports have been set up also at points of these components. External loads are forces F_{Ni} . Problem is observed as being planar. Quadrilateral two-dimensional isoparametric finite elements have been used. Cycloid disc model consists of 9227 finite elements and 9753 nodes. Steel 30CrMoV9 (WNr 1.7707) was selected as a cycloid disc material, with the following characteristics:

- Yield stress: $R_{eH} = 700$ MPa,
- Tensile strength: $R_m = 1100$ MPa,
- Modulus of elasticity: $E = 2,1 \cdot 10^5$ MPa,
- Poisson coefficient: $\mu = 0,3$.

Two from 6 analysed numerical models with loads and limitations presented, are shown in Figures 3 and 4.

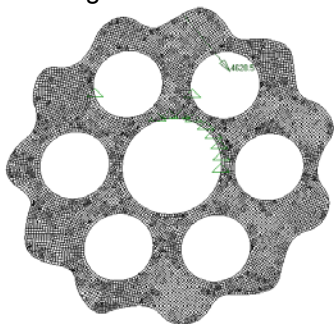


Fig. 3. Numerical model of cycloidal disc for the case of single meshing when force F_{N1} acts in one node

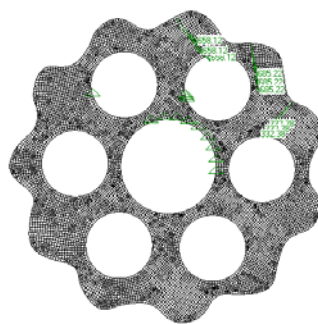


Fig. 4. Numerical model of cycloidal disc for the case of triple meshing when each of the forces F_{N1} , F_{N2} and F_{N3} is decomposed into three components

Beside analyzing single, double and triple meshing, stress and strain state of cycloid disc are analysed for cases when forces between housing rollers and cycloid disc are each decomposed into the three components, where at components of forces act upon the neighbouring nodes.

4. NUMERICAL ANALYSIS RESULTS

Stress and strain state analysis is realised by FEMAP software. Specifically, modeling, pre- and post-processing is done by FEMAP, while the calculation itself is done by MSC NASTRAN software. Stress and strain state for different models is represented in Figures 5, 6, 7, 8 and 9.

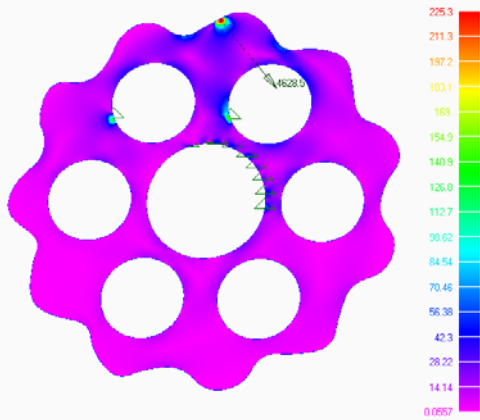


Fig. 5. Von-Mises stress distribution for the case of single meshing when force F_{N1} acts in one node

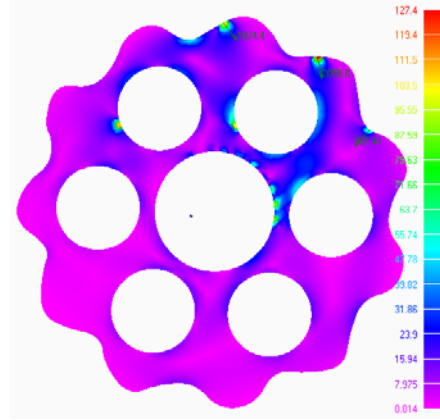


Fig. 6. Von-Mises stress distribution for the case of triple meshing when each of the forces F_{N1} , F_{N2} and F_{N3} act in one node

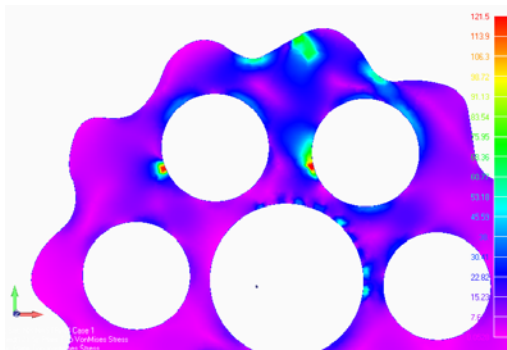


Fig. 7. Von-Mises stress distribution for the case of single meshing when force F_{N1} is decomposed into three components

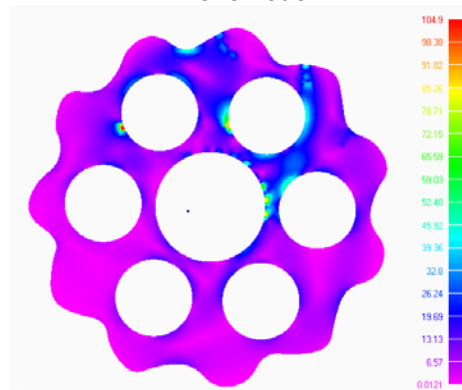


Fig. 8. Von-Mises stress distribution for the case of triple meshing when each of the forces F_{N1} , F_{N2} and F_{N3} is decomposed into three components

Maximum values of Von Mises stress and strain are depending on single, double or triple meshing and also on the forces between housing rollers and cycloid disc acting at one or three nodes. Diagrams are shown in figures 9 and 10.

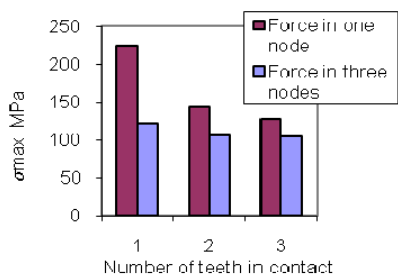


Fig. 9. Comparative analysis of Von Mises stress values when forces between housing rollers and cycloid disc act at one or three nodes

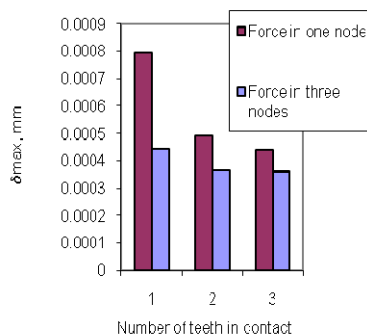


Fig. 10. Comparative analysis of maximum strain values when forces between housing rollers and cycloid disc act at one or three nodes

Values of stress and strain are the largest in case of single meshing and when total force acts at one node, what can be observed on diagrams in Figures 9 and 10. In that case: $\sigma_{\max} = 225,3 \text{ MPa}$ and $\delta_{\max} = 0,000795 \text{ mm}$. The lowest values of stress and strain are in case of triple meshing and when each of the forces F_{N1} , F_{N2} and F_{N3} is decomposed into three components. In that case: $\sigma_{\max} = 104,9 \text{ MPa}$ and $\delta_{\max} = 0,000360 \text{ mm}$. Obviously, values are almost doubled compared to each other, what certainly should be taken into account during design and manufacturing of the cycloidal speed reducer.

5. CONCLUSIONS

As with all machines and devices, there exist machining tolerances at cycloidal speed reducer. As a consequence to it, all housing rollers are not all simultaneously in contact with cycloid disc and do not all carry load. Three the most critical cases have been analysed in the paper, from aspects of stress and strain values. The cases of single, double and triple meshing have been analysed, when the total force between housing roller and cycloid disc acts at one node and also when that force is divided into three components and act at three neighbouring nodes.

Based on realised stress-strain analysis using FEM, the following conclusions can be made:

- The most unfavorable case, from aspect of stress and strain values, is the case of the single meshing when total force F_{Ni} acts at one node and the most favorable case is the triple meshing when each of the forces F_{N1} , F_{N2} and F_{N3} is decomposed into three components which act upon neighbouring nodes (stress values are in this case more than two times lower);
- Maximum stress and strain values, for numerical models where total force F_{Ni} acts at one node, are located exactly at these nodes (Figures 5 and 6);
- When forces F_{Ni} are decomposed into components, maximum stress and strain values are located in the contact zone of output rollers and cycloid disc - openings at the body of the cycloid disc (Figures 7 and 8);
- Even in the case of the most unfavorable single meshing, maximum stress and strain values are within the limits that provide reliable work of cycloid disks during the foreseen working life, what is extremely good recommendation for even more extensive use of cycloidal speed reducers.

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UTICAJ EURO NCAP TESTOVA NA MODIFIKACIJU KAROSERIJE U AUTOMOBILSKOJ INDUSTRIJI

Dejan Krstić¹

Rezime: Danas, više nego ikada, na prodaju vozila utiče njegova bezbednost. To je za današnje kupce vozila jedan od ključnih elemenata kupovne. Bitno je da kupci automobila dobijaju pouzdane i tačne uporedne informacije o bezbednosnim performansama pojedinačnih modela automobila. Svi novi modeli automobila moraju proći određene testove bezbednosti pre nego što se prodaju. Međutim, zakonodavstvo obezbeđuje samo minimum zakonskih normi sigurnosti za nove automobile, te je cilj Euro NCAP (engleski: The European New Car Assessment Programme) podsticaj proizvođačima da premaše minimalno propisane zakonske norme. Euro NCAP ima šesnaestogodišnje iskustvo testiranja novih automobila i procenjivanja zaštite pri simuliranju sudara. Tokom tog vremena, rang zvezda sistem je postao poznat i visoko cenjen od strane potrošača, kojima je bezbednost postala sve značajniji faktor pri izboru automobila, a i od proizvođača, jer su automobili sada mnogo sigurniji nego što su bile pre desetak godina. Ovaj uspeh može se delimično pripisati Euro NCAP kraš testovima, koji simuliraju širok raspon nesreća, a delimično i jednostavnosti ocene sistema koja donosi informacije dostupne svima. Euro Nacap je pre 2000. godine, svaki automobil ocenjavao sa najviše tri pojedinačne rang zvezde na osnovu bezbednosti odraslih, dece i zaštite pešaka. Ovaj sistem je zamenjen u 2009. godini sa jednim ukupnim rangom, čime je pojednostavljen postupak upoređivanja i stavljen sve veći naglasak na bezbednost i zaštitu pešaka. Svaka kategorija se sada ocenjuje na osnovu procenta i svaki izveštaj sadrži komentare koji objašnjavaju kriterijume donošenja zaključaka po testiranju automobila i kritične tačke performansi automobila iz svake oblasti ispitivanja. Ovi komentari obezbeđuju kupcima automobila još jasniju ukupnu sliku i omogućavaju lakša upoređivanja.

Ključne reči: kraš test, rang zvezda, performanse, bezbednost putnika, nova tehnologija, modifikacija karoserije automobila

IMPACT OF EURO NCAP TESTS ON BODY MODIFICATION IN AUTOMOTIVE INDUSTRY

Abstract: *Today, more than ever before, safety sells cars. For car buyers it is a key element of their purchasing decision. It's essential that motoring consumers can obtain reliable and accurate comparative information regarding the safety performance of individual car models. By law, all new car models must pass certain safety tests before they are sold. But legislation provides a minimum statutory standard of safety for new*

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cars, it is the aim of Euro NCAP to encourage manufacturers to exceed these minimum requirements. For ten years, Euro NCAP has been testing new cars and assessing the occupant protection they offer in the event of a crash. During that time, the star-rating system has become well known and highly regarded; by consumers, to whom safety has become an increasingly important factor when choosing a car; and by manufacturers, whose cars are now much safer than they were ten years ago. This success can be attributed partly to Euro NCAP's crash tests, perhaps the most comprehensive of their kind, which simulate a broad range of accidents, and partly to the simplicity of the rating system which makes the information accessible to all. Before 2009, each car was awarded three individual star ratings based on adult, child and pedestrian protection. This was replaced in 2009 with one overall rating, simplifying the comparison process and placing a greater emphasis on pedestrian protection. Each category is now rated on a percentage basis and every report includes comments explaining how the panel reached its conclusion and any fears they may have had about the car's performance in each test area. These comments give motorists a clearer overall picture and allow easier comparisons.

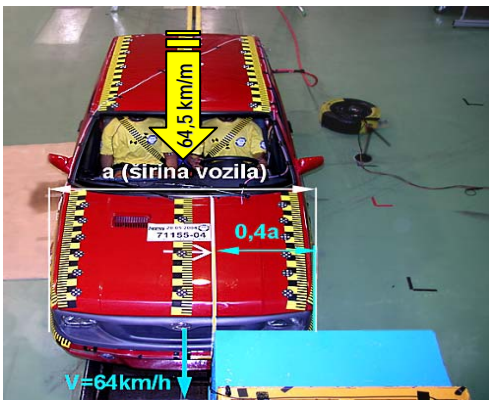
Keywords: *crash simulation, star rating, performance, passenger safety, new technology, modification of the car body*

1. UVOD

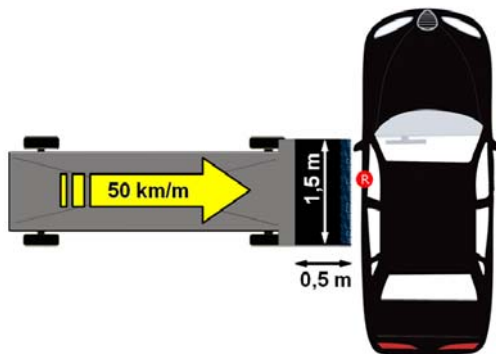
Na našim putevima je sve više automobila koji imaju moderne sisteme aktivne i pasivne zaštite putnika. Mnogi kupci danas pri izboru automobila vode računa o broju vazдушnih jastuka, i žele što bezbedniji auto za svoj novac. Iz želje da na putevima bude što manje nastradalih i teško povređenih, pet država EU, FIA, auto-moto društva i udruženja potrošača širom Evrope formirali su još 1997. godine Euro NCAP (European New Car Assessment Program) instituciju. Kreš testovi su se doduše i ranije sprovodili, ali je tek Euro NCAP uveo strogi sistem ispitivanja povreda putnika prilikom sudara, a da bi se kupci lakše snalazili uveden je sistem zvezdica (do maksimalnih pet zvezdica) i poena. Zahvaljujući popularizaciji Euro NCAP testa, proizvođači automobila nastoje da konstruišu što bezbednije automobile, na prvom mestu da bi ispunili propisani minimum bezbednosti koji je potrebno ispuniti da bi se vozilo uopšte prodavalo u zemljama EU, a potom i da bi nadmašili konkurenciju. Kao rezultat svega toga, poslednjih godina se beleži konstatni pad broja smrtno povređenih širom EU-a.

2. EURO NCAP TESTOVI

Euro NCAP test predstavlja simuliranje situacije iz stvarnog života. Tako se vrši frontalni, odnosno čeon sudar koji najbolje odslikava šta se dešava kada se dva automobila frontalno sudare pod određenim uglom, zatim bočni sudar, ali najnovijim simulacijama se mere i povrede pešaka koje nastaju eventualnim udarom automobila u istog, kao i simulacija saobraćajnih nezgoda u kojima učestvuju deca. Simulacija frontalnog sudara se odvija na prosečnoj brzini kretanja vozila pre neposrednog kontakta. Veliki procenat vozača kasno koči u opasnim situacijama, ali ipak uspeva da smanji brzinu sa 90-100 km/h na "prosečnih" 64 km/h. Odnosno, upravo se automobil na specijalno pripremljenoj stazi kreće brzinom od 64 km/h pre nego što sa prednjim delom udari sa 40 odsto svoje širine u deformabilnu barijeru dužine 1 metar. Takav tip sudar je ujedno i najčešći na putevima širom Evrope. Na slici br. 1. su prikazani parametri simuliranja frontalnog sudara, a na slici br. 2. parametri bočnog sudara.



Sl.1 Parametri Euro NCAP čeonog testa

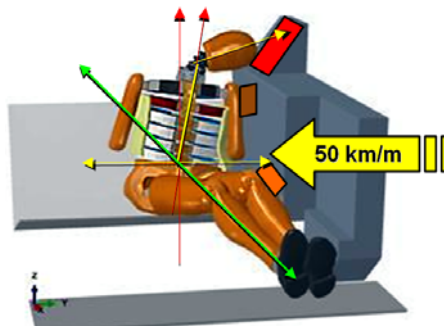


Sl. 2. Parametri Euro NCAP bočnog testa

Automobili su u proseku najranjiviji pri sudaru s boka, odnosno bočni sudar simulira ono što se svakodnevno dešava na raskrsnicama (procentualno najveća smrtnost je kod bočnih sudara). Sprovodi se tako što specijalna kolica, prikazana na slici br. 3. (sa deformabilnim prednjim delom širine 50 cm i dužine 150 cm) udaraju automobil brzinom od 50 km/h, tako da je centar udara u tzv. tački – T, odnosno mestu gde se nalazi toraks vozača. Time se ispituje bočna čvrstina karoserije, kao i efikasnost delovanja bočnih vazdušnih jastuka i zavesa na vozača (slika br. 4.).



Sl. 3 Simulacija bočog udar test kolicima



Sl. 4 3D model uticaja bočnog udara

Pored pomenutih testova, primenjuju se i simulacije manje karakterističnih stranjnih udara (slika br 5.), simulacije prevrtanja vozila (slika br. 6.) i mnogi drugi. Za Euro NCAP ispitivanja su referentni frontalni (kao statistički najčešći) i bočni (kao statistički najfatalniji) udari. Po realizaciji ovih testiranja se na osnovu dobijenih rezultata sabiraju poeni (čeonih i bočnih sudara) i time dobija ukupna ocena o nekom modelu, odnosno dodeljuju se Euro NCAP zvezdice. Pri tome, relevantno poređenje bezbednosti automobila se svodi na njihovu komparaciju zvezdica istih boja, ali samo iz istih klasa automobila, jer je na primer 5 zvezdica Clia III neuporedivo sa 5 zvezdica Lagune, iz razloga različitih kriterijuma za manje i veće automobile. Drugim rečima, bezbedniji automobil je onaj sa što više osvojenih poena (zvezdica) na EuroNCAP testu, i to što većih dimenzija i što veće težine.



Sl. 5 Prikaz stražnjeg kraš testa



Sl. 6 Prikaz testa na prevrtanje

Pored prvobitnih simulacija čeonog i bočnog sudara, Euro NCAP test danas ispituje i kolika je ugroženost pešaka (Pedestrian rating), pri čemu se takođe dodeljuju zvezdice, kao ocena sigurnosti. Tako se posebno ocenjuje koliko je automobil opasan po pešake, simulacijom naletanja vozila na pešaka pri brzini od 40 km/h. Pored ugroženosti pešaka, ispituje se i sigurnost male dece - Child Protection, a simuliraju se, kako udarci deteta pri naletanju na vozilo, tako i ispitivanje bezbednosti dece u vozilu (koja se po aktuelnim propisima moraju nalaziti u specijalnim dečijim sedištima, čiji su gabariti prilagođeni uzrastu deteta. Naime, testovi su pokazali da prilikom simulacije sudara, kada se vozilo kreće relativno malom brzinom od 50 km/h, četvorogodišnje dete koje neobezbeđeno sedi na zadnjem sedištu udara o prednje sedišta silom koja je ekvivalentna masi 400 kg. Za dečiji organizam ovakvi udari su fatalni. Uvođenjem Euro NCAP standarda za pravilan izbor i postavljanje dečijih sedišta (modeli lutaka simulacije od osamnaestomesečnog do trogodišnjeg uzrasta) se umanjila opasnost od fatalnih povreda za 75 %, a od ozbiljnih povreda za 67 %. I danas se permanentno istražuju nova rešenja, uz istovremeno stroga testiranja, u cilju povećanja bezbednosti dece koja se prevoze kolima. Kako bi sva prethodno navedena ispitivanja bila što upotrebljivija, za detaljne analize koriste se lutke koje su teške kao prosečni vozači, i koje imaju integrisane senzore za beleženje intenzitet sile udara u svaki deo tela ponasob. Neke od lutaka koje se koriste u testovima su prikazane na slikama br. 7 i br. 8.



Sl. 7 Prikaz lutke sa vratnim senzorom



Sl. 8 Prikaz kompletne lutke sa senzorima

Lutkama sa integriranim senzorima je moguće utvrditi koji su delovi tela najugroženiji kod pojedinih modela, takođe intenzitet povreda i njihovu opasnost po život, odnosno da li se pri akcidentu prolazi sa manjim ili težim povredama. Po Euro NCAP standardima su definisane zone i intenzitet povređivanja, kao što je prikazano na slici br. 9. [2]. Intenziteti povreda su rangirani po spektru boja.



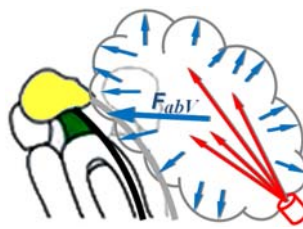
Sl.9 EuroNACAP standard i oznake posle promena 2009.g. uvođenjem ukupnog ranga

3. UTICAJ ZAŠTITNIH SISTEMA AIR BAG-a I POJASA NA PUTNIKE

Vazdušni jastuci su projektovani tako da apsorbuju veći deo energije prilikom sudara i aktiviraju se u hiljaditom delu sekunde prilikom sudara. Međutim, ukoliko sigurnosni pojas nije vezan, vazdušni jastuk može biti veoma opasan. Danas se koriste pojasevi sa tri tačke vezivanja koji prvo maksimalno zatežu telo putnika, a onda ih blago popuštaju kako ne bi došlo do oštećenja grudnog koša. Prilikom sudara, vozilo naglo usporava u kratkom vremenskom periodu i tada se putnici (ukoliko nisu vezani) usled inercije kreću velikom brzinom napred. U istom trenutku dolazi do aktiviranja vazdušnih jastuka. Air bag se aktivira paljenjem zapaljive materije (NaN₃) unutar inicijatora (slično ispaljivanju metka iz pištolja), a zatim ga ispunjava "radnim" gasom brzinom od 320 km/h. Odmah nakon toga, gas izlazi iz "jastuka" preko otvora sa njegove zadnje strane čime se amortizuje intenzitet usporavanja tela (što veće usporenje to veća opasnost od kidanja organa). Čitav ovaj proces se dešava u izuzetno kratkom periodu od $t = 0,25$ s. Preduslov bezbedne vožnje, kao i bezbednosti od samih air bag-ova je bezuslovno vezivanje sigurnosnih pojaseva.



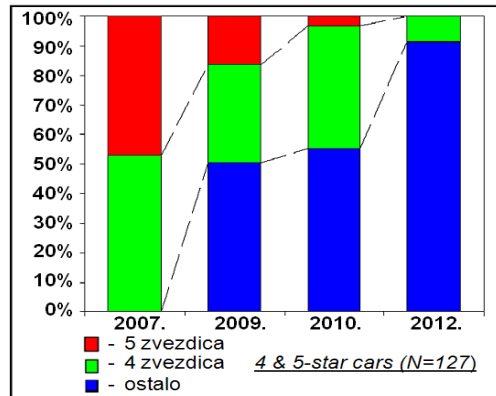
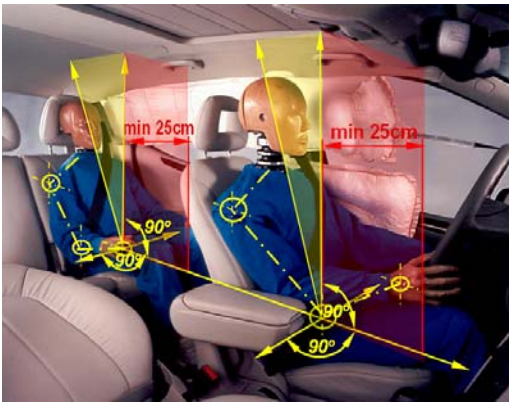
Sl. 10 Bez sigurnosnog pojasa



Sl. 11 Sa sigurnosnim pojansom

Međutim, ni prethodno istaknute mere sigurnosti nisu dovoljne za minimiziranje rizika povređivanja u slučaju saobraćajnih akcidenta i/ili incidenta. Jedna od najbitnijih činjenica je i u kom položaju sedi vozač i putnici, kao i podešenost visine volana (ako je volan podešiv), odnosno gde vozač drži ruke na istom. Vrlo često, na suvozačkom mestu, kao i na zadnjim sedištim sede osobe koje ne prate dešavanja na putu, a ono što je još gore od toga ne sede pravilno. Zapravo, vrlo je važno da vozač ali i suvozač i putnici na zadnjem sedištu, sede uspravno, pri čemu vozač mora biti udaljen od upravljača minimum 25 centimetara, jer je vazdušnom jastuku potreban prostor da se

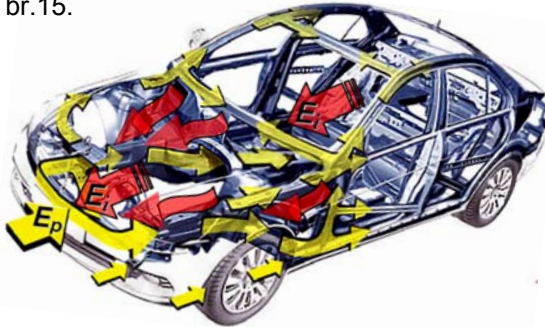
otvori. Takođe i putnici koji sede na zadnjem sedištu treba biti udaljeni bar 25 centimetara od prednjeg sedišta. Pravilan položaj tela vozača i putnika na zadnjem sedištu je prikazan na slici br. 12. [1]. Gotovo svi automobili sa vazдушnim jastucima imaju i volan podesiv po visini. Zapravo, vrlo je važno da centralni deo upravljača bude podešen u pravcu toraksa vozača, a ne u pravcu glave vozača. Pored toga, izuzetno je važno pravilno držanje ruku na upravljaču. Optimalno je da se ruke drže u takozvanoj poziciji "9h" i "15h" a najnepovoljnije u poziciji "10h" i "14h", jer ukoliko se ruke drže na gornjem delu volana prilikom otvaranja vazdušnog jastuka, doći će do njihovog loma udaranjem istih u sopstvenu glavu. Evolucija efekta "Meko prizemljenje" je prikazana slikom 13. [3]



Sl. 12 Pravilan položaj sedenja pri vožnji Sl.13 Evolucija efekata "Meko prizemljenje"

4. ENERGETSKI TOKOVI I NAPONSKA STANJA ČEONOG SUDARA

Energetski tokovi potencijalne energije i energije inercije u slučaju čeonog udara su prikazani slikom br.14, a akcija i reakcija sila air bag-a i inercije vozača slikom br.15.

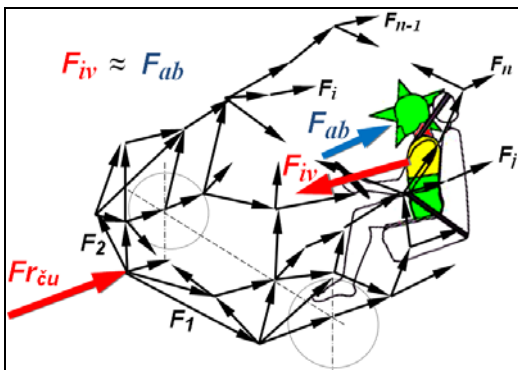


Sl. 14 Energetski tokovi čeonog sudara

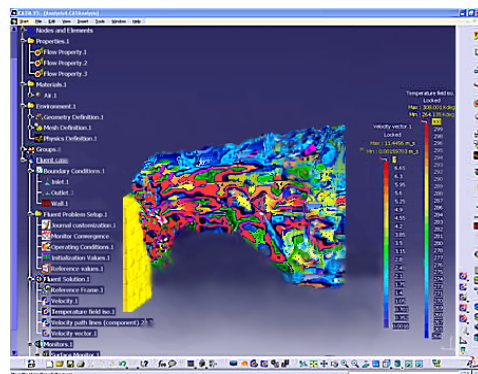
Sl.15 Reakcija inercije čeonog sudara

Kompleksnost analiza kraš-testova je velika zbog stohastičke prirode energetske transformacije (slika br.14.) i akcija i reakcija sila (slika br.16.), sa jedne strane, kao i zbog toga što se sam proces dinamike udara odigrava u vremenskom intervalu merenom milisekundama. Matematički model vektorske dekompozicije udarne sile i njeno razlaganje projekcijama na prostorne pravce (slika br.16) je domen teorije dinamike udara i deformacija, te se ovi složeni matematički problemi rešavaju

matricama krutosti i masa teorijom tenzorskog računa. Ovaj rad ne stavlja akcenat na višu matematiku tenzorskog rešavanja vektora u tri dimenzije, ali ukazuje na specijalizovane softverske pakete, poput CATIA 5 na operativnom sistemu UNIXS, kojom se u autoindustriji, pored konstrukcije delova, karoserije i kompletnog vozila, simuliraju i naponska stanja pri udaru. Najbitnije je da je sama konstrukcija karoserije definisana mrežnom metodom konačnih elemenata, što nam daje velike mogućnost analiza u trodimenzionalnom prostoru. Primer simulacije naponskih stanja (za vozilo Zastava-Yugo) pri čeonom sudaru je prikazan na slici br. 17. [1].



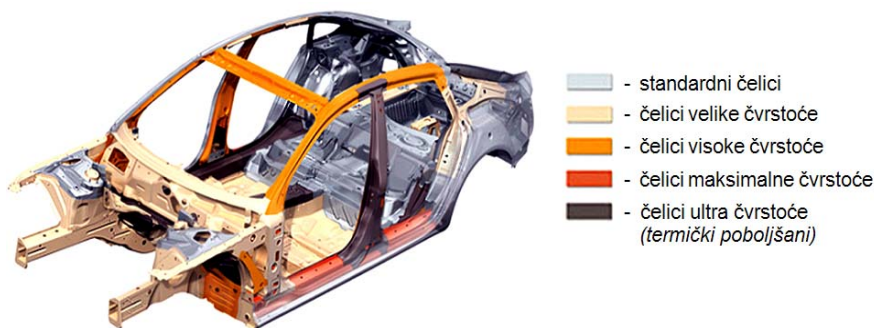
Sl. 16 Vektorska dekompozicija udarne sile



Sl. 17. Naponska stanja "Yugo" pri udaru

5. NOVI TRENDVI KAROSERIJSKE KONSTRUKCIJE I TEHNOLOGIJE

Kraš testovi Euro Nacapa i analize njihovih rezultata korišćenjem savremene opreme snimanja simuliranih događaja sudara u milisekundama, utiču i na napredak autoindustrije u smislu inalaženja novih konstruktivnih rešenja za poboljšanje performansi karoserije automobila, primenom novih tehnologija (umesto tačkastog zavaranja, dvostruko pertlovanje elemenata karoserije i lasersko varenje krovnog dela), primenu novih materijala za sklapanje karoserije (raznorodni čelici različitih karakteristika), geometrijsku korekciju oblika sa dodacima ukrućenja i drugo. Na slici br. 18. je prikazano novo rešenje karoserije kod vozila Audi, sastavljene iz čeličnih limova različitih otpornosti i krutosti, u zavisnosti od slabih i jakih tačaka po EuroNacap testovima.



Sl. 18 Novi trendovi sklapanja karoserije od čeličnih limova različite čvrstoće

6. ZAKLJUČAK

Euro NCAP testovi su značajno povećali bezbednost u saobraćaju, a kontinualnim proširenjem standarda se i u budućnosti očekuje daljnje smanjenje rizika od potencijalnih povreda i nesreća. U tom smislu, za tekuću 2012. godinu predviđeno je uvođenje još jedne rejting zvezde za automobile, koji poseduju kao standardnu opremu elektronski program kontrole stabilnosti "ESP". Što se tiče sigurnosnih pojaseva i naslona za glavu na zadnjim sedištima, u EU se više ne mogu registrovati automobili koji ih ne poseduju. Pored bezbednosnih aspekata, kraš testovi i analize ostvarenih rezultata, upotrebom savremene opreme snimanja događaja u milisekundama, utiču i na autoindustriju u smislu inalaženja novih konstruktivnih rešenja za poboljšanje performansi karoserije automobila, primenu novih tehnologija (umesto tačkastog zavarivanja, dvostruko pertlovanje elemenata karoserije i lasersko varenje krovnog dela), primenu novih materijala za sklapanje karoserije (raznorodni čelici različitih karakteristika) i drugo. Društveni uticaj EuroNCAP standarda je potvrđen i statističkim podacima, jer se njihovom primenom znatno smanjio broj povreda i smrtnosti u saobraćaju. U tekućoj 2012. godini je doneta i Direktiva EU u cilju da se do 2020. godine, broj smrtnosti u saobraćaju EU smanji za 50%. S druge strane, činjenica je da oni propisuju samo pasivnu zaštitu, i kao takvi obavezuju proizvođača automobila da svojim korisnicima i drugim licima u akcidentu i/ili incidentu sa njihovim automobilom, pruži bolju bezbednost, ali osnovnu bezbednost u suštini predstavlja prilagođena, savesna, koncentrisana i oprezna vožnja vozača, jer kod fatalnih i nekontrolisanih grešaka u saobraćaju su neizbežne i nesprečive fatalne posledice.

Pored svega navedenog, neophodno je i dalje konstantno raditi na podizanju saobraćajne kulture svih učesnika u saobraćaju, a naročito kod vozača snažnijih i luksuznijih automobila, jer nam statistički podaci o saobraćajnim nezgodama i stradanjima na putevima u Republici Srbiji ukazuju da je upravo kod njih najveći broj nesreća sa fatalnim posledicama. To znači da je na bezbednost saobraćaja značajnije prilagođavati vožnju u odnosu na vremenske prilike i stanja na putu, nego li se uzdati u keramičke kočnice, žiroskope i air beg-ove. Jednostavno rečeno, bitnije je gledati na kilometar sat, nego se pouzdati u performanse automobila, jer praksa pokazuje da pri velikim i neprilagođenim brzinama vozači nemaju na raspolaganju dovoljno sekundi da iskontrolišu vozilo. Nesavesna vožnja i arogancija u saobraćaju često anuliraju bezbednosne benefite EuroNCAP standarda, sa nažalost, fatalnim ishodima. To znači, da za takve ekstremne situacije pri vožnji prekomernom (ili čak nekontrolisanom) brzinom i/ili neprilagođenom vožnom vremenskim prilikama, sve što je autor izneo u ovom radu je nesvršishodno, i svi standardi Euro NCAP i moderni sistemi aktivne i pasivne zaštite putnika su nedovoljni i uzaludni.

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Session IV ***ENERGETICS AND THERMO -*** ***TECHNIQUE***



PROBLEMATIKA MATERIJALA KATALITIČKIH I KOTLOVSKO-TURBINSKIH POSTROJENJA

Milan Plavšić¹, Zdravko Božičković² Dušan Golubović³

Rezime: Katalitička i kotlovsko-turbinska postrojenja rade u vrlo složenim eksploatacionim uslovima, pa materijali za kritične komponente ovih postrojenja, pored dobrih mehaničkih osobina, trebaju da imaju i dobru otpornost na: koroziju, termički zamor, termički šok, puzanje, oksidaciju, itd. U ovom radu, dat je kratak pregled problematike vezane za eksploataciju, moguća oštećenja i materijale katalitičkih i kotlovsko-turbinskih postrojenja. (Abstract)

Ključne riječi: katalitičke cijevi, parovodi, kolektori, cijevi pregrijača, oštećenja

MATERIALS-RELATED ISSUES IN CATALYTIC AND BOILER-TURBINE PLANTS

Abstract: *Catalytic and boiler-turbine plants operate under very complex exploitation conditions, and as a result materials used for critical components of these plants need to have good mechanical properties as well as good resistance to: corrosion; thermal fatigue; thermal shock; crawling; oxidation, etc. This paper briefly summarizes exploitation, possible damages, and materials-related issues in catalytic and boiler-turbine plants.*

Keywords: catalytic tubes; vapour ducts; collectors; superheater tubes; damages

1. UVOD

U eksploataciji procesnih i energetskih postrojenja u petro-hemijskoj industriji, prisutni su brojni problemi. Ova postrojenja rade u veoma kompleksnim uslovima pri visokim radnim temperaturama i pritiscima procesnog medija, u uslovima: korozione "agresije" sa gasne strane (spoljašnja strana stijenke cijevi) i koroziono agresivnog procesnog medijuma koji struji kroz cijevi postrojenja, termičkog šoka bilo zbog "nagle" promjene radnog opterećenja, ili redovne i nužne obustave ovih postrojenja, termičkog zamora, itd. Sve to, a najviše vrlo izraženi zahtjevi za povećanjem: energetskog stepena iskorištenja, vijeka eksploatacije i sigurnosti u radu ovih postrojenja dovelo je do ubrzanog razvoja novih materijala. Značajniji stepen energetske efikasnosti postrojenja može se postići samo povećanjem radnih parametara, temperatura i pritiska, što uveliko ograničava upotrebu konvencionalnih materijala za izradu sastavnih komponenti savremenih procesno-energetskih postrojenja.

U ovom radu date su neke karakteristike koje se tiču rada i mogućih oštećenja

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na tehnološkom postrojenju za proizvodnju vodonika, odnosno u dijelu koji se odnosi na katalitičke cijevi parnog reformor postrojenja. Parna reformer peč (reformer) koja se nalazi u sklopu ovog postrojenja, postavljena je vertikalno i sastoji se od jedne, ili više radijacionih komora. Na sl.1, prikazana je šema reformera manjeg kapaciteta sa jednom radijacionom komorom. Osnovu konstrukcije svakog reformera čine katalitičke cijevi u kojima se odvijaju veoma složene endotermne termohemijske katalitičke reakcije, po kojima se ova postrojenja i nazivaju katalitičkim postrojenjima.

U drugom dijelu, opisana je problematika rada parnih kotlova i turbina i moguća oštećenja na kritičnim komponentama ovih postrojenja, isparivačkim i pregrijačkim cijevima, kolektorima, parovodima, lopatica turbina, itd. Kotlovsko-turbinska postrojenja su vrlo složena postrojenja i za njihov normalan rad potrebno je obezbijediti niz preduslova. Centralno mjesto u okviru ovih postrojenja zauzimaju parni kotlovi i parne turbine, koji se prilikom ugradnje i montaže prvi postavljaju i podešavaju na betonske temelje, nakon čega se postavljaju cjevovodi, mjerna, kontrolno-regulaciona i sva ostala oprema. Opisani su samo neki problemi koji se odnose na industrijske parne kotlove i turbine koji rade kontinuirano u sklopu i za potrebe rafinerijskih procesnih postrojenja, (izuzev za vrijeme redovnog godišnjeg pregleda-remonta, ili kvara).

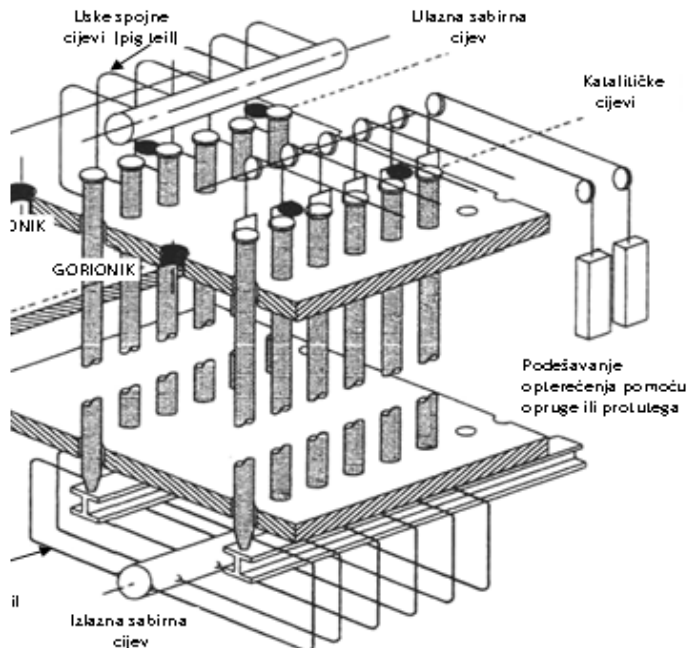
2. KATALITIČKA POSTROJENJA

Katalitičke cijevi

Katalitičke cijevi kao glavne komponente reformera, sl.1, rade u veoma složenim eksploatacionim uslovima. Reformeri zauzimaju centralno mjesto u sastavu tehnološkog postrojenja za proizvodnju vodonika. Oblici konstrukcije reformera mijenjali su se u cilju poboljšanja energetskog stepena iskorištenja, a posebno kako bi se riješili neki ozbiljni problemi koji su prisutni u eksploataciji ovih postrojenja. Tako su kod konvencionalnih postrojenja gasni gorionici koji služe za zagrijavanje (loženje peći) postavljeni horizontalno, sa bočnih strana peći. Zagrijavanje unutrašnjosti reformera i procesnog medijuma u katalitičkim cijevima, odvija se pomoću većeg broja gasnih gorionika s ciljem da se obezbijedi ravnomjerna raspodjela toplote po unutrašnjosti komora reformera. Gorionici se ugrađuju na bočne zidove reformera u horizontalnim redovima, u više nivoa po visini s ciljem da se obezbijedi stepenasta regulacija loženja, a kod savremenijih reformera sa gornje i donje strane (sl.1).

U sklopu reformera, pri vrhu u konvekcionoj zoni, ugrađuje se parni kotao koji za zagrijavanje vode i dobijanje pregriježane pare koristi toplotu nastalu sagorijevanjem pogonskog gasa na gorionicima, prirodni gas s minimalnim procentom sumpora, sastavljen od smjese gasova (vodonika, metana i drugih ugljenikovodonika). Ulazni medijum u katalitičke cijevi je procesni gas sastavljen od vodonika i raznih ugljenikovodonika s tehnoloških postrojenja za preradu nafte i pregrijana para temperature ~ 410 °C i pritiska 14 bara. Na izlazu iz cijevi pri radnoj temperaturi 780-800 °C, nakon katalitičke reakcije, nastaje vodonik kao glavni proizvod, ugljen-dioksid, ugljen-monoksid i vrlo male količine metana ($CH_4 \leq 1$). Vodonik se zajedno sa ostalim produktima dalje odvodi na hladnjak, zatim na konvertor visokog i niskog pritiska, pranje uz pomoć MEA i na kraju na reaktor-metanator. Kapaciteti reformera, količina proizvedenog vodonika u m^3/sat ili m^3/dan se razlikuju zavisno od potreba, oblika i konstrukcije reformera.

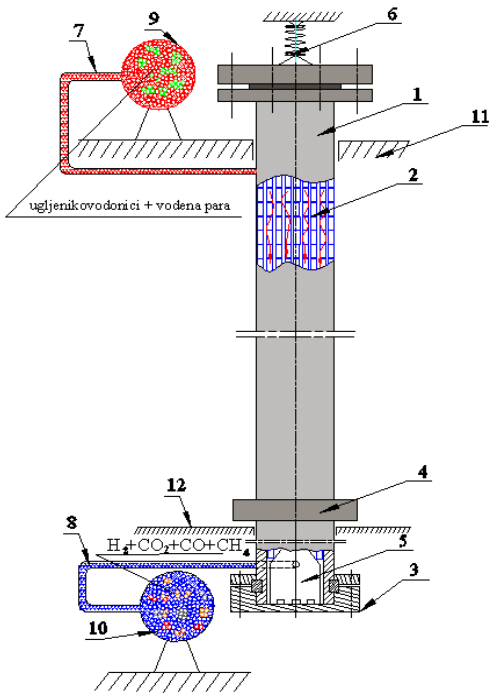
Na sl.1, prikazana je šema savremenog reformera manjeg kapaciteta koji umjesto opruga za elastičnu podesivu vezu koristi protutegove.



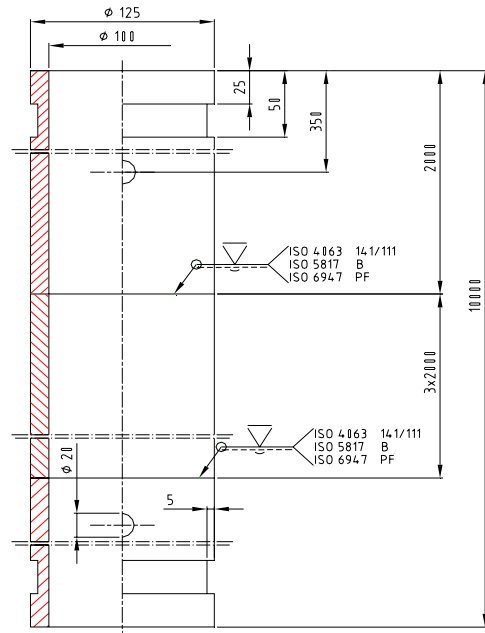
Sl. 1 Pojednostavljena šema parnog reformera [1, 2]

Kao što je već poznato, u radu reformera (parnog reforming postrojenja) najkritičnije komponente su katalitičke cijevi. One su skupe, a njihova zamjena je vrlo zahtjevna. Cijevi rade u složenim uslovima, jer su izložene uticajima veoma visokih radnih temperatura i pritisaka. Zbog ekstremnih temperaturnih uslova, ovdje su kao materijali za katalitičke cijevi potrebni visokolegirani čelici. Kod njih se sa povećanjem čvrstoće smanjuje duktilnost. Legure koje se koriste se ne mogu lako izvući ili ekstrudovati, zato se koriste livene strukture, najčešće HK i HP nivoa kvaliteta, standard ASTM. Centrifugalni livovi se sada uglavnom koriste, pošto je njihova struktura više ujednačenija i zrnca su im orijentisana u radijalnom pravcu, dajući čeliku veću čvrstoću i veću otpornost prema nastajanju prslina. Hemijski sastav legure HK-40, definisan je standardima: ASTM (A 297, A 351, A 567, A 608), DIN (G-X 40CrNiSi 25-20), AISI 310, a mehaničke osobine prema standardu ASTM A 297.

Osnovu konstrukcije nekog reformera čine katalitičke cijevi prečnika 100 do 200 mm, debljine stijenke od 10 do 25 mm i dužine cijevi od 10 do 20 m [1, 2]. Smještene su vertikalno u redove (kolone), u jednoj ili više komora. Dva reda cijevi čine jednu radijacionu komoru, sl.1. Na sl. 2, prikazana je pojednostavljena šema jedne eksploatisane katalitičke cijevi sa punjenjem-katalizatorom, priključnim vodovima i tokom procesnog medija [1], a uzdužni presjek ove katalitičke cijevi, veličina, oblik i dimenzije, dat je na sl. 3.



Sl. 2 Šema katalitičke cijevi, priključni vodovi i tok procesnog medija



Sl. 3 Uzdužni presjek katalitičke cijevi veličina, oblik i dimenzije [1]

1. Katalitička cijev; 2. Katalizator (punjenje cijevi); 3. Prirubnica; 4. Čelični prsten, oslonac; 5. Izlazna komora (oblik čahure); 6. Elastična podesiva veza; 7. Dovodna cijev procesnog medija; 8. Odvodna cijev procesnog medija; 9. Gornji - ulazni kolektor; 10. Donji - izlazni kolektor; 11. Gornji strop - krov reformera; 12. Podnica reformera.

U kolektoru (9) vodena para prikazana je crvenom, a smjesa ugljenikovodonika zelenom bojom. Kolektor (10), oko: 79 % H_2 (plava), 12% CO_2 (narandžasta), 8% CO (siva) i 1% CH_4 (crvena).

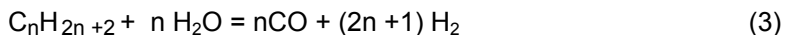
Katalitičke cijevi (1) se u eksploataciji, zajedno sa punjenjem (katalizatorom), oslanjaju na dva oslonca. Gornji dio cijevi je preko podesive elastične veze (6) povezan sa krovnim nosačem (11), a donji dio cijevi se oslanja preko čeličnog prstena (4) na podnicu reformera (12). Kada reformer nije u radu tada se raspon između donjeg oslonca-čeličnog prstena katalitičke cijevi (4) i podnice reformera-čelične ploče (12), odnosno ukupno opterećenje cijevi, težina cijevi zajedno sa punjenjem-katalizatorom (2), podesi pomoću elastične veze i zavrtnja, na raspon koji je potreban da u radu donji oslonac primi na sebe pola ukupnog opterećenja katalitičke cijevi. Proračunato istezanje katalitičke cijevi (dužina cijevi je 10 m) u eksploataciji je 150 mm. Svrha opružnih nosača je da prime sile istezanja u cijevima za vrijeme eksploatacije da bi spriječili prekomjerno savijanje cijevi. Opruge su tako podešene da se okretanjem zavrtnja obezbijedi da one nose ukupno opterećenje (težinu cijevi i njeno punjenje-katalizator) u "hladnom" stanju. U eksploataciji katalitičke cijevi se pomoću donjeg oslonca - prstena oslanjaju na čeličnu ploču, podnicu reformera i šire se prema

gore. Dio opterećenja katalitičke cijevi (50 % ukupne težine) prima na sebe podnica reformera preko čeličnog prstena. Iz ulaznog kolektora (9) se procesni medij preko tankih savitljivih cijevi (7) prečnika 3/4" (pig-tail, materijal incolloy 800) dovodi u katalitičku cijev, a pomoću istih takvih cijevi (8) se procesni medij odvodi u izlazni kolektor (10). Zbog složenih katalitičkih reakcija koje se odvijaju u katalitičkim cijevima pri visokim temperaturama, veoma je važno da odnos vodene pare i ugljenika bude odgovarajući.

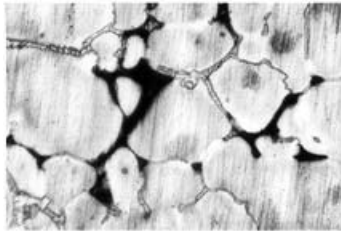
Ako se proces odvija sa čistim butanom, obično u fazi kretanja postrojenja, taj odnos mora biti manji od 6, a ako smjesu čine razni ugljenikvodonici taj odnos ne bi smio biti manji od 5, jer bi se u protivnom sadržaj metana znatno povećao. U tom slučaju došlo bi do stvaranja čađi na katalizatoru i pojave ozbiljnih oštećenja katalizatora u obliku lokalnih pregrijanja stijenke cijevi. Veoma bitan uslov je da sadržaj metana bude $\text{CH}_4 \leq 1\%$ [5]. Kod nekih drugih postrojenja za proizvodnju vodonika u svijetu dozvoljen je nešto veći sadržaj metana. Ovaj odnos može da ne bude u propisanim vrijednostima zbog: a) neodgovarajućeg odnosa $\text{H}_2\text{O}/\text{C}$, b) niže radne temperature u cijevima, c) loše raspodjele temperatura u katalitičkim cijevima.

Povećanje sadržaja metana (CH_4) iznad propisane vrijednosti ukazuje da je došlo do smanjene aktivnosti katalizatora, a što može dovesti do trovanja od sumpora. Ako se stanje ne popravi dodavanjem veće količine pare u periodu od najviše 24 h, mora se obavezno obustaviti postrojenje i zamijeniti katalizator. Rukovaoci postrojenja moraju prije svega količine metana držati u propisanim granicama ($\text{CH}_4 \leq 1$), jer kod prekoračenja podižu radnu temperaturu kako bi povećali aktivnost katalizatora. Ova pojava predstavlja tešku opasnost, jer može uzrokovati teška oštećenja i havarije.

Utvrđeno je, takođe, da prekoračenje radnih temperatura u eksploataciji katalitičkih cijevi značajno umanjuje vijek eksploatacije [1, 2]. Ugljenikvodonici se miješaju s pregrijanom parom prije ulaza u katalitičke cijevi. U dodiru sa katalizatorom ugljenikvodonici se oksidiraju sa kiseonikom iz vode dajući gas koji se sastoji od H_2 , CO_2 , CO i vrlo male količine CH_4 . Katalizatori su hemijske komponente kojima je zadatak samo da potmožu hemijske reakcije, odnosno da smanje energetski nivo na onaj u kojima su moguće sljedeće hemijske reakcije:



Katalitičke cijevi su u radu pri visokim temperaturama sklone senzitivizaciji (taloženje Cr_{23}C_6 i dr. krutih faza (sigma faza) na granici zrna i pojavi "podmukle" i daleko najopasnije interkristalne korozije, a u sadejstvu napona i naponske korozije koja uzrokuje iznenadna i veoma teška oštećenja cijevi reformera. Najčešća oštećenja koji se mogu pojaviti na kritičnim komponentama reformera su na katalitičkim cijevima, izlaznim pig-teilovima i kolektorima. Mehanizmi oštećenja na katalitičkim cijevima se pojavljuju u obliku: puzanja materijala, puzanja na zavarima, iskrivljenja cijevi i razugljenisanja materijala. Na izlaznim pig-tailima se može pojaviti puzanje materijala, razugljenisanje, nisko ciklično, visoko temperaturno puzanje – zamor. Na izlaznom kolektoru najčešća oštećenja su u obliku puzanja materijala i nisko ciklično, visoko temperaturno puzanje-zamor. Na sl. 4 prikazana je mikrostruktura katalitičke cijevi reformera s prisutnom interkristalnom korozijom [1, 3].



Sl. 4 Mikrostruktura katalitičke cijevi s prisutnom interkristalnom korozijom (Uvećanje 400 x) [1, 3]

Mikrostrukturno stanje materijala je austenitno uz prisustvo karbidnih segregata u vidu karbidnih traka, smeštenih po granicama austenitnih zrna. Karbidi iz karbidnih segregata bogati su Cr, tako da od osnovne mase sa kojom su u dodiru oduzimaju Cr, pri čemu sadržaj Cr u njoj opada ispod granice korozione otpornosti. Usled gore navedenog, a pod dejstvom korozivnih sredstava i pomanjkanja stabilizirajućih elemenata poput Nb došlo je do interkristalne korozije.

3. KOTLOVSKO-TURBINSKA POSTROJENJA

Kao što je već navedeno u uvodnom dijelu, ova postrojenja rade u veoma složenim eksploatacionim uslovima: visokih radnih temperatura i pritisaka pregrijane vodene pare, agresivne sredine, dugotrajnog neprekidnog rada sa velikim opterećenjima, itd. Kako tehnološka postrojenja za preradu nafte u rafinerijama rade neprestano tokom cijele godine, osim u vrijeme redovnog godišnjeg pregleda-remonta, to i kotlovska-turbinska postrojenja koja snabdjevaju proizvodno-tehnološka postrojenja električnom energijom, tehnološkom parom (npr. I- oduzimanje pare turbine, ~ 15 bara), ili grejnom parom (za grijanje šarže, kontrolnih sala i poslovnih i drugih prostorija (npr. II-oduzimanje pare turbine, ~ 6 bara) prate rad ovih postrojenja.

Poslije prvog i drugog oduzimanja sa parne turbine preostala para se kondenzuje u kondenzatoru koji je smješten ispod turbine, a kondenzat se pomoću kondenz-pumpi doprema ponovo u kotao. Danas je proizvodnja parnih kotlova znatno usavršena, u pogledu primjene novih materijala, stepena automatizacije, vijeka eksploatacije, te povećanja termoenergetskog stepena iskorištenja, kapaciteta proizvedene pregrijane vodene pare, itd. Parni kotlovi se dijele prema stepenu pregrijanosti vodene pare, radnim pritiscima i temperaturama pregrijane pare, vrsti goriva, stepenu automatizacije, načinu cirkulacije vode u cijevima kotla, itd. Prema načinu iskorištenja pregrijane pare parne turbine se dijele na: akcione, reakcione, kombinovane, prema broju stepeni turbine na jednostepene i višestepene, prema načinu strujanja pare u turbini na: aksijalne, radijalne i kombinovane, prema namjenskom zadatku na: turbine visokog pritiska pare i velike snage, industrijske turbine i pomoćne turbine, itd. Industrijske parne turbine se koriste za različite potrebe u industriji. Za pogon električnih generatora u Elektranama i velikih ratnih brodova služe parne turbine i turbinska postrojenja sastavljena od više turbina koji su u paralelnoj vezi (blokvske kotlovska-turbinske jedinice). Parne turbine su se do sada pokazale kao najbolji transformatori hemijske energije goriva u mehaničku energiju (mehanički rad). Parne turbine se mogu po mnogo čemu svrstati u red najsloženijih i najsavršenijih pogonskih mašina uopšte, s veoma visokim stepenom sigurnosti u radu.

Parne turbine, naročito one većih pritisaka, temperatura i snaga su po mnogo čemu specifične i imaju visok stepen termoenergetskog iskorištenja. Primjer, dvije potpuno nove industrijske parne turbine istih karakteristika (snage 12 MW) i od istog proizvođača imaju neke svoje specifične razlike u eksploataciji. Eksploatacioni vijek pravilno održavanih parnih turbina je oko 30 godina. Greške stručnog osoblja koje opslužuje i nadzire rad kotlovsko-turbinskog postrojenja su nedopustive, ali se ipak dešavaju i dovode do oštećenja i havarija na postrojenjima s teškim materijalnim, a ponekad nažalost i ljudskim posljedicama. Svako puštanje u rad i obustava ovih postrojenja se odvija prema dijagramu puštanja u rad i prema pisanim upustvima od strane proizvođača, koja se nalaze na vidnom i dostupnom mjestu na tim postrojenjima. Strojari kotlova i turbina moraju da imaju položene stručne ispite. Remont-redovni godišni pregled postrojenja, izvodi se jednom godišnje, a izvode ga, isključivo, veoma stručni ljudi- monter i specijalisti. Oštećenja turbine mogu nastati usljed pogonskih uzroka, vodenih udara, nestručne montaže, greške konstrukcije, itd.

Lopatice turbine su najkritičnije komponente turbine, jer su teško opterećene djelovanjem pare, i rade u vrlo teškim uslovima: termičkog zamora, erozije, korozije, taloženja kamenca, itd. Pored konstrukcijskih nedostataka, grešaka u fazi montaže kotlovsko-turbinskih postrojenja, te nestručnog rukovanja, na ovim postrojenjima se mogu pojaviti i oštećenja koja nastaju usljed nekvalitetne napojne vode. Najčešće dolazi do smanjenog protoka, začepljenja cijevi ili lokalnog pregrijavanja i pucanja isparivačkih cijevi (ali i dalje u sistemu) koja nastaju usljed vrlo tvrdog kamenca koji nastaje taloženjem soli alkalnih i zemno-alkalnih elemenata, najčešće soli magnezijuma i kalcijuma. U cjevovodima kroz koje struji kondenzat može se pojaviti ugljenična kiselina koja nagrizava metal i ubrzava korozione procese. Ugljenična kiselina nastaje rastvaranjem ugljen-dioksida u vodi, ili upotrebom vode iz koje nije odstranjen kiseonik, ili vode koja sadrži bikarbonatne soli. Mjere za sprečavanje ovih pojava, sastoje se od odstranjivanja kiseonika iz vode (odplinjavanje napojne vode), alkalne neutralizacije, kao i svih potrebnih radnji koje se odnose na hemijsku pripremu vode. Tvrdoca napojne vode, pH, veoma je važna i mora se nalaziti u propisanim granicama. Radi toga se obično svaki sat rade hemijske analize vode, ali i sve ostale potrebne analize. Kiseonik može ući u sistem, ili sa napojnom vodom, ili u vakuum sistemu. Sa spoljašnje strane cijevi kotla, i drugih komponenti postrojenja (sa dimne strane), vodena para koja je u procesu sagorijevanja goriva nošena strujom dima reaguje sa sumpor-dioksidom pri temperaturi ~140 °C stvarajući sumporastu i sumpornu kiselinu i uzrokujući vrlo opasnu nisku temperaturnu koroziju. Zato se o ovome mora povesti posebno računa, odnosno da temperatura izlaznih dimnih gasova bude dovoljno visoka, naročito u slučajevima naglog rasterećenja kotla.

Kotlovsko-turbinska postrojenja zauzimaju centralno mjesto u proizvodnji električne energije. Tako se npr. u Njemačkoj proizvede oko 85% električne energije na kotlovsko-turbinskom postrojenjima [4]. Zbog opasnosti od eksplozije u radu ovih postrojenja i složenosti samih postrojenja, svaka zemlja donosi posebne propise iz ove oblasti. Generalno uzevši, većina dijelova na kotlovsko turbinskom postrojenju radi u veoma teškim uslovima rada. Najkritičnije komponente su ipak isparivačke i pregrijačke cijevi, kolektori i parovodi, a na parnoj turbini lopatice turbine.

Materijali za kritične komponente postrojenja

Od materijala za lopatice parnih turbina se zahtijeva da imaju dovoljnu čvrstoću pri visokim radnim temperaturama i dobru otpornost na hemijsku koroziju. Za lopatice

turbine koje rade u dijelu visokih temperatura i pritisaka pare u turbini (do 550 °C), koristi se čelik na bazi nikla, s 5% Ni, i nerđajući čelik sa 15% Cr. Kod većih snaga i kod visokih temperatura upotrebljava se legura na bazi nikla, bakra i željeza (~ 65% Ni, 28% Cu, 5% Fe i manje količine Mn, Li, i C) - monel legure. Kod manjih turbina u dijelu turbine sa srednjim i nižim temperaturama podesan je mesing (do 200 °C) [4].

U literaturi se mogu pronaći brojni podaci o novim materijalima koji se koriste za isparivačke i pregrijačke cijevi, parovode i kolektore. Razvoj novih materijala za kritične komponente kotlovsko-turbinskih postrojenja visoke i ultra visoke čvrstoće i povećane korozione otpornosti kreće se u dva osnovna pravca. Kod radnih temperatura do max. 600 °C pregrijane pare istraživanja su usmjerena na razvoj i primjenu feritnih čelika, a za temperature preko 600 °C istraživanja su usmjerena na razvoj i primjenu novih austenitnih čelika i legura na bazi nikla.

4. ZAKLJUČAK

Katalitička i kotlovsko-turbinska postrojenja rade u veoma složenim uslovima: visokih radnih temperatura, pritisaka, promjenjivih i veoma visokih radnih opterećenja, korozione agresije, termičkog zamora, itd. Kako se nuklearna postrojenja za proizvodnju električne energije postepeno "gase" zbog katastrofalnih havarija koje su se u novije vrijeme desile na njima, razvoj i primjena novih kotlovsko-turbinskih postrojenja velikih kapaciteta, snaga, visokih radnih parametara za proizvodnju električne energije, sve je prisutnija.

U procesnoj industriji i energetici prisutna je stalna tendencija za povećanjem energetske stepena iskorištenja. Kako se stepen energetske iskorištenja može efikasnije povećati jedino povećanjem radnih parametara, temperatura i pritisaka, to se razvoju i primjeni novih metalnih materijala na katalitičkim i energetskim postrojenjima daje poseban značaj. Stalno se usavršavaju konstrukcije izvedbe postrojenja, a zbog veoma složenih uslova u kojima rade katalitička i kotlovsko-turbinska postrojenja posebna pažnja se posvećuje obuci osoblja koje rukuje i nadzire rad ovih postrojenja.

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USPOSTAVLJANJE SISTEMA ENERGETSKE EFIKASNOSTI U SKLADU SA ZAHTJEVIMA EVROPSKOG STANDARDA EN ISO 50001

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Rezime: Cilj ovog rada je predstavljanje sistema energetske efikasnosti u skladu sa zahtjevima evropskog standarda EN ISO 50001, objavljenim 2011. godine. Sistem upravljanja energijom uključuje niz procesa, koji omogućavaju organizaciji da koristi podatke i informacije za održavanje i poboljšanje energetske efikasnosti. Povećanjem operativne efikasnosti i smanjenjem energetske intenziteta sa ekonomskog aspekta omogućava značajne finansijske uštede, dok sa ekološkog aspekta smanjuje emisiju štetnih gasova u okolinu. Standard EN ISO 50001:2011 osigurava sistem kroz koji organizacija može postaviti i provoditi svoje ciljeve za poboljšanje energetske efikasnosti. Zemlje Evropske unije imaju obavezu izrade Nacionalnog plana za energetske efikasnosti (NEEAP), koji predstavlja temeljni put za implementaciju projekta energetske efikasnosti u svim sektorima potrošnje energije. Nacionalni planovi bazirani su na EU Direktivi o energetske efikasnosti (2006/32/EC), koja ima za cilj uštedu energije od 9% u periodu do 2016. godine, tj. za devet godina njene primjene.

Ključne riječi: energetska efikasnost, standard, sistem energetske upravljanja, EN ISO 50001.

ESTABLISHING ENERGY EFFICIENCY SYSTEM IN ACCORDANCE WITH THE REQUIREMENTS OF EN ISO 50001

Abstract: *The aim of this paper is to present the energy efficiency system in accordance with the requirements of EN ISO 50001, published in 2011. Energy management system includes a series of processes that enable the organization to use data and information for maintenance and improvement of energy efficiency. From the economic aspect, increasing operational efficiency and reducing energy intensity provides a significant financial savings, while from the environmental aspects, is reducing the emission of greenhouse gases into the environment. Standard EN ISO 50001:2011 provides a system through which an organization can set up and implement their goals for improvement of energy efficiency. The European Union countries are obliged to develop a National Energy Efficiency Action Plan (NEEAP), which represents a fundamental way to implement energy efficiency projects in all sectors of energy consumption. National plans are based on EU Directive on Energy Efficiency (2006/32/EC) which aims at saving energy for 9% till 2016, namely for nine*

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years on its implementation. Furthermore, European Union set for itself the following objectives to be achieved by 2020: reducing emissions of greenhouse gasses for at least 20%, improvement of energy efficiency by 20% and increasing the share of renewable energy sources up to 20%.

Keywords: energy efficiency, standard, energy management system, EN ISO 50001.

1. UVOD

Danas se svijet suočava s dva velika energetska problema. Prvi je nedostatak energije i nesigurnost u snabdijevanje, a drugi zagađenje okoline, te klimatske promjene uzrokovane prevelikom neracionalnom potrošnjom energije. Danas se energija većim dijelom dobija iz neobnovljivih izvora energije i svakim danom zalihe su sve manje, što recipročno povećava cijenu energenata i stepena zagađenja okoline. Proizvodnja, distribucija i potrošnja energije direktno ili indirektno utiču na socijalni i ekonomski napredak svake pojedine zemlje. Međutim, danas postoje velike energetske potrebe koje treba da se zadovolje a direktno utiču na socijalne, ekološke, ekonomske i sigurnosne aspekte korištenja energije. Ovaj problem prepoznale su prvenstveno razvijene zemlje koje su ustanovile da dosadašnji nekontrolisani pristup potrošnje energije nije održiv. Prioritet treba dati održivoj potrošnji energije kroz racionalno planiranje same potrošnje, te kroz implementaciju mjera energetske efikasnosti u sve segmente energetske sistema određene zemlje. Cijene energije i energenata će zbog globalnih i lokalnih razloga u narednom periodu i dalje rasti, što će direktno uticati na porast troškova života i poslovanja [2]. Međunarodna organizacija za standardizaciju (*International Organization for Standardization, ISO*) razvila je standard ISO 50001:2010, Sistemi energetske upravljanja – Zahtjevi sa uputstvom za korištenje (*Energy management systems - Requirements with guidance for use*), koji će pomoći organizacijama da upravljaju energetske efikasnošću sa ciljem smanjenja troškova energenata, smanjenja emisije štetnih gasova, veće društvene odgovornosti, boljeg imidža u zajednici kod kupaca i dobavljača. Takođe, navedeni standard je u identičnom obliku prihvatio i Evropski komitet za standarde (*European Committee for Standardization CEN*) kao EN ISO 50001:2011.

2. ENERGETSKA EFIKASNOST

Energetska efikasnost je niz isplaniranih procesa i provedenih mjera čiji je cilj korištenje minimalno moguće količine energije, tako da nivo udobnosti i stopa proizvodnje ostanu očuvani. Jednostavno rečeno, energetska efikasnost jeste upotreba manje količine energije za obavljanje istog posla, odnosno funkcije (grijanje ili hlađenje prostora, rasvjeta, proizvodnja različitih proizvoda, pogona vozila, itd.) [2].

Bitno je napomenuti da se energetska efikasnost nikako ne smije posmatrati kao štednja energije, jer štednja uvijek podrazumijeva određena odricanja, dok efikasna upotreba energije nikada ne narušava uslove rada i uslove života [2]. Ovdje je važno naglasiti da poboljšana efikasnost upotrebe energije rezultira njenom smanjenom potrošnjom za istu količinu proizvoda ili usluge, što konačno donosi novčane uštede.

Energetska efikasnost je osnovni element u borbi protiv klimatskih promjena. Dobijena energija iz neobnovljivih izvora nekontrolisanim sagorijevanjem fosilnih goriva ugrožava atmosferu, što ima za posljedicu izazivanje klimatskih promjena. Zbog toga

su zemlje članice Evropske unije (EU) razvile politiku zaštite životne sredine i održivog razvoja. Ključni elementi te politike su preventivne akcije i podjela odgovornosti [6].

Smanjenje korištenja energije i eliminisanje zagađenja životne sredine, koje je posljedica energetske transformacije, spadaju u glavni ciljeve energetske politike. EU pomaže implementaciju energetske efikasnosti na način da se obezbijedi konkurentnost, sigurnost snabdijevanja i preuzima obaveze predviđene Kjoto protokolom [2]. Određeni potencijal za smanjenje potrošnje je nesumnjivo prisutan, posebno u energetske intenzivnim sektorima kao što su zgrade, proizvodnja, konverzija energije i transport.

Energetska efikasnost u EU

Zemlje EU su energetske efikasnosti prepoznale kao jedan od ključnih načina za postizanje ciljeva održivog energetske razvoja kao i smanjenje emisije gasova sa efektom staklene bašte i drugih zagađujućih materija, što je Evropska komisija (European Commission, EK) i iskazala u svojim strateškim dokumentima, od kojih su najvažniji [4]:

- Akcijski plan energetske efikasnosti;
- Energija 2020;
- Plan energetske efikasnosti.

U cilju integrisanja energetske efikasnosti u nacionalne zakonske okvire i primjene politike energetske efikasnosti u državama članicama, Evropska komisija je pripremila i objavila ključne EU direktive iz ove oblasti:

- Direktiva o efikasnostima korištenja krajnje energije i energetske usluga (2006/32/EC) [4]

Navedena Direktiva daje niz obaveznih zahtjeva, kao što su :

- usvajanje i implementacija nacionalnih planova o energetske efikasnosti NEEAP;
- mjere za javni sektor;
- obaveze za distributere energije, itd;

Ovo je osnova za zakon o energetske efikasnosti. Zakon o energetske efikasnosti nije eksplicitan zahtjev Direktive, ali je najjednostavniji način da se ona prenese u nacionalno zakonodavstvo. Kako bi se ova Direktiva implementirala, mora biti prilagođen veliki broj regulativa, tehničkih standarda i akcija podrške.

- Direktiva o energetske karakteristikama zgrada (2010/31/EC) [4]

Najvažniji zahtjevi Direktive 2010/31/EC su sljedeći:

- Države članice dužne su uspostaviti metodologiju za izračunavanje integralnih energetske karakteristika zgrada, koja će biti u skladu sa opštim okvirom datim u Dodatku 1 Direktive, za nacionalni i regionalni nivo;
- Države članice su dužne uspostaviti svoje minimalne standarde energetske efikasnosti za zgrade i dijelove zgrade, koji imaju značajan uticaj na potrošnju energije. Pri tome, mogu se uspostaviti različiti zahtjevi za nove i postojeće zgrade kada se obnavljaju, a također se diferencijacija može izvršiti i prema tipovima zgrada;
- Direktiva o označavanju proizvoda koji troše energiju i standardne informacije o proizvodu (2010/30/EC) [5]

Ovom direktivom provodi se energetska označavanja na sve proizvode koji su vezani za energiju, a koji imaju značajan direktan ili indirektan uticaj na potrošnju energije. Uveden je novi sistem označavanja koji omogućava da se potrošači detaljno informišu.

Energetska efikasnost u BiH

Početakom 2008. godine izrađena je „Studija energetskega sektora BiH“ kojom se izvještava o rezultatima provedenih analiza, daju preporuke za reformu i jačanje energetskega sektora. Na osnovu provedene studije izrađene su i usvojene entitetske strategije razvoja energetskega sektora u BiH. Da bi se uspostavila energetska efikasnost u BiH, jedan od ključnih procesa je transpozicija i implementacija EU direktiva, što se ogleda u sljedećem [6]:

- Izrada Zakona o energetskega efikasnosti u BiH, (osnova za izradu ovog zakona je EU Direktiva 2006/32/EC);
- Izrada Nacionalnog plana o energetskega efikasnosti u BiH;
- Transpozicija i implementacija Direktive o energetskega karakteristikama zgrada (2010/31/EC)
- Transpozicija i implementacija Direktive o označavanju proizvoda koji troše energiju i standardne informacije o proizvodu (2010/30/EC);
- Izrada podzakonskih akata kojima bi se definisali nadležnosti, dužnosti i kaznene odredbe.

Na osnovu navedenog, može se zaključiti da je zakonska regulativa iz oblasti energetskega efikasnosti u Bosni i Hercegovini nepotpuna i da u proteklom periodu nije urađeno mnogo. Bosna i Hercegovina teži integrisanju u Evropsku uniju i kao zemlja članica Energetskega zajednice ima obaveze usklađivanja svoje zakonske regulative sa zahtjevima EU direktiva.

3. ENERGETSKO UPRAVLJANJE

Cilj energetskega upravljanja je uspostavljanje energetskega efikasnosti i uvođenje obnovljivih izvora energije. Energetskega upravljanje u opštem smislu predstavlja upravljanje parametrima energetskega tokova unutar neke organizacije, od procesa proizvodnje i nabavke energenata ili energije, preko procesa transformacije, sve do finalnog korištenja energije. Pri tome se pod pojmom parametara energetskega tokova podrazumijevaju različiti kvantitativni i kvalitativni parametri kojima se može opisati neki od navedenih procesa s tehničkog, ekonomskog i socijalnog aspekta, kao i s aspekta zaštite životne sredine [7]. Ako se ovako definisano upravljanje energetskega tokovima vrši organizovano, strukturirano, sistematično i trajno, onda u organizaciji postoji uspostavljen sistem energetskega upravljanja.

Sistemi energetskega upravljanja mogu biti veoma različiti po strukturi, obimu i složenosti, zavisno od toga na kojem se nivou uspostavljaju: nacionalnom, regionalnom, lokalnom ili na nivou same organizacije [7]. U svakom slučaju, sistem energetskega upravljanja predstavlja dio ukupnog sistema upravljanja državom, opštinom, firmom, kao takav uspostavljen unutar organizacione strukture definiše odgovornosti, aktivnosti, procedure i potrebne resurse za ostvarivanje unaprijed postavljenih ciljeva politike u oblasti energetike, a to su: [7]

- Obezbeđenje optimalnog i sigurnog snabdijevanja energentima i energijom,
- smanjenje potrošnje energije i troškova nabavke energije uz zadržavanje optimalnog nivoa usluga,
- stvaranje uslova da što većem broju korisnika budu dostupni i pristupačni različiti energenti (toplotna energija, gas, električna energija, obnovljivi izvori energije),
- smanjenje negativnog uticaja na životnu sredinu koje je nastalo korištenjem energije iz neobnovljivih izvora,
- upotreba obnovljivih izvora energije uz maksimalno korištenje resursa,
- promovisanje nove energetske tehnologije,
- integracija u postojeći sistem upravljanja u skladu sa standardima ISO 9001:2008, *Sistemi upravljanja kvalitetom – Zahtjevi*, ISO 14001, *Sistemi okolinskog upravljanja - Zahtjevi sa smjernicama za upotrebu* i OHSAS 18001, *Sistemi upravljanja zdravljem i sigurnošću na radu – Zahtjevi*.

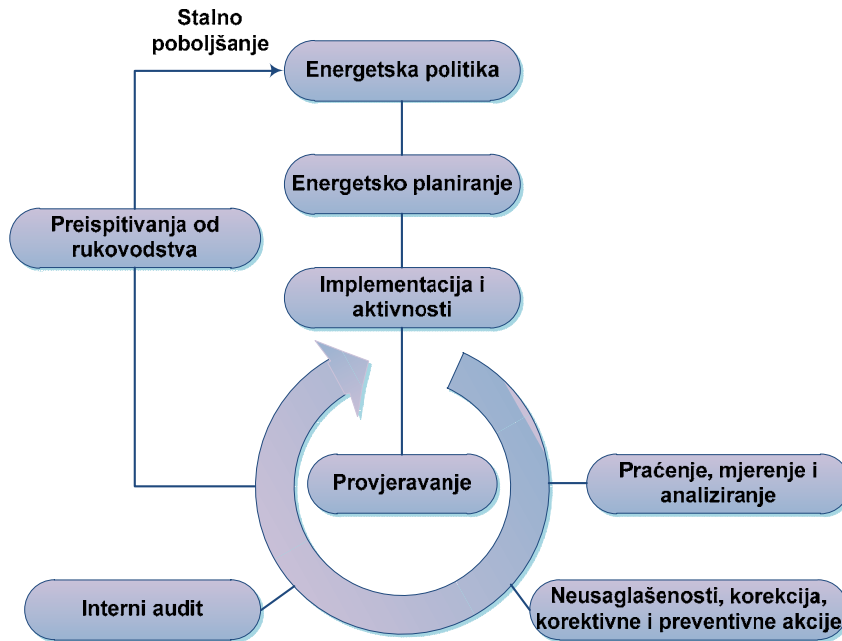
4. ZAHTJEVI STANDARDA EN ISO 50001

ISO 50001 je dobrovoljni međunarodni standard koji je razvila Međunarodna organizacija za standardizaciju (ISO), koji pruža organizacijama međunarodno priznate okvire za upravljanje i poboljšanje energetske efikasnosti. Standard je primjenljiv na sve vrste organizacija, bez obzira na veličinu i vrstu djelatnosti. Uspostavljanje energetskog upravljanja ne smije se smatrati troškom, nego investicijom. Prednosti uvođenja sistema energetskog upravljanja su sljedeće [1]:

- upravljanje potrošnjom i troškovima energenata;
- uštede realizacijom programa;
- smanjenje negativnog uticaja na okolinu;
- dokumentacija za praćenje potrošnje energenata kojom se može svim zainteresovanim stranama dokazati ušteta;
- bolji imidž preduzeća prema klijentima, poslovnim partnerima i zajednici;
- povećanje svjesnosti o aspektu energije među zaposlenicima;
- kompetitivna prednost na tenderima.

Opšti zahtjevi standarda:

- uspostavljanje, dokumentovanje, održavanje i poboljšavanje sistema energetskog upravljanja;
- definisanje i dokumentovanje područja primjene i granice sistema energetskog upravljanja;
- ispunjavanje zahtjeva ovog međunarodnog standarda u cilju postizanja stalnog poboljšanja energetske performansi.



Sl. 1 Model sistema upravljanja energijom [1]

Odgovornost rukovodstva

Rukovodstvo organizacije mora da pokaže svoju posvećenost kroz pružanje podrške uspostavljanju sistema energetskog upravljanja, kroz definisanje, uspostavljanje i primjenu energetske politike, imenovanje predstavnika rukovodstva i tima za energetsko upravljanje, obezbjeđivanje neophodnih resursa, ustanovljavanje ciljeva i zadataka, razmatranje energetske efikasnosti sa dugoročnim planiranjem [1].

Energetska politika

Rukovodstvo organizacije mora definisati energetska politiku koja mora da sadrži sljedeće [1]:

- definisan obim korištenja i potrošnje energije;
- stalno poboljšanje energetske efikasnosti;
- dostupnost informacijama i neophodnim sredstvima za postizanje ciljeva i zadataka;
- zahtjeve važećih zakona i drugih zahtjeva koje je propisala organizacija koji se odnose na korištenje energije, potrošnje i efikasnosti;
- okvir za postavljanja i preispitivanja energetskih ciljeva i zadataka;
- kupovinu energetski efikasnih proizvoda i usluga;
- dokumentaciju dostupnu na svim nivoima u organizaciji;
- redovno pregledanje i ažuriranje po potrebi.

Energetsko planiranje

Organizacija mora dokumentovati i sprovoditi procese energetske planiranja. Energetsko planiranje treba da bude u skladu sa energetske politikom i treba da dovede do aktivnosti koje kontinuirano poboljšavaju energetske performanse unutar organizacije. U sklopu energetske planiranja organizacija mora da [1]:

- izvrši analizu i implementira zakonske i podzakonske zahtjeve koji su vezani za energiju, potrošnju energije i energetske efikasnosti;
- sprovodi, razvije, evidentira i održava energetske pregled. U sklopu energetske pregleda vrši se analiza potrošnje energije, identifikuju se potrošači (objekti, oprema, sistemi, procesi), određuje trenutna energetska efikasnost i dr.;
- uspostavi energetske polazne osnovu, koja predstavlja podatke iz prvog energetske pregleda, i sve promjene u energetske efikasnosti se mjere u odnosu na energetske polazne osnovu;
- utvrdi energetske pokazatelje za praćenje i mjerenje energetske efikasnosti;
- utvrdi, implementira i dokumentuje energetske ciljeve u skladu sa akcionim planom.

Implementacija i aktivnosti

Implementacija i aktivnosti se sprovode u skladu sa akcionim planom. Organizacija mora definisati nadležnosti, sprovoditi obuke i savjetovanje zaposlenih, kako bi svi zaposleni bili upoznati sa važnostima primjene energetske politike, njihovom ulogom u procesu energetske upravljanja, poboljšanjem energetske efikasnosti i dr. Proces energetske upravljanja mora biti dokumentovan i sadržavati sljedeće [1]:

- energetske politiku;
- energetske ciljeve i akcioni plan;
- sve neophodne dokumente u zavisnosti od veličine organizacije, složenosti procesa i vrste aktivnosti.

U procesu uspostavljanja energetske upravljanja svi procesi moraju biti kontrolisani putem kontrolnih dokumenata [1]. Organizacija mora razmatrati mogućnosti energetske poboljšanja performansi i sprovoditi operativnu kontrolu kod projektovanja novih i renoviranja postojećih objekata, uvođenja nove opreme, sistema i procesa, koji mogu imati značajan uticaj na energetske performanse.

Provjeravanje

Organizacija mora da definiše kontrolne tačke kako bi mogla da prati, mjeri i analizira energetske performanse svog sistema.

U cilju održavanja uspostavljenog sistema upravljanja energijom, provođenja energetske ciljeva i analize stanja, organizacija mora provoditi interne audite. Nakon provedenog internog audita, organizacija treba da razmotri potencijalne neusaglašenosti, izvrši analizu i preduzme korektivne i preventivne mjere. Proces provjeravanja mora biti dokumentovan.

Preispitivanja od rukovodstva

Proces preispitivanja od rukovodstva se provodi u skladu sa dokumentovanom procedurom sa ciljem da se obezbijedi kontinuitet provođenja energetske politike i ostvarivanja postavljenih ciljeva. Sve aktivnosti prati proces „Planiraj-Uradi-Provjeri-Djeluj“ za stalno poboljšanje sistema energetskeg upravljanja [1].

5. ZAKLJUČAK

Energetska efikasnost je vrlo važna, a u budućnosti će biti još i važnija. Da bi se postigla energetska efikasnost, Bosna i Hercegovina se mora prilagoditi novim EU zakonskim okvirima, novim izvorima energije i novim načinima uštede energije. Bosna i Hercegovina značajno zaostaje za zemljama regiona u uspostavljanju politike energetske efikasnosti i stvaranju zakonske regulative za podsticanje energetske efikasnosti. Povećanjem energetske efikasnosti u organizacijama u Bosni i Hercegovini, kroz implementaciju sistema energetskeg upravljanja, mogu se ostvariti značajne finansijske uštede, koje mogu biti uložene u daljni razvoj organizacije, a samim tim i u nova zapošljavanja stanovništva. Budući da je ovaj standard tek objavljen, očekuje se da će uskoro pobuditi veliki interes i u našoj zemlji.

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RISK ASSESSMENT IN NATURAL GAS TRANSMISSION SYSTEM

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Summary: In this paper some experiences in risk assesment of workplaces in company GA-MA Ltd Skopje are described. On the basis of results obtained by processing of prepared check lists, and results from the measurements of microclimate parameters and physical hazards, identification of present risks and hazards were done. The risk assessment was performed using the software package LatiPRO. After defining the level of risk, measures for prevention, reduction and elimination of risks at workplaces where increased risk was found were recommended.

Key words: occupational risk assessment, risks, hazards

1. INTRODUCTION

Safety and health at work is a very important issue for every employer, regardless of the scope of works of the company. This segment of labour in Republic of Macedonia is regulated from the year 2007 when the Law on Safety and Health at Work [1], was adopted. The essence of the Law on Safety and Health at Work is the protection of workers based on the application of preventive measures, in order to create a safer and healthier workplace. Particular attention must be dedicated to the risk assessment. Risk assessment for each workplace, as well as developing and implementing the concept of safety is the initial declaration and the basic step in the process of risk management for workplaces and work environment. They must be developed in accordance with the Law on Safety and Health at Work, [1], and on the basis of the Rulebook on the manner of making safety statement, its contents and the information on which the risk assessment [2], should be based.

The main professional activity of company GA-MA Ltd is natural gas transmission and natural gas pipeline system management in the Republic of Macedonia. The natural gas transmission system in the Republic of Macedonia is part of the Russian transit natural gas pipeline which passes through Ukraine, Romania and Bulgaria, and is intended for Turkey, Greece, Serbia and Montenegro. The high pressure part of the gas pipeline system has been designed for annual physical capacity of 800 million m_N^3 of natural gas at working pressure of 40 bar. The main measuring station (MMS) is located in the place called Zidilovo and has capacity of

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240.000 Nm³/h. The projected pressure in the constructed gas pipeline may be above 54 bar.

On the line part, accompanying facilities have been built, among which a launching and receiving station, 8 block valve stations, 8 block valve stations for distribution system and a cathode protection system. There are 5 main measuring – regulating stations (MMRS) in the high pressure part. These stations connect the high pressure part with the low pressure – distribution city networks in Kriva Palanka, Kratovo, Kumanovo and Skopje. In the same cities, city gas pipeline networks with operating pressure of 12 bar have been constructed. The users are connected to the city gas pipeline networks through the measuring-regulating stations.

In this paper, the process of risk assessment of workplaces in the company GA-MA Ltd Skopje, as well as measures to prevent, reduce and eliminate risks at workplaces where increased risk is defined, are described.

2. RISK ASSESSEMENT

A risk assessment under the Law on health and safety at work, is defined as systematic recording and evaluation of risk factors (risks and hazards) in the working process, which can cause occupational injury, illness or damage to health, and identifying possibility, ways to prevent, reduce or eliminate the risk. The basic purpose of identifying the risk factors is the identification of all possible dangers and hazards, without omitting any risk.

The risk assessment at workplaces in company GA-MA Ltd, Skopje has been realized in several phases:

The **first phase** includes:

- Adoption of a written decision by the employer and development of a plan for implementation of risk assessment
- Engagement of authorized institutions to carry out professional activities for safety at work or entrepreneur who has authorization - license for carrying out activities related to safety at work
- Forming a team to perform the risk assessment
- Informing the employees about the activities.

The **second phase** is related to:

- Recording and analyzing the organization of work
- General information of the employee
- Description of the technological and working process
- Description of the tools of labour and its grouping
- Description of the resources and personal protective equipment at work
- Screening and analyzing the work organization (systematization and grouping of workplaces)
- Recognition and identification of dangers and hazards at workplace and work environment
- Establishing the list of hazards
- Risk assessment according to identified dangers and hazards and
- Determination of ways and measures for eliminating, reducing and preventing risk.

The **third phase** consists of processing and analyzing the results

- Defined on the basis of priority list of dangers and hazards, the level of risk for each work position is being determined and a plan with proposed measures to eliminate, reduce or prevent identified risk is being prepared.

Forth phase is comprised of:

- Making conclusion, priorities for eliminating of the risk.

For identification of risk factors (dangers and hazards), at workplace and work environment, there are different tools and techniques, such as:

- Advanced tools and techniques
- Measurements of microclimate, physical, chemical and biological hazards
- Onsite inspection
- Interview with the employees
- Regular and periodical review of work equipment.

In 2011, risk assessment for all workplaces in the company GA-MA Ltd, Skopje [3], was performed by authorized persons from the Faculty of Technical Sciences in Bitola. A survey was conducted with the employees in which they were asked to describe their daily activities and to indicate any dangers and hazards observed during performing of their daily activities. For identification of dangers and hazards in the occupational environment on people's health, measurements of microclimate conditions and physical hazards have been conducted [4].

3. RESULTS AND DISCUSSION

The risk assessment, identification and determination of present dangers and hazards has been made for workplaces (system operator in sector for metrology and gas admission, engineer in sector for metrology and gas admission, system operator in sector for exploitation and maintenance, technician and engineer in sector for exploitation and maintenance, manager of sector for exploitation and maintenance, technician and manager of dispatch center for measuring regulating station and main measuring station). In Table 1, the values of conducted measurements of microclimate conditions (temperature, relative humidity of air and velocity of air circulation), physical hazards (lighting and noise) are given. The measurements of microclimate and physical hazards are made with calibrated instrument, product of METREL Slovenia.

Table 1 *Measured values of microclimatic conditions and physical hazards*

Workplaces	Microclimatic conditions			Physical hazard	
	Measurement value			Measurement value	
	Air temperature t [°C]	Air humidity φ [%]	Air velocity v [m/s]	Lighting [Lx]	Noise [dB]
Maing Measuring Station (MMS) Command room	23,40	36,50	0,10	489	55.80
Maing Measuring Station (MMS) Premise for instruments and equipments	23,20	36,50	0,12	392	64.80
Measuring - regulation stations (MRS)	25,70	54,70	0,11	159	84.70

From table 1, one can note that the microclimate conditions (temperature and relative humidity of air, as well as velocity of air circulation) are in the allowable limits for the summer period of measurements. Except for the workplaces (system operator and engineer in sector for metrology and gas admission in MMS - command room and

premises for instruments and equipment) in main measuring station where the value of relative humidity of air is below allowable border value. The allowed values for the summer period are: $t = 15\div 28$ °C, $\varphi = 40\div 60\%$, $v = 0.7$ m/s. The results of the conducted measurements of lighting show that the measured values are within the range of allowed values according to MKS.U.C9.100 standard (300÷500 Lx for inspection – supervision areas). Except for the workplaces in measuring - regulating station where the value of lighting is below the recommended value. The measured values for the level of noise in all workplaces are in the allowed range, according to the exposure limit value of 87 dB, defined by the Rulebook for safety and health at work for the employees exposed to a risk of noise [5].

For the listed workplaces, the following dangers are identified:

- **Mechanical hazards that occur by usage of work equipment** (using dangerous means of work that can cause explosions or fire, inability or limitations for timely transfer in manhole, exposure to closure, mechanical impact)
- **Hazards related with the characteristics of the workplace** (danger of narrow surfaces trampling down in the shaft, work depth in accordance with the regulations for safety and health at work - work in the shaft, work in narrow and confined or hazardous space - work in the shaft which is not sufficiently lit or ventilated, preferably from slipping while working in the shaft, other hazards related with the characteristics of the workplace and the way of work - dangers that occur with the release of gas in the pipeline, after cleaning the pipeline and replacing the equipment of the pipeline, with the testing of the hermetic equipment and supply armature in MMS and MRS, with the exhaustion and adjustments of the equipment in MMS and MRS, with the release of gas after the adjustment of the equipment, with the replacement of filters in MMS and MRS, during the welding or cutting the supply fittings in the shaft, blast caused by pipeline not disconnected from main supply may occur, with direct connection to the newly built line to the existing in things related with the removal of defects in technical maintenance and repair of fittings, when measuring the pressure in city pipeline network)
- **Hazards associated with the use of electricity:** electrical arc that can be transferred from the auxiliary power supply to power supply of the system for remote control and management in the workspace where the gas chromatograph is located, electrical arc that can be transferred from the auxiliary power supply used to power the system remote control and management in the workspace where the measuring and regulating equipment is located, from fire and explosion due to improper grounding, from electrostatic electricity and disconnection of metal surfaces by bridging, from electrical and mechanical spark, electrical arc of lights and junction boxes while turning them on or off, from electric arc that can be transferred from the auxiliary power supply that is used to power the remote control and management system in the workspace where measuring and regulating equipment is located, due to work in the shaft when electrochemical protection system is not excluded, when viewing the feeder stations and countervailing adjustable joints, during measurement of the protection and OFF potential, while controlling the correctness of the reference electrodes, while controlling the accuracy of the anodic, bearings, measuring the power of each anode and the correctness of the same, with setup feeder stations that can be achieved with adequate protection of the entire pipeline route, in place of interruption detection

measurement cord protective grounding, and electrical and mechanical generated spark, electric arc lamps and switchgear boxes on and off the same MRS)

- **Hazards which arise or occur during the working process-chemical hazards:** from inhalation of concentrations of natural gas higher than 5% leading to asphyxiation due to gas leakage by reinforcement of condensate discharge from condensing pot, due to lack of hermeticity of the system for odorisation, by inhalation of CO concentrations above the maximum permissible concentration of 58 mg/m³, by inhalation of H₂S concentrations above the maximum permissible concentration of 10 mg/m³, occurred from the discharge of condensate from condensing pot, maximum permissible concentration in the work environment is more than 300 mg/m³, from the presence of CH₄, its concentration in the mixture is greater than a certain minimum value called lower explosive limit L_d = 5 vol%, less than a certain maximum value called upper explosive limit L_g = 15 vol%; **physical hazards:** increased noise in the discharge line of the main pipeline, harmful influences from the microclimate factors, inadequate-low lighting of GMRS, harmful atmospheric conditions-outdoor work, adverse impacts from the use of flammable and explosive materials-work with natural gas which is flammable and explosive; **biological hazards:** while working in shaft that has microorganisms, larvae and worms; **hazards incurred by the use of hazardous substances in the production, transportation, handling, packaging, storage or destruction:** presence of ethane at workplace, carbon monoxide, hydrogen sulphide and metilmerkaptanie, their concentration in the mixture is greater than a certain minimum value called lower explosive limit, or less than a certain maximum value-upper explosive limit, at workplace while welding the gas concentration in the air
- **Hazards arising from the physical and psycho physiological efforts** - efforts and physical stresses: during loading and unloading of cylinders pressurized with N₂ and He, by replacement and lubrication of valves, dismantling of gas valves, with technical maintenance and overhaul shaft efforts from raising metal balls and setting up so-called sledge during the pipeline cleaning, with technical maintenance and repairs; **psychological pressure** - stress due to work in an environment with high pressure installation
- **Hazards related to the organization of work:** overtime, shift work, standby in case of interventions
- **Other hazards that occur in the workplaces:** work space where an explosive atmosphere can occur, work in the hazard zones 1 and 2, work near the dispatch pipeline-cleaning station - primary source of risk, Working in the block station - a secondary source of danger, hazards that may occur in direct connection to the newly built line connected to the existing.

For conducting the risk assessment, processing and analyzing, "LatiPRO" software package is used, [6]. For estimation of the values, the following formula is used:

$$\text{RISK}=\text{TP}\times\text{UI}\times\text{VP}\times\text{BO}$$

Where the parameters indicate: TP-weight of potential injury, UI- frequency of exposure to dangers, VP-probability of injury and BO-number of exposed people.

For defining of TP factor - weight of potential injury, multi criteria scale with 7 levels, is used.

Weight of potential injury	Values of TP factor
Scratches, bruises etc.	0.1
Cuts, lacerations etc.	0.5
Temporary minor illness, minor broken bones etc.	2.0
Temporary serious illness, major broken bones etc.	4.0
Permanent illness, loss of an eye, sense of hearing, limbs etc.	6.0
Serious permanent illness, loss of sight, limbs etc.	10.0
Fatal injuries-mortal income	15.0

For defining of UI factor - frequency of exposure to dangers, multi criteria scale with 6 levels is used.

Frequency of exposure to dangers	Values of UI factor
Once a year	0.5
Once a month	1.0
Once a week	1.5
Once a day	2.5
Each hour	4.0
Continuously	5.0

For defining of VP factor - probability of injury, multi criteria scale with 8 levels is used.

Probability of injury	Values of VP factor
Almost impossible, only under exceptional circumstances	0.33
Highly unlikely, but possible	1.0
Unlikely, although it can happen	1.5
It can happen but it is unusual	2.0
There is a real chance to happen	5.0
Possible, not surprisingly	8.0
Probably, should be expected to happen	10.0
Surely, there will be no doubt	15.0

For defining of BO factor-number of exposed people, a scale with 5 levels is used.

Number of exposed persons	Values of BO factor
1÷2	1.0
3÷7	2.0
8÷15	4.0
16÷50	8.0
50 and more	12.0

With multiplication of values of previously defined factors, the total value of estimated risk is obtained, and thus categorized according to the values shown in the following table:

Risk category	RISK = TP x UI x VP x BO
NEGLIGIBLE RISK does not require any action to reduce the risk	0÷5
LOW RISK low risk to safety and health at work	6÷50
MODERATE RISK there is a risk, it is necessary to determine the extent of its reduction	51÷250
HIGH RISK significant risk, determine the measures required to reduce it	251÷500
UNACCEPTABLE RISK work at such risk is unacceptable	> 500

In Table 2, the workplaces at which the assessment is carried out and workplaces that are determined as work places with increased risk, are given. The analysis of identified dangers and hazards, as well as the values of estimated risk in accordance with the adopted methodology show that the largest number of hazards and dangers occur at the workplace technician in exploitation sector.

For this workplace, a total of 38 risks have been indentified, out of which 18 are characterised as high risk value (400). For this workplace the dangers and hazars that lead to high risk can be grouped into few categories: mechanical dangers that occur with the use of work equipment, dangers related with the characteristics of the workplace, chemical hazards, harmful influences due to use of flammable and explosive materials, hazards that occur from phisycal and psycho physiological efforts, workplace where an explosive atmosphere-workplace in dangerzone 1 and 2 can occur, dangers due to work in dispatch-cleaning station as a prime source of danger.

Table 2 Workplaces for which risk assessment is done

System operator in sector for metrology and gas admission						
Total risk	Negligible risk	Low risk	Moderate risk	High risk	Unacceptable risk	Max risk
28	0	10	12	6	0	400.00
Engineer in sector for metrology and gas admission						
Total risks	Negligible risk	Low risk	Moderate risk	High risk	Unacceptable risk	Max risk
24	0	8	10	16	0	400.00
System operator in sector for exploitation and maintenance						
Total risks	Negligible risk	Low risk	Moderate risk	High risk	Unacceptable risk	Max risk
21	0	6	8	7	0	400.00
Technician in sector for exploitation and maintenance						
Total risks	Negligible risk	Low risk	Moderate risk	High risk	Unacceptable risk	Max risk
38	0	5	15	18	0	400.00
Engineer in sector for exploitation and maintenance						
Total risks	Negligible risk	Low risk	Moderate risk	High risk	Unacceptable risk	Max risk

26	0	16	4	6	0	400.00
Manager of sector for exploitation and maintenance						
Total risks	Negligible risk	Low risk	Moderate risk	High risk	Unacceptable risk	Max risk
23	0	5	7	11	0	400.00
Technician of dispatch center for MRS and MMS						
Total risks	Negligible risk	Low risk	Moderate risk	High risk	Unacceptable risk	Max risk
34	0	12	12	10	0	400.00
Manager of dispatch center for MRS and MMS						
Total risks	Negligible risk	Low risk	Moderate risk	High risk	Unacceptable risk	Max risk
24	0	9	9	6	0	400.00

For reduction of the previously determined risks, it is necessary to provide and enforce all collective and individual measures. These measures can be grouped in several groups:

- During work in shaft, first thing to do is to determine the presence of CO, H₂S, CH₄ and metilmerkaptan with gas analyzer. Ventilation of the shaft must be performed, and after that, another check if there is presence of the gas. If in the shaft has water inside, it should be pumped out first. Use of personal protection equipment (gas masks, rescue belts with ropes) is mandatory. Man must be lowered down into the shaft by a rescue belt with rope and gas mask, if necessary. Out of the shaft on the side of the wind, at least two members of the team must hold the ends of the ropes from the rescue belts, as well as the hose of the gas mask. The gas mask and rescue belts should be checked prior any activity. In case there is a gas in the shaft, a worker with a permission of the manager should be lowered in the shaft with a gas mask. If the quantity of gas is high, work is prohibited. If there is a gas leak from fittings or cracks and distortions, as well as other more serious damage to the pipeline, work in the shaft must be stopped. Removing the gas leak and failure is performed under another account that will provide safety measures depending on the nature of the defect. In the period of gas equipment repairment in the shafts, electro-chemical protection devices must be turned off by an authorized employee of the company. If serious defects that could cause an accident are discovered, and they must be repaired, the shaft should be vented first. The worker entering the shaft should be dressed in special clothes and shoes without steel nails (rubber boots). At a distance of 5 meters from the open pit, a fence by the road should be set up, and at 10÷15 m distance a warning signs must be put in visible place.. Workers must wear orange vests. All members of the team should be able to provide first aid for burns, injuries, suffocation from gas, electricity impact.
- If in the shaft, the oxygen concentration is not satisfactory, entry is not allowed until forced mechanical ventilation is performed by means of portable electric fan with flexible tubes. Ventilation rate must not be lower than 3 air changes per minute. Ventilation of the shaft, where the existence of dangerous gases or insufficient amount of oxygen is established, should be performed for at least 5 minutes. In case of ventilating fan failure, workers must immediately leave the shaft, and before re-entering it, all

previously described operations must be repeated. When the work with the flexible tube is stopped, it should be pulled out of the shaft in order to avoid the collection of gas mixtures in it. Before putting the flexible tube in the shaft again, the same should be vented out at open space for at least 1 minute. During the operation, the fan must be at least 3 meters away from the aperture of the shaft.

- The direct conection of the newly built city pipeline to the existing should be carried out with gas pressure in the range of 40-200 dPa and should be controlled all the time. The direct conection of the newly constructed pipeline to the existing without disconnection or reduction of the gas pressure should be performed with use of special device. Testing of hermetics for the newly built pipeline must be performed under pressure of 0.02 MPa. The pressure drop during the test, should not be higher than 10 dPa per hour. Work should be performed by a team comprised of, at least three workers.
- When working in danger zones 1 and 2, prior to any commencement of works, and occasionally during the work, measurement-detection of the presence of gas using portable manual detector must be performed. During measurements, two workers must be present at any time. The equipment and protective systems need to be selected as an equipment category 1 and 2 and equipment category 1. Setting up a warning sign in accordance with article 8, paragraph 3 of the rules for minimum safety and health requirements for employees who are potentially exposed at risk from explosive atmospheres (Official gazette of Republic of Macedonia No.74/09). For safety reasons, the enforcement of tasks needs to be carried out by at least two workers, at any time.
- In dispatch-cleaning station, the “cannon” surfaces that are closed, must be lubricated with grease. Careful handling while opening and closing of the “cannon” must be performed because of high pressure value of 2 bar. After the discharge into the pipeline, ventilation must be provided for up to 5% due to gas explosiveness. When the pipeline is filled with gas, first it must be drained and lowered to reccomended pressure levels, prior any cleaning works. The drain valves must be fully opened. All discharges of the condensate must be carried out in a container or specially designed vessels. Exhaust pipe for gas discharge from the cleaning tube must be isntalled vertically, and the opening of the pipe must be placed at an angle of more than 5 ° to the shutter of the tube. Weights greater than 45 kg must not be lifted by hand.

4. CONCLUSION

In this paper, the risk asesment for workplaces in company GA-MA Ltd Skopje is shown together with determined increased risks. The risk asesment is conducted with the help of software package LatiPro. It can be concluded that the highest number of dangers and hazards are present at the workplace: technican in the sector for exploitation and maintenance. For this workplace, measures are provided and they should be followed strictly while conducting work activities in order to prevent and reduce present dangers and hazards.

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WEATHER CONDITIONS IMPACT ON ELECTRICITY CONSUMPTION

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Abstract: This paper presents the analysis of the impact of weather conditions on the consumption of electricity for the City of Kragujevac in the five-year period from 2006 to 2010. It points out the mean daily air temperature as the most influential climate (meteorological) parameter, and gives an overview of deviations from the mean values compared to the reference period. Increases and decreases in power consumption depending on the deviations of the mean daily temperature from the normal (average) values are also indicated. In periods of strong and long-lasting cold spells in winter months, there is increased power consumption as a result of heating of residential and office premises. During extremely hot summer periods, there is also a tendency of increased electricity consumption because of home air conditioning. A timely and accurate weather forecast can certainly help prevent the electrical power system overload and reduce the risk of possible power system damage.

Keywords: Weather, Electricity consumption, Cooling, Heating, Climate change

1. INTRODUCTION

Increasing demands for energy and dramatic reductions in reserves of energy resources, primarily fossil fuels, make each research on energy consumption significant.

In recent decades, we have witnessed climate changes for which most scientists believe to be of an anthropogenic origin. An enormous consumption of fossil fuels has led to a significant increase in the concentration of greenhouse gases (CO₂, CH₄, NO₂, etc.) which are considered the main cause of the increase in the global average temperature.

The residential sector has significant electricity consumption in most power systems. Changes in electricity consumption in this sector are associated with changes in weather conditions and they often cause undesirable peaks [3] in the total power consumption within a power system.

Electricity consumption depends on characteristics of the building envelope, quality of the windows and occupant behaviour which further complicates this

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dependence [2, 4, 5]. Important elements [2] in the study of the influence of weather parameters on energy consumption include the local position of the object (orientation, slope, solar radiation, wind exposure, presence of vegetation, etc.) and its geographic position (primarily the climate zone of a particular location).

There is a significant number of papers dealing with the studied topic. The paper [1] shows the analysis of weather sensitivity of household appliances energy consumption (refrigerators, air conditioners, heating, etc.) in Sydney, Australia. The core temperature was established and it was the starting point from which the additional heating or cooling of residential and office premises began. The U.S. Energy Information Agency conducted extensive surveys related to the number of possible influencing factors on the electrical energy consumption in the residential sector [2]. The paper [7] studied the effect of changes in air temperature, wind speed and direction, and relative humidity on the energy consumption and it determined how this effect varied in different climate zones. In the papers [6, 7], the impacts of climate factors, object construction properties, socio-cultural and other factors are considered.

The objective of this paper is to present data on the mean temperature and electricity consumption for a five year period at the City of Kragujevac and then to determine the impact of changes in the mean daily temperature on the power consumption of buildings.

2. METHODS

2.1. Location

The city of Kragujevac (44.02 latitude and 20.93 longitude) has an altitude of about 200 meters with a moderate continental climate.

2.2. The obtained data

Temperature measurements were performed at the meteorological station Kragujevac. The variation in the mean daily air temperature for the City of Kragujevac for a five-year period time from 1 January 2006 to 31 December 2010 was recorded.

The mean daily temperature was calculated based on the equation

$$t_{md} = \frac{1}{24} \sum_{i=1}^{24} t_{hi} \quad (1)$$

where

t_{hi} stands for the measured temperature value for each hour i . The mean daily temperatures were used to calculate the mean monthly temperature as

$$t_{mm} = \frac{1}{n_d} \sum_{i=1}^{n_d} t_{mdi} \quad (2)$$

where t_{mdi} stands for the mean daily temperature for the i -th day of the month and n_d stands for the number of days in the month ($n_d=28, 29, 30$ or 31).

The data on electricity consumption were taken from the transformer station (TS Kragujevac 2). This transformer station supplies the mainly residential area with no significant industrial plants.

The transformer station TS Kragujevac 2 supplies electrical power to the largest part of the City of Kragujevac (about 200 000 inhabitants). Since this is mainly residential area, the ratio of residential to industrial power consumption is 9 to 1. Out of

103 000 consumers supplied by the TS Kragujevac 2, 96 000 are residential consumers. This transformer station supplies power only to 55 industrial consumers, 54 of which are supplied with medium voltage electricity (10 kV and 35 kV), and one of which is connected to the network of high voltage (110 kV). Public lightning has 657 connections.

It is significant to note that in the area covered by the TS Kragujevac there are about 10 000 gas connections and 25 000 users of the remote controlled heating system.

Therefore, the structure of the electric power system of the TS Kragujevac 2 is such that the impact of the air temperature variations on the power consumed for heating or cooling of residential premises is high.

An important factor with a great influence on the level of power consumption is certainly the price of fuels (gas, coal, fuel oil, wood, electric power). The object of our further investigations will be to determine a more accurate relation between the meteorological (climate) parameters and the electrical power consumption.

3. RESULTS

As results of this investigation, diagrams of mean daily temperatures and daily electricity consumptions for the period from 2006 to 2010 are given in Figures 1-5. The gradual increase in the number of customers and in the number of electrical devices that burden the system is not considered.

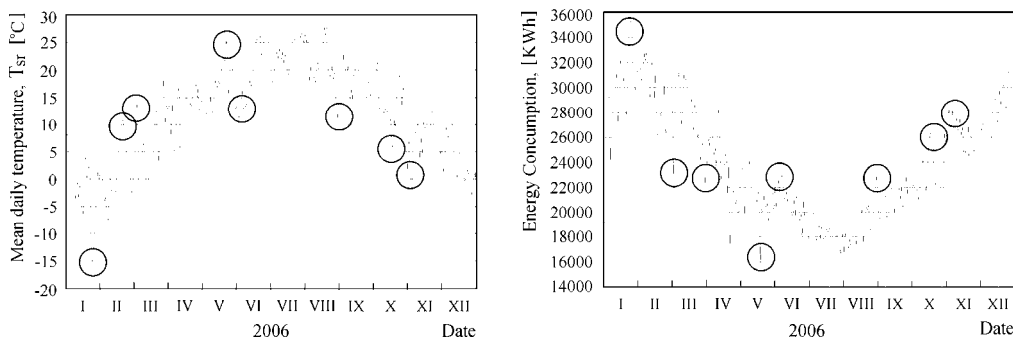


Fig. 1 Mean daily temperature and mean daily electricity consumption for 2006 (Average consumption for a period of 15 min)

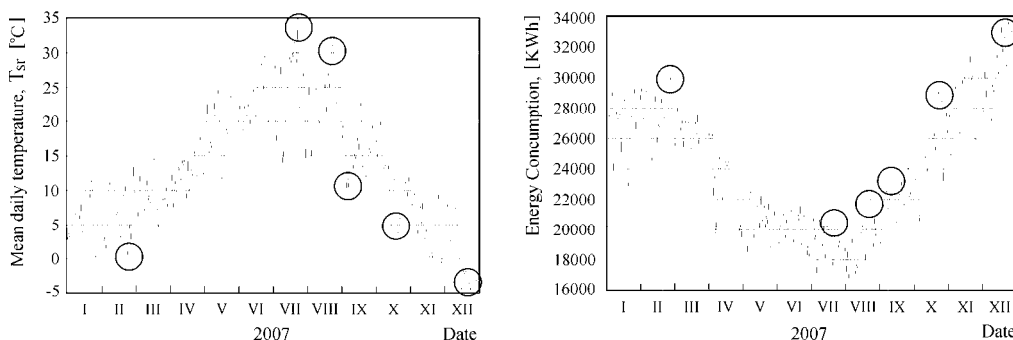


Fig. 2 Mean daily temperature and mean daily electricity consumption for 2007 (Average consumption for a period of 15 min)

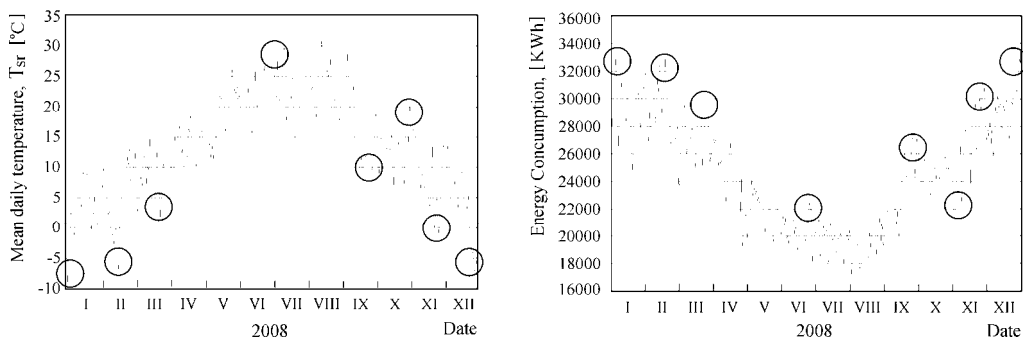


Fig. 3 Mean daily temperature and mean daily electricity consumption for 2008 (Average consumption for a period of 15 min)

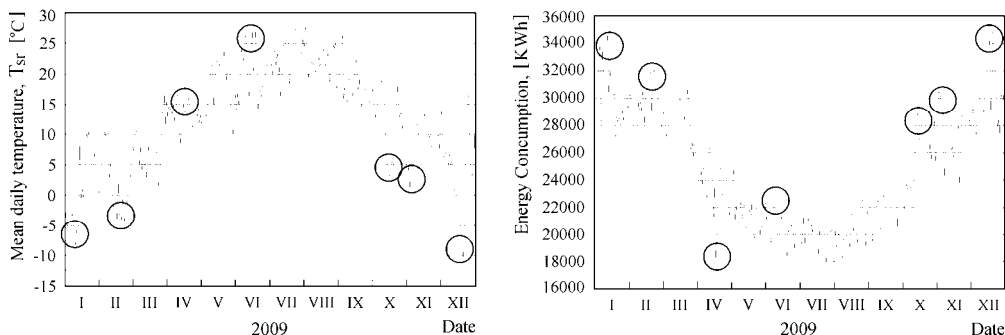


Fig. 4 Mean daily temperature and mean daily electricity consumption for 2009 (Average consumption for a period of 15 min)

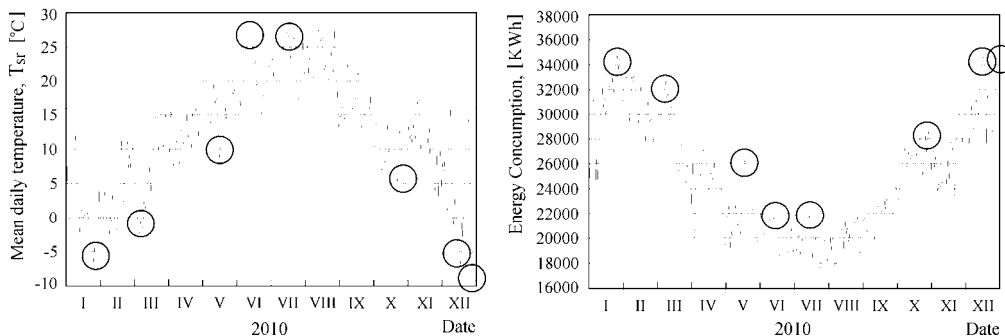


Fig. 5 Mean daily temperature and mean daily electricity consumption for 2010 (Average consumption for a period of 15 min)

4. DISCUSSION

Figures 1-5 show the influence of external temperatures to power consumption by buildings. Peaks in the power consumption (rounded peaks in the diagrams) correspond to the peaks in mean daily temperatures.

In periods of strong cold spells especially in winter months, there is a need for additional heating of residential premises. The amount of electrical power consumed for additional heating depends on a number of factors. Based on the peak intensities in the shown diagrams (Figures 1-5), it can be concluded that the intensity of external

temperature variations is a predominant factor with a great influence on the quantity of additionally consumed electrical power.

The length of strong cold spells or the length of warm spells in winter months also influences the electric power consumption. Other factors that have an influence on the intensity of power consumption peaks include usage of fuels, periods of major religious and state holidays, prices of fuels, construction characteristics of the buildings etc.

Due to obvious climate changes, periods of extremely hot weather in summer have become both more frequent and longer. During these periods, air conditioners are intensively used for cooling of residential premises; therefore, electrical power consumption is significantly increased.

In transient periods (autumn and spring) when the remote controlled heating system is not in function, there is an increased risk of overloading the electric power system.

Geographic location and the climate zone affect the overall dependence of electric power consumption on different weather conditions.

It is observed that there are high peaks in power consumption associated with high (summer) and low (winter) temperature peaks.

There are also some variations in power consumption for minor changes in the air temperature, but they could hardly endanger the operation of the electric power system.

5. CONCLUSION

It is obvious that there is a strong relationship between changes in the external temperature and energy consumption in the residential sector. Based on the diagrams of power consumption for a five-year period (2006-2010) for the City of Kragujevac, it can be concluded that there is high electricity consumption in the residential sector as a response to extreme changes in the mean daily air temperature.

Lower air temperatures (in winter) present a greater danger to operation of the electric power system because the system is already heavily loaded in winter. A timely and accurate weather forecast followed by an appropriate response from both those in control of the power system and the consumers can certainly contribute to energy savings and prevent power system damage with serious consequences.

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ENERGY EFFICIENCY OF A COGENERATION SYSTEM

Buzatu Gabriel Cosmin¹, Mircea Paul Mihai², Dinu Radu Cristian³

Abstract: Since the main feature of the Craiova heat supply system is the low loading installations and heat transport, is seeking to improve the performance of CET Craiova II cogeneration plant, including as and assignation of a total 11 district heating plants in cogeneration. The analysis period covers the last five years of operation; the authors reserved their right to make some estimates regarding the evolution of fuel prices and Gcal by 2013.

Keywords: energy analysis, cogeneration, economic analysis, audit, efficiency

1. INTRODUCTION

CET Craiova II is a mixed type cogeneration plant, designed and originally designed to supply urban consumers and industrial area located in Craiova. Conducted in three distinct phases over 10 years, CET Craiova II has a total production capacity of heat about 840 Gcal/h. Hot water preparation scheme currently comprises four basic exchangers supplied with steam extracted from the turbine intake double adjustable, four hot water boilers (HWB) of 100 Gcal/h and two heat exchangers top.

2. AUDIT OF THERMAL POWER PLANTS

Heat used in centralized heat supply for heating and domestic hot water is hot water.

The study presented in this work started by analyzing the 11 district heating plants from Craiova focused on the new installed capacity to ensure the necessary heat (rel.1) from the total equivalent heating surface $S_{ech.t.inc}$. Also, specific heat demand calculation, according to the literature fund their housing during construction in Craiova is 525 W/m^2 area equivalent to an internal temperature of 18°C and computing values of temperature calculation flow / return heating hot water $95/75^\circ\text{C}$, corrected for internal temperature of 20°C and computing $90/70^\circ\text{C}$.

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$$(q_i^c)_{CT} = q_c \cdot \left(\frac{\frac{t_{act(20^\circ)} - t_{act(20^\circ)} - t_{iSTAS}}{2}}{\frac{t_{act(18^\circ)} - t_{act(18^\circ)} - t_{ic}}{2}} \right) \cdot 10^{-6} \cdot S_{echiv.inc.calc.} \quad [Gcal/h] \quad (1)$$

where: q_c - specific heat demand calculation [W/m²]; $t_{act(20^\circ)}$ - hot water flow temperature, to ensure internal temperature of 20°C; $t_{act(20^\circ)}$ - hot water return temperature, to ensure the interior temperature 20°C; $t_{act(18^\circ)}$ - hot water flow temperature, to ensure the internal temperature of 18°C; $t_{act(18^\circ)}$ - return hot water temperature to ensure an internal temperature of 18 °C calculation; t_{ic} - indoor temperature calculation, [°C]; t_{iSTAS} - indoor temperature calculation, according to STAS 1907/1-90, [°C].

The annual heating heat continuously (rel.3.2) is established on account of weather conditions "computing" specific Craiova, the methodology of SR 1907 - "Heating, heat demand computing, computation requirements" and the SR 4839 - "Heating, annual number of degree days".

$$Q_{iCT} = D_{inc} \cdot \frac{t_{iSTAS} - t_{med,z}}{t_{iSTAS} - t_c^c} \cdot (q_i^c)_{CT} \quad [Gcal/an] \quad (2)$$

where, for Craiova, we have minimum outside temperature calculation: during annual heating period: $D_{inc} = 192$ days / year ($192 \cdot 24 = 4608$ h / year) average annual number of degree days calculation: $N_{inc} = 3170$ degree days, annual average outdoor temperature: $t_{med, z} = 3.5$ ° C.

Calculation of the maximum heat demand for a boiler hot water take in into account the standard hot water consumption per person (110 l / day person) by a factor of hot water supply system (0.17 h / day), a coefficient depending on the destination building with hot water supplied by a non-uniformity coefficient proportional to the number of people supplied with hot water, the number of people fed and the number of taps for tertiary consumers.

Following the analysis revealed the following (table 1):

Table 1 Energy audit and economic results for the 11 CT neighborhood Craiova New

Nr. crt.	Quantity	UM	2008	2009	2010
1	2	3	4	5	6
1.1	Heat produced in the form of hot water	Tcal/year	124,486	109,871	85,088
1.2	Gaseous fuel consumed	mil. mcn/year	20,46	17,99	15,37
1.3	Power consumption of electricity	GWh/year	1,36	1,23	1,004
1.4	Calorific value fuel gas	Mcal/mcn	8,46	8,5	8,41
1.5	Average price of gas fuel	RON/mcn	1,032	1,867	2,751
1.6	Gaseous fuel costs	RON	2.111.000	3.359.000	4.229.000
1.7	Total expenditure fuel	mld lei	2.111.000	3.359.000	4.229.000

Energy efficiency of a cogeneration system

Nr. crt.	Quantity	UM	2008	2009	2010
1.8	Primary energy between the fuel gas	Tcal/year	173,11	152,96	129,3
1.9	Total primary energy between fuel	Tcal/year	173,11	152,96	129,3
1.10	Primary energy between gas fuel	GWh/year	201,33	177,88	150,37
1.11	Total primary energy between fuel	GWh/year	201,33	177,88	150,37
1.12	Heat produced in the form of hot water	GWh/an	144,78	127,78	98,95
1.13	Gross overall efficiency of CT	-	0,71	0,71	0,65
1.14	Industrial water costs	RON	30.000	48.000	33.000
1.15	Labor costs	RON	396.000	592.000	470.000
1.16	Expenditures for repairs	RON	44.000	43.000	25.000
1.17	Expenditure on	RON	74.000	117.000	77.000
1.18	Other expenses	RON	301.000	466.000	795.000
1.19	Depreciation	RON	83.000	68.000	39.000
1.20	Total annual expenses	RON	3.039.000	4.693.000	5.668.000
1.21	Total annual bill	RON	2.946.000	4.633.000	5.041.000
1.22	Costs for heat production	mil EUR/year	1,37	1,07	0,99
1.23	Invoices for thermal energy	mil EUR/year	1,34	1,06	0,89
1.24	Corrected specific cost of thermal energy	EUR/MWh	7,08	7,20	7,74
1.25	Average purchase price of primary energy	EUR/MWh	3,53	3,65	4,12
1.26	Gcal cost	EUR/Gcal	11,84	12,4	14,32
1.27	Annual average rate	RON/EUR	3,6691	4.2911	4.3084

3. TECHNICAL PERFORMANCE AND ECONOMIC ANALYSIS CONDUCTED BY CET CRAIOVA II

The analysis was based on data provided by CET Craiova II, the analyzed period covering the last five years: 2006, 2007, 2008, 2009, 2010.

Energy analysis CET Craiova II, aims to determine the gross yield electricity production (rel.3), gross efficiency of heat generation (rel.4) net overall yield, gross overall efficiency, heat index (rel.5) and reduce heat index (rel.6).

$$\eta_{\text{CET}} = \eta_c \cdot \frac{1 + B}{1 + B \cdot \eta_c} \quad (3)$$

were: η_c – under pure efficiency condensing boiler, [%]; B – energy coefficient, expressed as the ratio of power produced by steam outlets and steam power output capacitor.

$$\eta_t = \frac{Q_u}{Q_i + \Delta Q} \quad (4)$$

were: Q_u – used heat, [kW]; Q_i - amount of heat introduced into the heat producing equipment, [kW]; ΔQ – heat losses, [kW].

$$y_p = \frac{P_p}{Q_p} \quad (5)$$

were: P_p – electrical power produced by steam flow relaxation, [kW]; Q_p – heat flow delivered from the turbine, [Gcal / h].

$$\Delta y_p = \frac{\Delta i \cdot \eta_m \cdot \eta_g}{(i_2 - i_{2s}) \cdot 860 \cdot 10^{-6}} \quad (6)$$

were: Δi - enthalpy variation in the heat exchanger [kJ / kg]; η_m – mechanical efficiency of the turbine; η_g – generator efficiency; i_2 – enthalpy of steam at the turbine end real relaxation, [kcal / kgf]; i_{2s} – enthalpy of the steam turbine at the end of detente in the saturation temperature, [kcal / kgf].

The results obtained from the analysis are summarized in Table 2 and show two main trends that keep the entire period of analysis, namely: - the amount of electricity supplied to the power system increases every year, while the amount of heat supplied to consumers subordinated decreases each year - the largest share is held by coal, fuel oil and natural gas are used in only insignificant amounts of flame holder.

Table 2 The main technical and economic performance indicators for CET Craiova II

Quantity	UM	2006	2007	2008	2009	2010
1	2	3	4	5	6	7
Heat as hot water based	Tcal/an	683,2	653,9	632,4	613,8	604,4
Heat as hot water to the top	Tcal/an	284,1	280,6	212,9	182,7	156,
Heat as hot water	Tcal/an	967,3	934,5	845,3	789,8	737,9
Form of steam heat to the top	Tcal/an	8,93	33,9	13,99	10,4	10,4
Electricity from heat	GWh/an	328,3	311,1	298,4	284,5	271,2
Electricity produced in condensing	GWh/an	1071,2	935,0	1143	1163	1185
Total energy produced	GWh/an	1399,5	1246	1441	1449	1459
Solid fuel consumed	mii t/an	2533,8	2173	2367	2466	2570
Oil consumed	mii t/an	25,31	17,36	11,28	7,53	11,28
Gaseous fuel consumed	milmcn/an	1,17	33,06	40,12	43,99	48,24
Electricity consumption of electricity	GWh/an	226,09	211	233,4	238,2	243,0
Power consumption of electricity to produce heat	GWh/an	10	10	10	10	10
Gross global output	%	46,10	47,30	44,30	44,45	44,50
Global output net	%	41,80	42,90	39,90	40,05	40,09
Gross efficiency of electricity production	%	32,70	32,70	32,20	32,53	32,48

Energy efficiency of a cogeneration system

Quantity	UM	2006	2007	2008	2009	2010
1	2	3	4	5	6	7
Gross efficiency of heat production	%	93,40	93,00	94,20	94,20	94,20
Index structure of energy production	-	1,23	1,11	1,44	1,37	1,37
The degree of heating	%	0,23	0,25	0,21	0,21	0,21
Average loading capacity of electricity generation	%	53,60	47,70	55,20	55,20	55,20
Average loading capacity of thermal power	%	13,20	13,20	12,77	12,39	12,20
Share of own consumption of electricity	%	16,90	17,70	16,90	17,00	17,11
Solid fuel expenses	mld.lei	766,61	820,2	1220,5	1189,5	1325
Liquid fuel expenses	mld.lei	65,57	64,88	45,89	64,293	90,07
Gas fuel expenses	mld.lei	1,46	73,33	135,94	142,08	204,1
Total expenditure of fuel consumed	mld.lei	833,64	958,4	1402,4	1395,9	1619,
The share of primary energy costs in total costs	%	57,1	68	62,8	62,7	37,8
Coal price	Euro/t	13	15,6	15,3	16	18
Average purchase price of primary energy	Euro/MWh	7,67	6,84	6,99	6,58	7,71
Average specific energy cost of producing useful	Euro/MWh	26,6	20,1	21	21,58	24,71
Corrected specific cost of electricity delivered	Euro/MWh	55,8	38,6	35,5	40,6	54,4
Corrected specific cost of thermal energy supplied	Euro/MWh	6,04	11,53	16,41	20,24	26,20

Homogenization treatment for the five years analyzed, in 2006, 2007, 2008 was considered the same household consumption of electricity for heat production as in 2009 and 2010, approximately 10 GWh / year.

Analysis of data from Tables 2 and 3 allows highlighting several aspects. Thus, the efficiency of electricity production is reduced values due to the large share of electricity produced in condensing mode (heating level is between 0.21 and 0.29) for the same reason, overall yields were low values for CET while heat output is elevated (Fig. 1 and 2). Own services electrical consumption is a share between 17 and 22% of electricity consumption share of own technological power is relatively high, but this is justified by the reduced workload of installed capacity

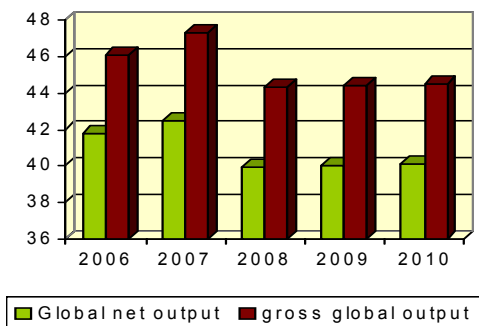


Fig. 1 Global efficiency variation ,
i.e. net CET Craiova II

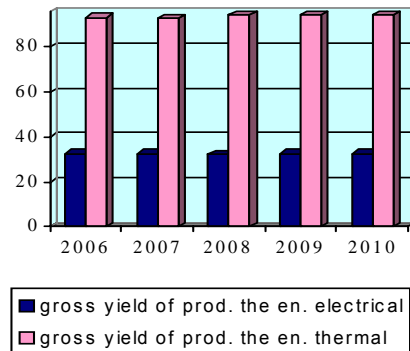


Fig. 2 Production efficiency
variation of electricity and heat

The average load capacity thermal power (Figure 4) does not exceed 15% (1047 MW 900Gcal / h), because the maximum heat demand of consumers are currently connected to nearly half of installed capacity for heat production, and the average load electric power generation capacity (Figure 5) was obtained 31 ... 55% ie a capacity of 300MW. Share of production of thermal energy in the form of steam is negligible, ranging between 2 and 5%.

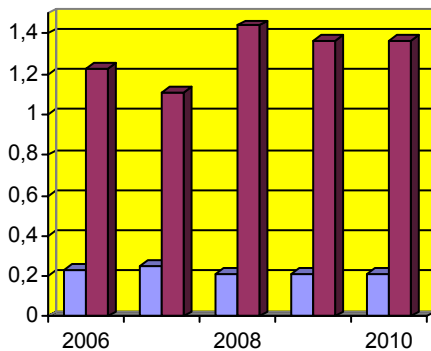


Fig. 3 Variation of the degree of heating, respectively an index structure of energy production

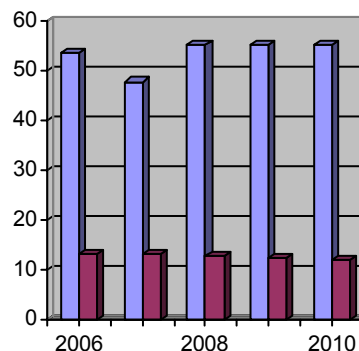


Fig. 4 Capacity average load for producing electrical and thermal energy

In the analysis of economic performance, it may indicate that the fuel costs for CET Craiova II is about 57% of total production costs.

Evolution ratio between average specific cost of producing useful energy (heat and electricity) and the average purchase price of primary energy is influenced primarily by the latter, and the relationship between fixed costs and variable and range from 2.94 and 3.47, and the five-year average is 3.22.

Heat is obtained at a unit cost below the national reference price represented than other CHPs specific cost of electricity production corrected with relatively high. This is due to strong charge condensing steam turbines, heat or low level achieved between 0.2 and 0.29.

Craiova II CET economic performance reflects actual conditions in which this plant has operated in the past five years, the electricity production has been done especially without a condensing heat applications installed production capacity measure.

4. PROPOSALS TO IMPROVE THE PERFORMANCE CET CRAIOVA II

Technical performance of C.E.T. Craiova II is good fitting and operation for today conditions. From a technical standpoint, the only way to improve it makes it possible to search and connection of new customers to the existing network heat. Load increase production capacity installed in CHP can improve its economic performance.

Installing a new performance unit, an excess capacity will not bring any significant improvement in performance terms CET. In principle, increasing the average annual heat index would help improve their performance. Negative effects that would convey preferential load the rest of the new units CET existing aggregates could significantly reduce this advantage.

A Method of Optimizing the economic and technical parameters of CET 2 Craiova by Increasing the heat index by 60% as of 11 CT neighborhood assignation Craiova existing system by installing new connections with lengths between 100 m and 400 m maximum pre-insulated pipe with DN 150 mm Directly in the soil environment. Would this supplement the heat output at Least 88,000 Gcal per year without affecting the economic and technical activity allowing FOG Increasing heating by 60%, the index structure of energy production by 16.5% (Fig. 5), return on net 19.6% overall (Fig. 6), the load average thermal energy production capacity by 16.6% (Fig. 7) Electricity Consumption and Their share by 2.17% (Fig. 8).

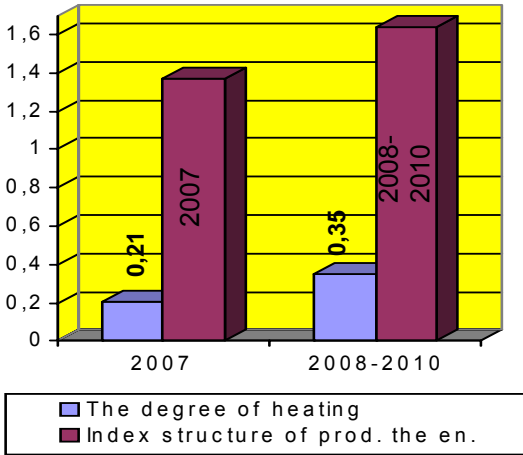


Fig. 5 Variation of heating degree from Craiova CET II, after processing in PT CT sites in Craiova New

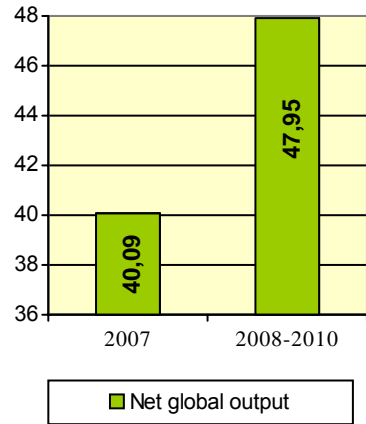


Fig. 6 The benefits of global net CET Craiova II after its processing in PT CT sites in Craiova New

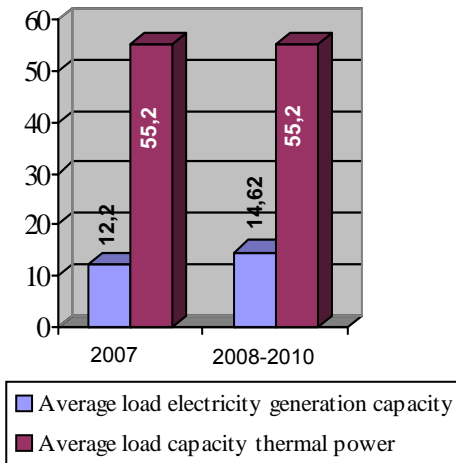


Fig. 7 Variation of average loading capacity of thermal power CET II after processing in PT CT sites in Craiova New

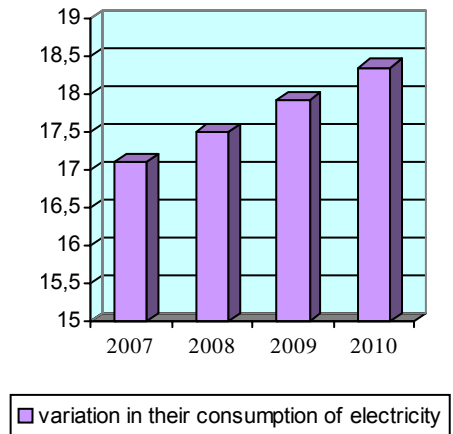


Fig. 8 Change in consumption of electricity by transforming the PT CT sites in Craiova New

5. CONCLUSIONS

Following the expansion in Craiova Craiova II CET New heating plants by transforming CT1, CT2, CT3, CT6, CT6A, CT7, CT8, CT9, CT10, CT11 and CT12 in thermal, since 2005, total investment in CHP are 124.23 billion lei (12.423 RON mill). Considering that the proceeds from the extension would be a total of 330.06 billion lei (33.006 RON mill), return on investment would be possible in 5 years.

Light of changing price of fuel used to produce heat, gigacalories price increase under these conditions is estimated at around 45 Euro / Gcal, excluding VAT.

Load increase production capacity installed in CHP can improve its economic performance, own consumption of electricity and heating technology of producing two forms of energy allowing energy costing more accurately delivered.

Stands out the most viable solution is a centralized heat production because there holding leads to a decrease in coal prices from 18 to 15.6 € / t

Local CHP as effective if not different loads minimum load thermal power-max and min-max thermal power.

Autonomous investment required for expansion of District CET is cost effective and can be done from own sources, the energy efficiency optimization programs, leading to a more efficient environmental costs.

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ANALIZA ENERGETSKE I EKONOMSKE EFIKASNOSTI RAZDVOJENIH SISTEMA U SISTEMU CENTRALIZOVANOG SNABDEVANJA TOPLOTNOM I RASHLADNOM ENERGIJOM

Šefik Bajmak¹

Rezime: U mnogim granama privrede široko se primenjuje toplotna i rashladna energija za ostvarivanje različitih tehnoloških procesa. Na osnovu analize projektnjih rešenja ustanovljeno je, da pri centralizovanom snabdevanju rashladnom energijom sa vodom kao nosiocem rashladne energije, uložena sredstva na jedinicu proizvodne rashladne energije mogu se smanjiti do 2 puta, predviđenu snagu rashladne stanice (oprema) do 1,3 puta, troškovi elektro energije do 1,5 puta a broj radnika koji opslužuje rashladni sistem od 2,5 do 3,5 puta. U tom cilju, u radu su analizirane ekonomski i energetski pokazatelji razdvojenjih sistema centralizovanog snabdevanja rashladnom energijom za uslove našeg podneblja kod sledećih varijanti:

- *Toplifikaciona termocentra (TEC) – Absorbiciona rashladna stanica (ABRS) ;*
- *Toplifikaciona termocentra (TEC) –Ejektorska rashladna stanica (ERS) ;*
- *Kondenzaciona termocentrala (KEC) – kotao - Turbo kompresorska rashladna stanica (TKRS) ;*

Na osnovu izloženog proizilazi, da uporedo sa poznatim pokazateljima klimatskog zoniranja, sversishodnije je sprovesti klimatsko zoniranje po kompleksnoj veličini

$$A = \bar{K}_{oh} \cdot \bar{n} + \bar{K}_{stv} (\bar{n} + 1)$$

Ključne riječi: analiza, efikasnost, energetska, ekonomska, daljinskoMgrejanja i hlađenje,

ANALYSIS OF ENERGY EFFICIENCY AND ECONOMIC SEPARATED SYSTEMS WITHIN THE SUPPLY CENTRALIZED HEAT AND COOLING ENERGY

Abstract: *In many industries and is widely applied heat and cooling energy to achieve different technological processes. Based on the analysis of project solutions was determined that the centralized supply of cooling energy with water as a carrier of cooling energy, amount spent per unit of production from cooling energy can be reduced to 2 times the intended effect of cooling stations (equipment) up to 1.3 times, the cost of electrical energy by 1.5 times and the number of workers who serviced the cooling system from 2.5 to 3.5 times. To this end, this paper analyzes the economic and energy indicators disaggregated system of centralized supply cooling energy requirements for our area of the variants:*

- *Heating-power station (HPS) - an absorption refrigeration cells (ARC);*

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- Heating-power station (HPS) -Ejectors cooling stations(ECS);
- Condensing power plant (CPP) - boiler - Turbo compressor cooling stations (TCCS);

Based on the above it follows that along with known indicators of climate zoning, all encompassing climatic zoning is implemented by the size of the complex $A = \bar{K}_{oh} \cdot \bar{n} + \bar{K}_{stv} (\bar{n} + 1)$

Keywords: analysis, effectiveness, efficiency, economy, district heating and cooling,

1. OSNOVNI NAČELA I IZRAZI U ANALIZI ENERGETSKIH I EKONOMSKIH POKAZATELJA

Za ocenu ekonomske efektivnosti razdvojenih SCSTRE treba analizirati sledeće moguće kombinacije : prva-TEC-ABRS; druga- TEC-EJRS; treća- KEC-kotao-TKRS.U prvom i drugom slučaju leti snabdevanje rashladnom energijom ostvauje se pomoću ABRS ili EJRS, a grejanje u zimskom periodu i celogodišnje snabdevanje sanitarnom toplom vodom ostvauje se na bazi snabdevanja toplotnom energijom sa toplifikacionog oduzimanja TEC. U trećem slučaju , leti sanbdevanje rashladnom energijom ostvaruje se pomoću TKRS na bazi snabdevanja energijom od KEC, a zagrevanje u zimskom periodu i celogodišnje snabdevanje sanitarnom toplom vodom ostvauje se na bazi toplotne energije proizvedne u rejonskoj kotlarnici. Pošto se primenjuje te ista oprema, uložena sredstva u SCSTRE sa kombinacijom TEC-ABRS i TEC-EJRS su od prilike ista. Uložena sredstva u SCSTRE sa kombinacijom KEC-kotao-TKRS su veća , nego uložena sredstva za SCSTRE sa kobinacijom KEC-TKRS za vrednost rejonske kotlarnice. Specifična uložena sredstva u kompleks KEC-rejonska kotlarnica-eletrična mreža iznosi respektivno:

$$\bar{T}_{KEC-RK-EM}^{TKO} / \bar{T}_{KEC-RK-EM}^{CG} / \bar{T}_{KEC-RK-EM}^{TG} = 2260/1410/1110 / (Eura/KW)$$

Specifična uložena sredstva u SCSTRE sa kombinacijom TEC-ABRS prikazana su na slici 2 a za SCSTRE sa KEC-kotao-TKRS iznosi respektivno

$$\bar{T}_{KEC-RK-TKRS}^{TKO} / \bar{T}_{KEC-RK-TKRS}^{G} / \bar{T}_{KEC-RK-TKRS}^{TG} = 3000 / 2150 / 1850 / (Eura/KW).$$

Da bi odredili eksploatacione troškove neophodno je predhodno da odredimo energetske pokazatelje razmatranog SCSTRE. U prvom redu treba izraziti godišnju potrošnju toplote dobijenu u kotlovima TEC, KEC i rejonske kotlarnice neophodnu za pokrivanje toplotnih opterećenja za potrebe zagrevanja i snabdevanja sanitarnom toplom vodom , a takoše i za potrebe snbdevanja rashladnom energijom SKV. Potrošnja toplote u TEC Q_{TEC}^h za pokrivanje sezonskog opterećenja sezonskog toplotnog dobitka $Q_{td} n_h$ pomoću ABRS ili EJRS određuje se po izrazu:

$$Q_{TEC}^h = Q_{td}^sr n_h q_{SCSTRE}^{TEC-TRM} \quad (1)$$

Potrošnja toplote u TEC za potrebe grejanja zimi Q_{TEC}^{sr} i celogodišnje snabdevanje sanitarnom toplom vodom Q_{TEC}^{stv} određuje se po sledećim izrazima:

$$Q_{TEC}^{sr} = \frac{Q_{gr} n_{gr}}{\eta_{iv} \eta_{kp} \eta_{gut} \eta_{kv} \varphi} \quad (2); \quad Q_{TEC}^{stv} = \frac{Q_{stv} (n_h + n_{gr})}{\eta_{iv} \eta_{kp} \eta_{gut} \varphi} \quad (3)$$

Ukupna specifična potrošnja toplote u kotlu pri kombinaciji TEC-TRM , za celogodišnje snabdevanje toplotnom i rashladnom energijom rejona pomoću SCSTRE , u odnosu na srednosezonsko opterećenje od toplotnih dobitaka $Q_{td}^{sr} n_h$ određuje se pomoću obrasca:

$$q_{SCTRE}^{TEC-TRM} = q_{SCRE}^{TEC-TRM} + \frac{\bar{K}_h n + \bar{K}_{stv} (n+1)}{\eta_{tv} \eta_{kp} \eta_{gui} \eta_{gu,kv} \rho} \quad (4)$$

Pri čemu je : $\bar{K}_{oh} = \frac{Q_{gr}}{Q_{id}^{sr}}$; $\bar{K}_{stv} = \frac{Q_{stv}}{Q_{id}^{sr}}$; $\bar{n} = \frac{n_{gr}}{n_h}$

Ukupna proizvodnja energije u TEC po toplifikacionom režimu za potrebe grejanja i pripremu sanitarne tople vode određuje se po izrazu:

$$P_{TEC}^{gr} + P_{TEC}^{stv} = [Q_{gr} n_{gr} + Q_{stv} (n_{gr} + n_h)] \frac{(\eta_{TEC}^T + 0,43 \eta_{TEC}^K \bar{I}) \eta_{oi}}{(1 - \eta_{TEC}^T \eta_{oi}) \eta_{gut}} \quad (5)$$

Potrošnja energije za cirkulacione pumpe tranzitnog toplovoda od TEC do potrošača za grejanje i pripremu sanitarne tople vode izračunava se po izrazu:

$$P_{CP} = \frac{10^{-3} \Delta p_{tp}}{c_{nt} \rho_{nt} \eta_{pu}} \left[\frac{Q_{stv} (n_{gr} + n_h)}{\Delta t_{stv}} + \frac{Q_{gr} n_{gr}}{\Delta t_{gr}} \right] \quad (6)$$

Proizvodnja korisne energije po toplifikacionom režimu za zagrevanje i za pripremu sanitarne tople vode može se izraziti sledećim izrazom:

$$P_{TEC}^{gr, stv} = P_{gr} + P_{stv} - P_{cp} = [Q_{gr} n_{gr} + Q_{stv} (n_{gr} + n_h)] \cdot \left[\frac{(\eta_{TEC}^T + 0,43 \eta_{TEC}^K \bar{I}) \eta_{oi}}{1 - \eta_{TEC}^T \eta_{oi} \eta_{gut}} - \frac{10^{-3} \Delta p_{tt}}{c_{nt} \rho_{nt} \eta_{pu}} \right] \quad (7)$$

Proizvodnja korisne energije $P_{TEC}^{h,k}$ po toplifikacionom režimu za potrebe toplotnih rashladnih mašina (absorpcione rashladne mašine, ejektorske rashladne mašine) određuje se po izrazu:

$$P_{TEC}^{h,k} = P_{TEC}^h - P_{TT,P} - P_{KU,TEC} - P_{TPM,P} - P_{KU,TM} \quad (8)$$

Odnosno posle sređivanja izraza (8) imamo da je:

$$P_{TEC}^h = \frac{Q_{id}}{\eta_{gu,h} \cdot \eta_{gu,kv} \cdot \eta_{gu,t} \cdot \xi_{AB}} \left\{ \eta_{oi} \frac{\eta_{TEC}^{to} + 0,43 \cdot \eta_{TEC}^{ko} \cdot I}{1 - \eta_{TEC}^{to} \cdot \eta_{oi}} - \frac{10^{-3}}{\eta_{pu} \cdot c_w} \left[\frac{\Delta p_{tt,p}}{(t_{nt} - t_{kon}) \cdot \rho_w} + \frac{0,43 \cdot \Delta p_{ku,TEC} \cdot (1 - \eta_{TEC}^{ko} \cdot \eta_{oi})}{\rho_w \cdot \Delta t_w \cdot (1 - \eta_{TEC}^{to} \cdot \eta_{oi})} + 10^3 \cdot \Omega_{AB} \cdot \frac{\xi_{AB} \cdot \eta_{gu,t} \cdot \eta_{pu} \cdot c_w}{\eta_{gu,e}} + \frac{(1 + \xi_{AB}) \cdot \eta_{gu,t}}{\eta_{gu,e}} \left(\frac{\Delta p_{ku,p}}{\rho_w \Delta t_w} + \frac{\Delta p_{ku,ve} \cdot \eta_{pu} \cdot c_{nt}}{c_v \cdot \rho_v (t_s - t_{vt}) \cdot \eta_{ku} \cdot \eta_{ve}} \right) \right] \right\} \quad (9)$$

Podelimo i pomnožimo li jednačinu (7) sa $Q_{id} n_h$ za određivanje $P_{TEC}^{gr, stv}$ imamo sledeći izraz:

$$P_{TEC}^{gr, stv} = Q_{id} \cdot n_h \left[\bar{K}_{oh} \bar{n} + \bar{K}_{stv} (\bar{n} + 1) \right] \cdot \left[\frac{(\eta_{TEC}^T + 0,43 \eta_{TEC}^K \bar{I}) \eta_{oi}}{1 - \eta_{TEC}^T \eta_{oi} \eta_{gut}} - \frac{10^{-3} \Delta p_{tt}}{c_{nt} \rho_{nt} \eta_{pu}} \right] \quad (10)$$

Temperaturni pad Δt_{nt} u izmenjivaču toplote rejonskog toplotnog izvora za pripremu sanitarne tople vode za grejanje i pripremu sanitarne tople vode uzima se da je $\Delta t_{nt} = 15^0 C$. Na osnovu izraza (9) i (10) možemo odrediti ukupnu godišnju proizvodnju korisne električne energije po toplifikacionom režimu:

$$\Sigma P_{TEC}^k = P_{TEC}^{h,k} + P_{TEC}^{gr,stv} \quad (11)$$

U formuli (10) kompleksna veličina (12)

$$\frac{Q_{gr}n_{gr} + Q_{stv}(n_{gr} + n_h)}{Q_{id}n_h} = \frac{Q_{gr}n_{gr}}{Q_{id}n_h} + \frac{Q_{stv}(n_{gr} + n_h)}{Q_{id}n_h} = \bar{K}_{oh}\bar{n} + \bar{K}_{stv}(\bar{n} + 1) = A \quad (12)$$

Karakteristiše se klimatskim uslovima i potrebnom energijom rejonu. Ova veličinu nazivamo često energetska – klimatološkim pokazateljem rejonu i označavamo je sa A. Na osnovu analize za naše uslove ovaj pokazatelj iznosi: $A = 2,5762$

Na osnovu formula (4) i (11) možemo izračunati vrednosti specifične potrošnje toplote q_{SCSTRE}^{TEC-TM} i ukupnu specifičnu proizvodnju korisne električne energije ΣP_{TEC}^{kor} kod odgovarajućih temperatura nosioca toplote Δt_{nt} , vrste goriva i toplifikacionog ciklusa. Rezultati proračuna su prikazani na slici 1,2,3 i 4. Specifični eksploatacioni troškovi goriva određuju se prema izrazu:

$$\bar{T}_{gor} = 3600 q_{SCSTRE}^{TEC-TM} \frac{C_{gor}n_h}{H_d} \quad (13)$$

Na osnovu izloženog, celokupna analiza je prikazana na slici 1,2,3 i 4 za TEC-TM za rejon gde je $A = 2,5762$. Za energetske razdvojene SCSTRE sa kombinacijom KEC-kotao-TKRS, specifična potrošnja toplote određuje se iz uslova, da se u KEC proizvodi korisna električna energija u količini ΣP_{TEC}^{ko} i energija P_{KEC}^h za proizvodnju rashladne energije sa ciljem pokrivanja toplotnih dobitaka $Q_{id}n_h$, a u kotlarnici se proizvodi toplota za pokrivanje potreba grejanja i pripreme sanitarne tople vode. Na osnovu ovoga, ukupna godišnja proizvodnja energije u KEC treba da bude jednaka izrazu:

$$P_{KEC} = P_{KEC}^h + \Sigma P_{TEC}^{ko} + P_{KEC-TK}^{sop} \quad (14)$$

Ukupna godišnja potrošnja toplote Q_{KEC}^{RK} u SCSTRE sa kombinacijom KEC-rejonska kotlarnica-TKRS jednaka je izrazu:

$$Q_{KEC}^{RK} = Q_{KEC} + Q_{REK} \quad (15)$$

Veličina P_{KEC}^h određuje se po izrazu:

$$P_{KEC}^h = \frac{Q_{id}n_h}{\eta_{kv}\eta_{guh}\eta_{tk}\eta_{gue}\varepsilon} \quad (16)$$

Sopstvena potrošnja energije SCSTRE određuje se po izrazu:

$$P_{KEC-TEK}^{sop} = 0,12 Q_{id}n_h \quad (17)$$

Ukupna godišnja proizvodnja energije u KEC jednaka je izrazu:

$$P_{KEC} = Q_{id}n_h \left(\frac{1}{\eta_{kv}\eta_{guh}\eta_{tk}\eta_{gue}\varepsilon} + \frac{\Sigma P_{TEC}^{kr}}{Q_{id}n_h} + 0,12 \right) \quad (18)$$

Potrošnja toplote u kotlovskom agregatu KEC za proizvodnju snage P_{KEC} pri sledećim vrednostima $\eta_{kv} = 0,95; \eta_{guh} = 0,93; \eta_{tk} = 0,70; \eta_{gue} = 0,95; \varepsilon = 6,5$; iznosi:

$$Q_{KEC} = \frac{Q_{id}n_h}{\eta_{KEC}^T \eta_{kp} \eta_{oi}} \left(0,4604 + \frac{\Sigma P_{KEC}^K}{Q_{id}n_h} \right) \quad (19)$$

Potrošnja toplote u rejonskoj kotlarnici (RK), Q_{REK} za potrebe pokrivanja opterećenja grejanja i pripreme sanitarne tople vode izračunava se po izrazu:

$$Q_{REK} = \frac{Q_{stv}(n_{gr} + n_h) + Q_{gr}n_{gr}}{\eta_{kp}} = Q_{id}n_h \frac{\bar{K}_{stv}(\bar{n} + 1) + \bar{K}_h\bar{n}}{\eta_{kp}} \quad (20)$$

Nakon sređivanja izraza (15) immao da je :

$$Q_{KEC}^{RK} = Q_{id}n_h \left[\frac{A}{\eta_{rek}} + \frac{1}{\eta_{KEC}^T \eta_{kp} \eta_{oi}} \left(0,4604 + \frac{\Sigma P_{TEC}^{kor}}{Q_{id}n_h} \right) \right] \quad (21)$$

Ukupna specifična potrošnja toplote za pokrivanje 1KW toplotnog dobitka u SCSTRE sa kombinacijom KEC-rejonska kotlarnica-TKRS proizilazi iz izraza (21) i jednaka je izrazu:

$$q_{SCSTRE}^{KEC-TK} = \frac{Q_{KEC}^{RK}}{Q_{id}n_h} = \frac{A}{\eta_{rek}} + \frac{1}{\eta_{TEC}^T \eta_{kp} \eta_{oi}} \left(0,4606 + \frac{\Sigma P_{TEC}^{kr}}{Q_{id}n_h} \right) \quad (22)$$

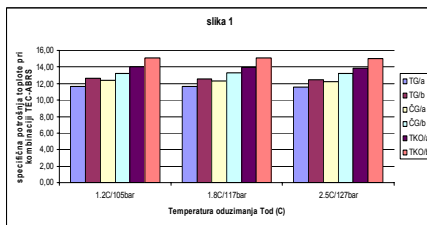
Specifični eksploatacioni troškovi goriva izračunavaju se po izrazu:

$$\bar{T}_{gor} = 3600 q_{SCSTRE}^{KEC-TK} \frac{C_{gor}n_h}{H_d} \quad (23)$$

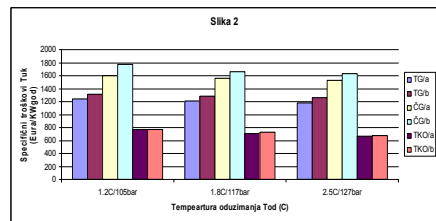
Specifični troškovi uloženi u kompleks KEC-RK-TKRS- vod tople i hladne vode iznose, respektivno: $\bar{T}_{SIS} = \bar{T}_{TKO} / \bar{T}_{TG} / \bar{T}_{TG} = 3000 / 2150 / 1850 / (Eura / KW)$. Za ovaj sistem celokupna analiza je prikazana na slici 5 i 6. Uslov relativne energetske prednosti razmotrenog sistema SCSTRE izražava se nejednačinom:

$$q_{SCSTRE}^{KEC-TK} / q_{SCSTRE}^{TEC-ABRS} < 1 \quad (24)$$

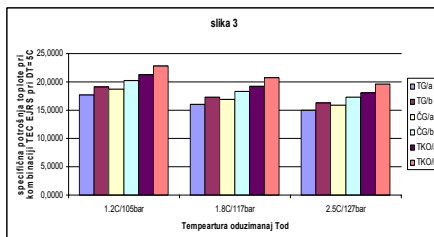
Na osnovu ovog odnosa definišemo vrednost kompleksa A pri kome SCSTRE sa kombinacijom KEC-kotao-TKRS je ekonomski efektivniji u poređenju sa SCSTRE sa kombinacijom TEC-ABRS ili TEC-EJRS.



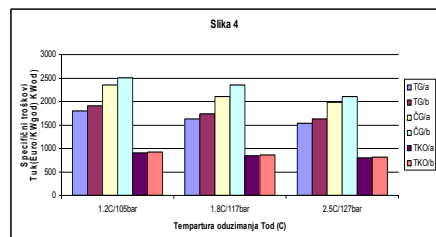
Slika 1. Energetski pokazatelji sistema sa TEC-ABRS



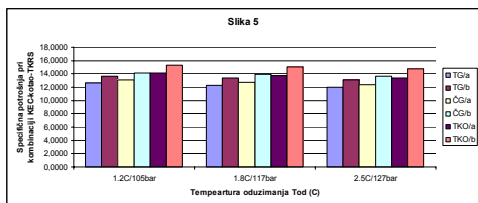
Slika 2. Ekonomski pokazatelji sistema sa TEC-ABRS



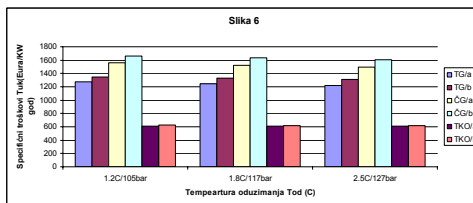
Slika 3. Energetski pokazatelji sistema sa TEC-EJRS



Slika 4. Ekonomski pokazatelji sistema sa TEC-EJRS



Slika 5. Energetski pokazatelji sistema sa KEC-koatao-TKRS



Slika 6. Ekonomski pokazatelji sistema sa KEC-kotao-TKRS

2. ZAKLJUČAK

U ovom radu su analizirane ekonomska i energetska efektivnost za usvojenu energetska strukturu. Radi verodostojnijeg prikaza problema analiza je sprovedena za:

1. toplifikacionu termocentralu (TEC) i kondenzacionu termocentralu (KEC) na čvrsto i tečno gorivo i za tvrdi komunalni otpad (spalionu otpada);
 2. temperaturu nosioca toplotne energije je izabrana respektivno , 105/117/127⁰C ;
 3. toplifikacione cikluse bez međupregrevanja (ciklus „a“) i sa međupregrevanjem (ciklus „b“);
 4. analizirani su sledeće kombinacije:
 - ✓ toplifikaciona termocentrala – absorbciona rashladna stanica ;
 - ✓ toplifikaciona termocentrala – ejektorska rashladna stanica ;
 - ✓ kondenzaciona termocentrala – kotao – turbokompresorska rashladna stanica;
- Na osnovu analize može se utvrditi sledeće :

- ✓ Proizvodnja toplotne i rashladne energije u sistemu centralizovanog snabdevanja toplotnom i rashladnom energijom sa toplifikacionom termocentralom i ejektorskom rashladnom stanicom (SCSTRE-TEC-EJRS) je skuplja u odnosu na sistem centralizovanog snabdevanja toplotnom i rashladnom energijom sa toplifikacionom termocentralom i absorbcionom rashladnom stanicom (SCSTRE-TEC-ABRS) za 17÷45%. Manja vrednost procenta se odnosi na toplifikacionu termocentralu (TEC) koja kao gorivo koristi tvrdi komunalni otpad (TKO).
- ✓ Sistem centralizovanog snabdevanja toplotnom i rashladnom energijom sa toplifikacionom termocentralom i absorbcionom rashladnom stanicom (SCSTRE-TEC-ABRS) na TKO je jeftiniji za 60÷80% u odnosu na tečno gorivo, a 2÷2,3 puta u odnosu na čvrsto gorivo;
- ✓ Upoređivanje specifičnih troškova ,sistema centralizovanog snabdevanja toplotnom i rashladnom energijom sa kondnzacionom rashladnom stanicom – kotlom i turbokompresorskom rashladnom stanicom (SCSTRE-KEC-koatao-TKRS) , je efektivniji u odnosu na SCSTRE-TEC-ABRS i SCSTRE-TEC-EJRS. Ta efektivnost je izražena kod toplifikacione termocentrale (TEC) na tvrdi komunalni otpad.
- ✓ Uslov relativne energetske prednosti sistema centralizovanog snabdevanja toplotnom i rashladnom energijom sa kondnzacionom rashladnom stanicom – kotlom i turbokompresorskom rashladnom stanicom (SCSTRE-KEC-koatao-TKRS) u odnosu na sistem centralizovanog snabdevanja toplotnom i rashladnom energijom sa toplifikacionom termocentralom i absorbcionom

rashladnom stanicom (SCSTRE-TEC-ABRS) izražava se nejednačinom

$$q_{SCSTRE}^{KEC-TK} / q_{SCSTRE}^{TEC-ABRS} < 1$$

Iz izloženog proizilazi, da uporedo sa poznatim pokazateljima klimatskog zoniranja, svesishodnije je sprovesti klimatsko zoniranje po kompleksnoj veličini $A = K_{oh} \cdot \bar{n} + K_{stv}(\bar{n} + 1)$, omogućavajući na taj način ocenu energetske svesishodnosti korišćenja odgovarajućeg tipa SCSTRE.

3. OZNAKE I ZNAČICE

A-Energetsko klimatološki pokazatelj reiona; Q - toplotna energija ,KW; η -koeficijent korisnog dejstva; n -vreme trajanja perioda grejanaj ili hlađenja; $\bar{K}_{oh}, \bar{K}_{stv}$ -konstante; P -električna energija , KW; φ -koeficijent, energetski gubitak u truboagregatu i toplifikacionom ciklusu; C -cena (Eu/kg ili u Eu/KW) ; \bar{T} -specifični troškovi, Eu/KWgod; \bar{T}_{gor} - specifični eksploatacioni troškovi za gorivo, Eu/KW; $q_{SCSTRE}^{TEC-TRM}$ - specifična potrošnja toplote u termocentrali za potrebe SCSTRE sa TRM, KW_{te} / KW_{re} ; q_{SCSTRE}^{TEC-TK} specifična potrošnja toplote za pokrivanje 1KW toplotnog dobitka u SCSTRE sa kombinacijom KEC-REK-TKRS, KW_{te} / KW_{re} ;

SCSTRE-sistema centralizovanog snabdevanja toplotnom i rashladnom energijom; TEC-ABRS- toplifikaciona termocentrala –absorbciona rashladna stanica; TEC-EJRS- toplifikaciona termocentrala-ejektorska rashladna stanica; KEC-TKRS-kondenzaciona termocentrala - turbokompresorska rashladna stanica; KEC-kotao-TKRS kondenzaciona termocentrala –kotao-turbokompresorska rashladna stanica;ABRS-absorbciono rashladne stanice;EJRSejektorske rashladne stanice ;TEC- toplifikaciona termocentrala;TKRS-turbokompresorske rashladne stanice;KEC -kondenzaciona termocentrala ; TEC-TRM-toplifikaciona termocentrala –toplotne rashladne mašine (absorbciona ili ejektorska ;TEC-TM-toplifikacionu termocentralu – toplotne mašine ;KEC-RK-TKRS-kondenzaciona termocentrala-rejonska kotlarnica- turbokompresorska rashladna stanica; TKO-tvrđi komunalni otpad; TG-tečno gorivo; CG-čvrsto gorivo;TT,P-tranzitni cevovod , pumpa; KU-TEC-rashladna kula termocentrale;KU-TM-rashladna kula toplotne rashladne mašine ;EM-električna mreža; TRM-toplotna rashladna mašina; gr-grejanje; stv-sanitarna topla voda; gu,t-gubitak toplote; gu,e-gubitaka električne energije; ku-kula; ve-ventilator; sr-srednja; td-toplotni dobici; kp-kotlovska postrojenja; ttv-tranzitni toplovod; gor-gorivo

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IZBOR PRORAČUNA KOD VERTIKALNOG PNEUMATSKOG TRANSPORTA PRAŠINASTOG MATERIJALA

Jela Burazer¹ Dragana Kalabić², Mirko Dobrnjac³,

Rezime: Jedan od najzastupljenijih vidova transporta materijala u različitim granama industrije jeste pneumatski transport. Mogući su različiti proračuni ovakvog vida transporta. U ovom radu se razmatra uticaj vrste primenjenog proračuna na pad pritiska.

Ključne riječi: pneumatski transport, fluid-lift, proračun.

CALCULATION CHOICE AT THE VERTICAL PNEUMATIC TRANSPORT OF THE DUST MATERIAL

Abstract: One of the most common types of material transport in different branches of industry is pneumatic transport. There are different types of calculations of this kind of transport. The influence of different kind of calculation on the pressure drop is the subject of this work.

Keywords: pneumatic transport, fluid-lift, calculation.

1. UVOD

Još od kraja XIX veka kada se vazduh prvi put počeo koristiti za transport prašiniastih i zrnastih materijala, pa sve do danas, pneumatski transport je, sasvim zasluženno, zauzeo značajno mesto u hemijskoj, metaloprerađivačkoj industriji u poljoprivredi ali i u svakodnevnom transportu administrativnih pošiljki u poštama, novinskim agencijama. Jednostavno, kada se uporedi ovaj vid transporta sa npr. mehaničkim, uvideće se čitav niz prednosti. Prostorno gledano, pneumatski transport se može obavljati u svim pravcima i položajima transportnog voda, tj. horizontalno, vertikalno, sa nagibom pod nekim uglom, prilagođavajući se potrebama, raspoloživom prostoru i ostalim uslovima. Obzirom na druge načine, transport materijala kroz cev nosi niz prednosti, smanjeno je rasipanje transportovanog materijala a samim tim i zagađivanje okoline. Dakle, higijenski uslovi su poboljšani u odnosu na druge vidove transporta. Imajući u vidu da se kao fluid za transport koristi vazduh, jasno je da se transportovani materijal u toku samog transporta može sušiti ili vlažiti u zavisnosti od tehnoloških zahteva i termofizičkih parametara vazduha.

Postavlja se pitanje načina proračuna jednog ovakvog vida transporta. Cilj ovog rada je određivanje razlike u padu pritiska koji se dobije, ako se primene dva

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različita proračuna.

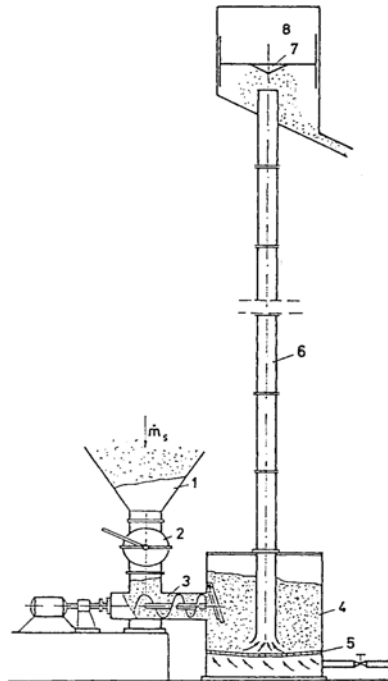
2. VERTIKALNI PNEUMATSKI TRANSPORT

Kada se spominje pneumatski transport onda se najčešće misli na transport prašinih i zrnastih materijala cevima i kanalima u struji vazduha. Vrlo često se susreće pri istovaru, pretovaru ili odvozu prašinih ili zrnastih materijala u rasutom stanju, kao što su npr. cement, koncentrat stočne hrane, žitarice, biljno seme, ugajl u prahu kao i elektrofilterski pepeo u velikim kotlarnicama i termoelektranama, deterdženti uprahu i kalcinisana soda u hemijskoj industriji i dr.

Već je ukazano na činjenicu da se pneumatski transport može odvijati u najrazličitijim pravcima. Jedan od specijalnih vidova pneumatskog transporta jeste pneumatski transport u vertikalnom pravcu koji se vrlo često naziva fluid lift. Naime, reč je o transportu materijala u vertikalnom pravcu na gore, uz pomoć vazduha koji struji određenom brzinom.

Materijal koji je potrebno transportovati fluid liftom se doprema iz silosa i preko dozatora dospeva u korito puža, odakle se potom potiskuje u komoru za fluidizaciju. Donji deo ove komore čini porozno dno kroz koje se uduvava vazduh ravnomerno po celom poprečnom preseku ove komore. Vazduh struji između čestica materijala brzinom koja mora biti veća od druge kritične brzine fluidizacije. Usled toga, dolazi do fluidizacije transportovanog materijala i njegovog kretanja vertikalno naviše kroz cev na čijem kraju se nalazi prigušnik čija je uloga stvaranje potrebnog protivpritiska na kraju strujnog toka.

Zbog naglog proširenja protočnog preseka u gornjoj komori, materijal se izdvaja iz vazdušne struje a vazduh sa delom sitnijih čestica prolazi kroz filter i izlazi u atmosferu.



Sl.1 Shematski prikaz fluid lifta:
1–silos, 2–sektorski dozator, 3–korito puža, 4–komora za fluidizaciju, 5–porozno dno, 6–cev, 7–prigušnik, 8–filter [2]

3. PRORAČUN FLUID LIFTA

Postoje različiti pristupi proračunu fluid lifta. Ako se strujanje vazduha smatra nestišljivim, ukupan pad pritiska pri strujanju vazduha između čestica materijala je posledica dizanja materijala Δp_g , trenja fluidizovanih čestica o unutrašnjost cevi Δp_{tr} i savladavanja protivpritiska na kraju cevi Δp_e [1]:

$$\Delta p = \Delta p_g + \Delta p_{tr} + \Delta p_e. \quad (1)$$

Pad pritiska usled trenja vazduha o zid cevi se uglavnom zanemaruje. Koristeći Darsijev obrazac i jednačinu ravnoteže sila koje deluju na masu fluidizovanog materijala, dobija se algebarski izraz za određivanje pada pritiska kao:

$$\Delta p_s = g \rho_\varepsilon L + \frac{4 \lambda_r \mu_r \Delta p_e L}{D}, \quad (2)$$

gde su: g [m/s²] - ubrzanje Zemljine teže, ρ_ε [kg/m³] - nasipna gustina transportovanog materijala, λ_r [-] - koeficijent srazmere između radijalnog i aksijalnog pritiska, μ_r [-] - koeficijent trenja transportovanog materijala o zid cevi, L [m] - visina dizanja materijala i D [m] - prečnik cevi fluid lifta.

Pri tom je potrebno odrediti Rejnoldsov broj prema sledećem izrazu:

$$Re_s = \frac{1}{1 - \varepsilon} \frac{w d}{\nu_v}, \quad (3)$$

pri čemu su: w [m/s] - brzina strujanja vazduha, d [m] - ekvivalentni prečnik kuglice, ε [-] - poroznost mešavine i ν_v [m²/s] - kinematička viskoznost vazduha na datoj temperaturi.

Da bi došlo do fluidizacije par vrednosti λ_s i Re_s se moraju nalaziti na krivoj koja se analitički može predstaviti sledećim izrazima:

$$\lambda_s = \frac{340}{Re_s}, \quad Re_s < 1 \quad i \quad (4)$$

$$\lambda_s = \frac{325}{Re_s} + \frac{9}{Re_s^{0,12}}, \quad 1 < Re_s < 10^4. \quad (5)$$

Pad pritiska se određuje u prvom koraku proračuna, pa se na osnovu te vrednosti u nastavku proračun sprovodi iterativno. Pretpostavlja se koeficijent λ_s , na osnovu kojeg se računa Rejnoldsov broj (3) pa se pomoću jednačine (4) ili (5) proverava pretpostavljena vrednost koeficijenta trenja dok se ne postigne unapred zadata tačnost.

Pri tome se protok vazduha koji je potreban da bi se ostvarila fluidizacija određuje iz izraza:

$$G_v = \frac{G_s}{\rho_v c_k} \quad [\text{m}^3/\text{s}], \quad (6)$$

gde su G_s [kg/s] kapacitet fluid lifta, c_k [kg/kg] masena koncentracija, ρ_v [kg/m³] gustina vazduha.

Sa druge strane, pad pritiska se može odrediti i kao zbir pada pritiska usled savladavanja otpora cevovoda Δp_n , usled podizanja pepela Δp_{pod} i pada pritiska na ulazu u cevovod Δp_{vh} [3]:

$$\Delta p = \Delta p_n + \Delta p_{pod} + \Delta p_{vh}. \quad (7)$$

Pad pritiska usled savladavanja otpora cevovoda se određuje iz izraza:

$$\Delta p_n = K c_k \lambda \frac{\rho_v w^2}{2g} \frac{L}{D} \cdot 10^{-4} \quad [\text{bar}], \quad (8)$$

gde su: $K = \frac{90D}{w^{0,9}}$ - koeficijent otpora i λ [-] koeficijent trenja hidraulički glatkih cevi.

Pad pritiska usled podizanja pepela se određuje primenom sledeće relacije

$$\Delta p_{pod} = \rho_v' c_k L \cdot 10^{-4} \text{ [bar]}, \quad (9)$$

pri čemu je ρ_v' srednja gustina vazduha uzimajući u obzir i raspodelu pritiska.
Iz izraza

$$\Delta p_{vh} = (\chi + c_k) \frac{\rho_{vh} w_h^2}{2g} \cdot 10^{-4} \text{ [bar]} \quad (10)$$

se određuje pad pritiska na ulazu u cevovod. U izrazu (10) brzina strujanja vazduha na ulazu u cevovod se određuje primenom relacije:

$$w_h = w \frac{\rho_o}{\Delta p_n + \Delta p_{pod} + 1} \text{ [m/s]}, \quad (11)$$

dok je gustina vazduha na ulazu u cevovod određena sa:

$$\rho_{vh} = \rho_v \frac{\Delta p_n + \Delta p_{pod} + 1}{\rho_o} \text{ [kg/m}^3\text{]}. \quad (12)$$

Za pepeo karakteristika navedenih u tabeli 1, urađen je proračun pada pritiska, prema prikazanim metodama. Prema prvo prikazanoj metodi, dobija se da je pad pritiska 0,121 bar, dok se primenom druge metode dobija vrednost 0,244 bar. Za fluidizaciju ovog materijala, pri prečniku cevi fluid lifta 250 mm i visini dizanja 18,9 m potrebno je obezbediti 3334 m³/h vazduha.

Tabela 1 Karakteristike pepela [2]

materijal	d, mm	ε	μ_r	λ_r
pepeo	0,14	0,545	0,5	0,2

4. ZAKLJUČAK

U radu su razmatrani različiti pristupi proračunu pada pritiska pri pneumatskom transportu materijala u fluid liftu. Vidi se da se manji pad pritiska dobija kada se proračun sprovodi prema metodi u kojoj se vazduh smatra nestišljivim. Međutim, iz izloženog postupka proračuna, kako u jednoj, tako i u drugoj metodi, vidi se da vrednost pada pritiska u velikoj meri zavisi od veličina μ_r i λ_r koje se određuju eksperimentalno. Takođe, tu su i podatak o prečniku ekvivalentne kuglice kao i koeficijent otpora K koji se određuje iz izraza koji je najverovatnije rezultat »fitovanja« krivih, koje su opet posledica nekog eksperimenta.

Ne može se sa sigurnošću reći koja je metoda tačnija i po kojoj treba sprovoditi proračun, budući da ima dosta uticajnih veličina koje se praktično mogu suviše slobodno usvajati.

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MATHEMATICAL MODEL OF THE SYSTEM FOR REGULATION OF ROLLING THICKNESS ON FIVE STRANDS TWIN TRAIN

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Abstract: the paper presents a mathematical model of the system for regulation of rolling thickness on five strands twin train.

Key words: mathematical model, rolling thickness, twin train.

1. INTRODUCTION

The system consists of: self-regulation piston-axial pump 1, filter 2, starting distributor 3, storage battery 4, servo-valve 5, hydraulic cylinder 8 with piston 9, lower support roller 10, lower working roller 11, rolling strip 12, upper working roller 13, upper support roller 14, device for setting up the given strip thickness (worm-pair) 15 together with strand casing 16, (spring with 15 denotes elasticity of complete structure) and an empty rectangle 18 which shows the electronic part of the system for automatic regulation. Number 17 denotes converter of position signal into electrical signal.

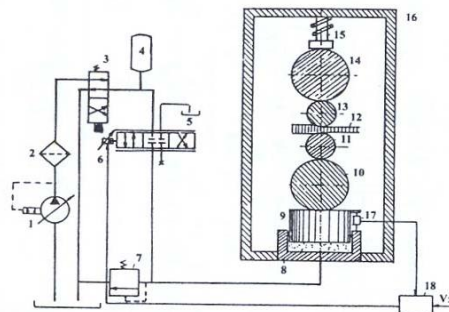


Fig. 1. System for automatic control of strip thickness

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2. PRINCIPLE OF OPERATION

Before entry into the strand, distributor 3 is in the position shown in the figure so that the piston 9 is withdrawn, and by threaded ring the clearance of the rollers is set up according to the entering strip thickness. After that the spindle is blocked and clearance regulation (i.e. strip thickness) is done by the system presented in the figure 1. Piston-axial pump 1 gives the constant pressure p , and the flow which is required by servo-valve 5. Computer 18, based on the wanted clearance of rollers and measuring value of cylinder position, sends the error signal into regulating part of servo-valve 6. Piston 9 presses the lower support roller and the lower support roller presses the lower working roller. Lower working roller presses the strip and effects the rolling force.

Structural diagram of this System for Automatic Control (SAC) is presented in fig. 2.

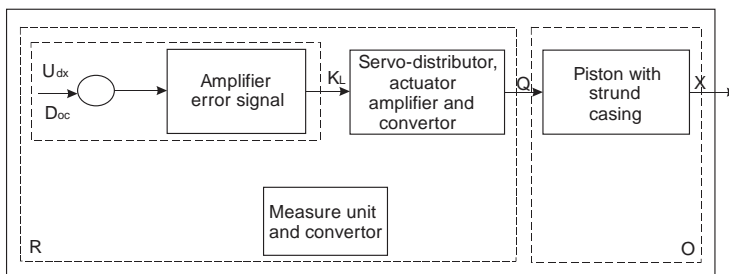


Fig 2. Structural diagram of the system for automatic control (SAC)

If the system from fig. 1 is drawn in a more detailed form appropriate for modeling, we shall obtain the models presented in fig. 3 and 4.

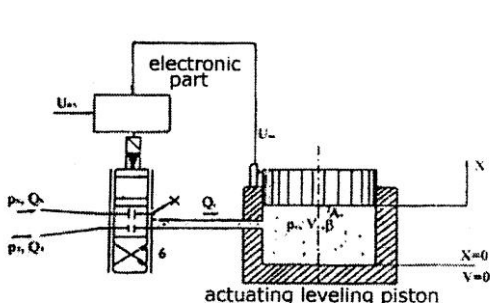
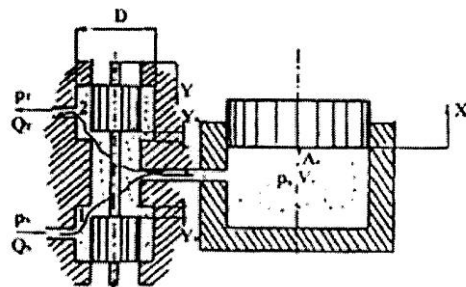


Fig. 3. Schematic diagram of the connection between servo-valve and cylinder



$A_1 = W \cdot (Y + Y_0)$; $A_2 = W \cdot (Y - Y_0)$
Fig. 4. Hydraulic diagram of servo-valve and cylinder

2. 1. Comparator, giver and amplifier (booster) of the error signal is the computer

Assumption 1: Flow through servo-valve openings is turbulent.

This assumption enables application of Bernouille's equation for 1-3 and 2-3 in the form:

$$Q_1 = \frac{C_d \cdot W}{Y_0} + \left[\frac{2}{\rho} \cdot (p_s - p) \right]^{\frac{1}{2}}, \quad Q_2 = \frac{C_d \cdot W}{Y_0} + \left[\frac{2}{\rho} \cdot (p - p_1) \right]^{\frac{1}{2}} \quad (1)$$

Assumption 2: Supply pressure at entry into the servo-valve is constant : $p_s = const$

1. Inertia forces of working fluid are negligibly small.
2. The effect of temperature change on working fluid is neglected , which as a consequence has the fact that the fluid has a constant viscosity.
3. Hydro-dynamic forces are very small, so that they are neglected.
4. Zone or insensitivity threshold in servo-valve is neglected.
5. The loss of flow though side openings between the piston and servo-valve casing is neglected.
6. Hysteresis in electro-mechanical converter (torque-motor) of servo-valve is neglected.
7. In the gear and mechanical connections dead strokes are neglected.
8. Non-linearity of saturation in each component (electronic booster, hydraulic booster, servo-valve piston stroke, slope plate of servo-pump etc.) is also neglected.
9. Oil compressibility module is constant and independent of pressure and temperature.
10. In working fluid (oil) the content of free air is negligible.
11. Pipes under pressure are absolutely rigid.
12. Flow orifice in servo-valve is rectangular, i.e. the area gradient of flow orifice $W = \frac{dA}{A}$ is a linear function of of servo-valve piston.
13. Servo-pump driving motor has the ideal mechanical characteristic, i.e. its revolutions are not the function of system load.
14. Coefficient $K_e = \frac{\partial Q_{sr}}{\partial p_{sr}}$ is the curve slope of a general static characteristic of servo-

valve in the working point.

Flow boosting coefficient of servo-valve $K_q = \frac{\partial Q_{sr}}{\partial Y}$ is the slope of servo-valve

flow characteristic and is valuable only in the limited working area, excluding the non-linear part of the curve and the saturation area. Storage battery volume is small.

2.2. Servo-valves

According to the literature, and due to the assumption that Tx as a very small value is neglected, for the case of distributor with negative overlap, Y_0 is written as a Bernouille's equation for 1-3 , i.e. 3-2 (fig. 4) so that:

$$Q_1 = \frac{C_d \cdot W}{Y_0} + \left[\frac{2}{\rho} \cdot (p_s - p) \right]^{\frac{1}{2}}, \quad Q_2 = \frac{C_d \cdot W}{Y_0} + \left[\frac{2}{\rho} \cdot (p - p_1) \right]^{\frac{1}{2}} \quad (2)$$

One must pay attention to the positive direction of the value Y, so that, if it is assumed that $p_1 \approx 0$ one obtains:

$$Q_2 = C_d \cdot W \cdot (Y_0 - Y) \cdot \sqrt{\frac{2}{\rho} \cdot p} \tag{3}$$

From which it follows that:

$$Q_{SR} = Q_1 - Q_2 = C_d \cdot W \cdot (Y_0 - Y) \cdot \left[\frac{2}{\rho} (p_s - p) \right]^{\frac{1}{2}} - C_d \cdot W \cdot (Y_0 - Y) \cdot \left[\frac{2}{\rho} \cdot (p) \right]^{\frac{1}{2}} \tag{4}$$

If one adopts that $K_q = C_d \cdot W \cdot \sqrt{\frac{2}{\rho}}$ then we have:

$$Q_{SR} = K_q \cdot (Y_0 + Y) \cdot \sqrt{p_s - p} - K_q \cdot (Y_0 - Y) \cdot \sqrt{p} \tag{5}$$

Where:

Q_{SR} – flow through servo-valve, which goes into the cylinder, $Q_1 = Q_s$ – flow that goes into servovalve,, $Q_2 = Q_T$ – flow that goes from servovalve to the reservoir,, W – rate at which flow is effected, C_d – coefficient of outflow.

2.3. Cylinder

Equation of flow, based on the literature is:

$$Q_{SR} + C_i \cdot (p - p_o) = \frac{dV_c}{dt} + \frac{V_c}{\beta} \cdot \frac{dp}{dt} \tag{6}$$

According to the assumption: according to the literature [7], flow assumption of servo-valve might be linearized in relation to the declination of plate from neutral position and difference of pressure acting on the piston, the leakage is neglected $C_i \approx 0$, where: V_c – oil volume in the cylinder at any time, V_0 – oil volume in the starting moment, then we have, $V_c = V_0 + A_c X$.

So that:

$$\frac{dV_c}{dt} = \frac{dV_0}{dt} + A_c \cdot \frac{dX}{dt} = A_c \cdot \dot{X} \tag{7}$$

2.4. Strand casing

Fig. 5 gives schematic diagram of the strand casing.

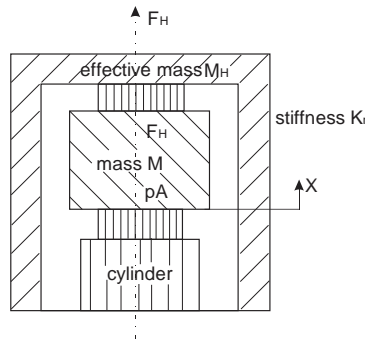


Fig. 5. Schematic diagram of the strand casing

Due to application of the assumption : according to the literature [7] servo-valve flow assumption may be linearized related to the plate declination from the neutral position and the pressure difference acting on the piston, the following equation is valid:

$$F_H - K_R \cdot (X - X_0) = M_H \cdot \ddot{x}, \quad F_H = K_R \cdot (X - X_0) + M_H \cdot \ddot{X}. \quad (8)$$

2.5. Cylinder

Based on fig. 5, it follows that:

$$P \cdot A_c - F_H = M \cdot \ddot{X} \Rightarrow P \cdot A_c = F_H + M \cdot \ddot{X}. \quad (9)$$

Relying on the literature, the following assumption may be written: Piston movement depends on input current I_y according to the formula: $Y = V(s) \cdot I$.

2.6. Servo-valve supply circuit

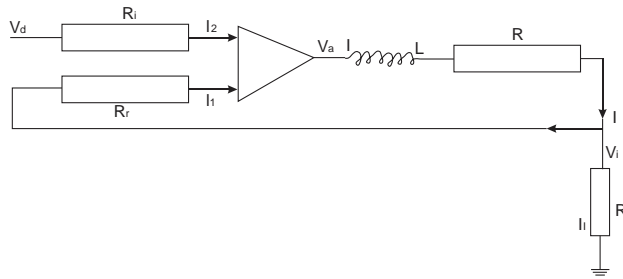


Fig. 6. *Servo-valve supply circuit*

Based on fig. 6 with the application of Kirhov's rules and the equation of current-voltage amplifier [7] the following equations are obtained:

$$\left(\frac{V_d}{R_i} + \frac{V_i}{R_f} \right) \cdot (-K_a) = V_a, \quad I = \frac{V_a - V_i}{LS + R}, \quad I = I_f + I_1. \quad (10)$$

2.7. Converter of position signal into voltage signal

Signal converter effects the amplification K_f . These converters are simple to use but they introduce the noise into the system so that because of that this noise is removed by introduction of time constant τ_f by which the effect of that noise is reduced.

According to the literature [6] one may write the equation:

$$U_{oc} = \frac{K_f}{1 + T_f \cdot S}. \quad (11)$$

2.8. Error signal amplifier

This amplifier reacts to the difference between wanted and achieved voltage and effects the voltage which is proportional to that error and according to the literature [6] one may write the equation:

$$(U_{bx} - U_{oc}) \cdot K_a = -V_d. \quad (12)$$

All preceding equations represent a non-linear mathematical model of this system for controlling the strip thickness. Fig. 7 presents an analogue diagram of the system for control of strip thickness based on all previous equations.

3. ELABORATION OF THE LINEARIZED MATHEMATICAL MODEL LINEARIZATION OF SERVO-VALVE FLOW CHARACTERISTIC

We shall observe the functioning of servo-valve around the zero position (i.e. small deviations from neutral position) – $Y_0 < Y < Y_0$.

$$q = \frac{\partial Q}{\partial Y_n} \int Y + \frac{\partial Q}{\partial P_n} \int P + R_4. \quad (13)$$

R_4 is neglected as a small value.

From the equation:

$$Q_{SR} = K_q \cdot (Y_0 + Y) \cdot \sqrt{p_s - p} - K_q \cdot (Y_0 - Y) \cdot \sqrt{p}. \quad (14)$$

It follows,

$$\frac{\partial Q}{\partial p} = \frac{K_q(Y_0 + Y)}{-2\sqrt{p_s - p}} - \frac{K_q(Y_0 - Y)}{2\sqrt{p}} = C_p, \quad \frac{\partial Q}{\partial Y} = K_q \cdot \sqrt{p_s - p} + K_q \cdot \sqrt{p} = C_y. \quad (15)$$

From which one obtains:

$$q = \left(K_q \cdot \sqrt{p_s - p} + K_q \cdot \sqrt{p} + \frac{K_q(Y_0 + Y)}{-2\sqrt{p_s - p}} - \frac{K_q(Y_0 - Y)}{2\sqrt{p}} \right) \cdot p = C_y \cdot y + C_p \cdot p. \quad (16)$$

In the literature [4] it is shown that $C_p \approx 0$ so that: $q \approx C_y \cdot y$.

Casing: $f_H = K_R x + M_H \ddot{x}$,

Cylinder $pA - f_H = M \ddot{x}$.

Equation of the oil flow in the cylinder is:

$$Q = A \dot{X} + \frac{V_c}{B} \cdot \dot{P} = Q(\dot{X}, \dot{V}_c, \dot{P}). \quad (17)$$

If this equation is developed into Taylor's series, one shall obtain:

$$q = \frac{\partial Q}{\partial X_n} \int \dot{x} + \frac{\partial Q}{\partial V_c_n} \int \dot{V}_c + \frac{\partial Q}{\partial P_n} \int \dot{p} + R_5. \quad (18)$$

R_5 is neglected as a small value.

$$q = A \cdot \ddot{x} + \frac{V_c}{B} \cdot \dot{v}_c + \frac{V_c}{B} \cdot \dot{p}. \quad (19)$$

If pressure deviations are small, $P = \text{const} \Rightarrow \dot{P} = 0$, then we have:

$$q = A \dot{X} + \frac{V_c}{B} \cdot \dot{p}. \quad (20)$$

Servo-valve supply is: $Y = V_{(s)} \cdot I.$

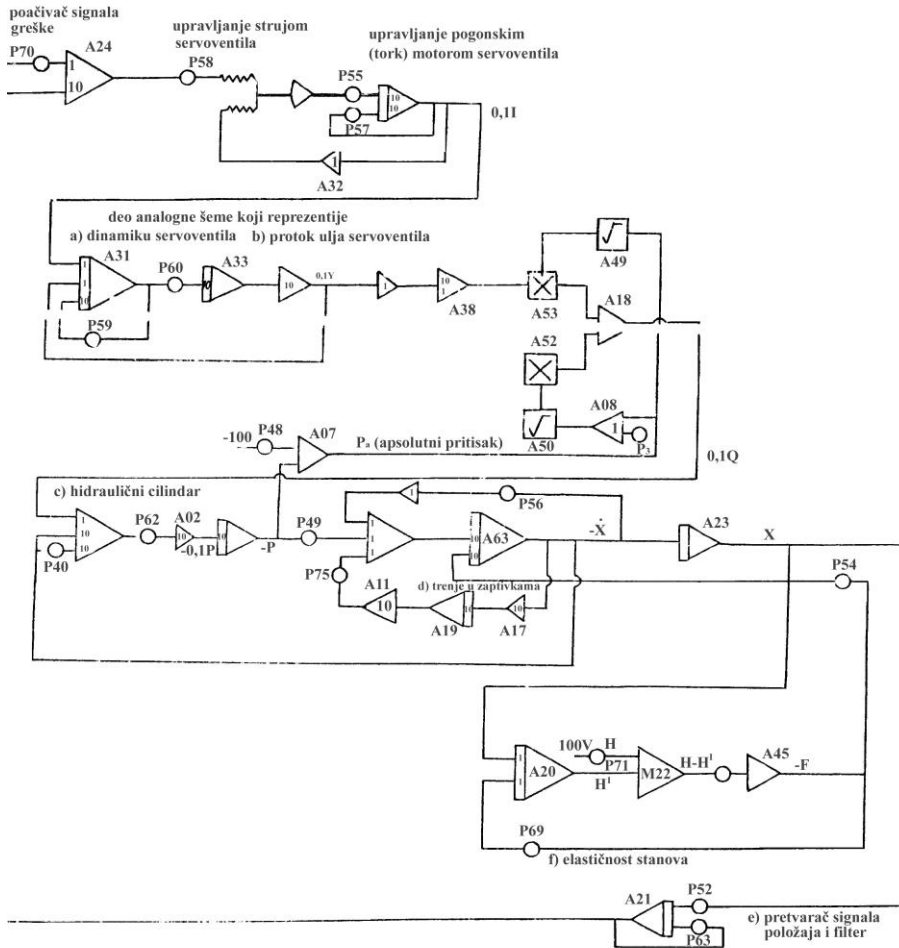


Fig. 7. Analogue diagram of the System for Automatic Control (SAC) of rolling thickness

Servo-valve supply circuit

Fig. 8 shows the block diagram of servo-valve supply circuit.

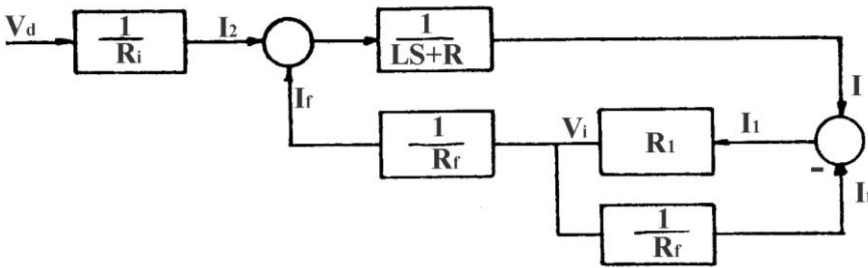


Figure 8. Block diagram of servo-valve supply circuit

From the block diagram of servo-valve supply circuit (fig.1), one obtains:

$$W_k = \frac{K_e}{R_i} \cdot \frac{1}{LS+R+K_e \cdot \frac{R_1}{R_1+R_f}} = \frac{1}{LS+R+K_e \cdot \frac{R_1}{R_1+R}} = \frac{\frac{1}{R+K_e \cdot \left(\frac{R_1}{R_1+R_f}\right)}}{R+K_e \cdot \left(\frac{R_1}{R_1+R_f}\right) + LS} = \frac{\frac{1}{R+K_e \cdot \frac{R_1}{R_1+R}}}{1 + \frac{LS}{R+K_e \cdot \left(\frac{R_1}{R_1+R}\right)}} \quad (21)$$

From which it follows:

$$I = \frac{\frac{1}{R_i} \cdot \frac{K_e}{R+K_e \cdot \left(\frac{R_1}{R_1+R_f}\right)}}{1 + \frac{LS}{R+K_e \cdot \frac{R_1}{R_1+R}}} \cdot V_d = \frac{K_x}{1+T_x S} \cdot V_d \quad (22)$$

Converter of position signal into voltage signal $V_{oc} = \frac{K_f X}{1+T_f S}$

Error signal amplifier $K_a \cdot (V_{bx} - V_{oc}) = -V_d$

Previous equations represent a linearized mathematical model of the System for Automatic Control (SAC) according to deviations.

By applying Laplace's transformations, for zero starting conditions, for each equation from this system one obtains the following system of equations:

$$Q_{(s)} = C_y Y_{(s)}, F_H = K_R X_{(s)} + M_H S^2 X_{(s)}, PA = F_H + MS^2 X_{(s)}, Q_{(s)} = ASX_{(s)} + \frac{V}{B} SP_{(s)},$$

$$I_{(s)} = \frac{K_x}{1+T_x S} \cdot V_d, V_{oc(s)} = \frac{K_f}{1+T_f S} \cdot X_{(s)}, K_a \cdot (V_{bx} - V_{oc}) = -V_d, Y_{(s)} = V_{(s)} - I_{(s)} \quad (23)$$

From equations:

$$W_{\theta i(s)} = \frac{\theta_{(s)}}{I_{y(s)}} = \frac{K_{\theta i}}{T_{\theta}^2 S^2 + 2\xi_k T_{\theta} S + 1} \quad (24)$$

and,

$$W_{y\theta(s)} = \frac{Y(s)}{\theta(s)} = \frac{K_{y\theta}}{T_{1H}S+1} \quad (25)$$

With the validity of the assumption from the literature [7] that $T_{\theta 1}$ is a small value which may be neglected, it follows that:

$$V(s) = \frac{K_3}{T_{\theta 3}^2 S^2 + 2\xi_{k3} T_{\theta 3} S + 1} \quad (26)$$

Accordingly, because of that, we have:

$$Y(s) = \frac{K_3}{T_{\theta 3}^2 S^2 + 2\xi_{k3} T_{\theta 3} S + 1} \cdot I(s) \quad (27)$$

Based on previous equations a block diagram may be drawn of the system for controlling the strip thickness (fig. 9).

If the block diagram from fig. 9 is represented in the basic form, we shall obtain:

$$W_{ok} = \frac{K_A \cdot K_x}{1 + \tau_x S} \cdot \frac{K_3}{T_{\theta 3}^2 S^2 + 2\xi_{\theta 3} T_{\theta 3} S + 1} \cdot C_y \cdot \frac{K_4}{S^2 + K_5^2} \cdot \frac{1}{S} \cdot \frac{K_f}{1 + \tau_f S} \quad (28)$$

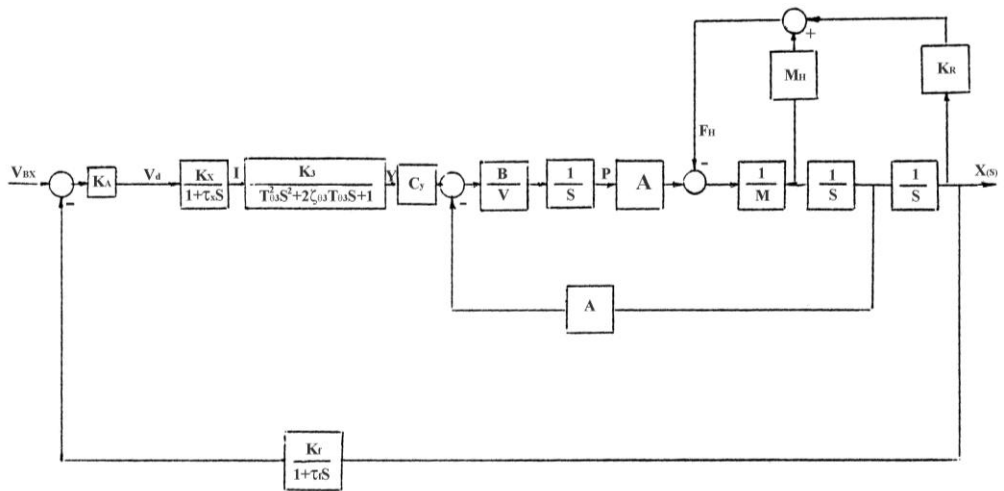


Fig. 9. Block diagram of the system for strip thickness control

4. APPLICATION OF THE METHOD OF GEOMETRICAL PLACES OF ROOTS (GPR)

By application of the method of Geometrical Places of Roots (GPR), for the system which is applied in the steel mill Smederevo, the following values are valid:

$$A = \frac{d^2 \pi}{4} = \frac{0,86^2 \pi}{4} = 0,58 \text{m}^2, V = A \cdot h_k = 0,58 \cdot 0,01 = 0,0058 \text{m}^3, B = 1400 \text{MPa}, P_s = 240 \text{bar}, C_y = 0,97 \cdot 10^{-6} \frac{\text{m}^3}{\text{MA}},$$

$$K_R = 57,7 \cdot 10^7 \frac{\text{kg}}{\text{m}}, \tau_f = 2,5 \cdot 10^{-3} \text{s}, M_H = 61000 \text{kg}.$$

Based on which one obtains that:

$$W_{ok} = K_a \cdot \frac{10 \cdot 0,764 \cdot 433}{S + 433} \cdot \frac{2,8 \cdot 10^4 \cdot 975^2}{S^2 + 1850 \cdot S + 855634} \cdot \frac{1,53}{S^2 + 688^2} \cdot \frac{1}{S} \cdot \frac{0,4 \cdot 1820}{S + 1820}$$

4.1. Determination of starting points of GPR

Starting points are poles W_{ok} , i.e.:

$$S_1 = -433, S_2 = -925 - 3j, S_3 = -925 + 3j, S_4 = -688j, S_5 = +688j, S_6 = 0, S_7 = -1820.$$

Due to symmetry of GPR related to the real axis, for drawing one does not use the poles $-925 - 3j$ and $-688j$.

4.2. Determination of final points of GPR

Since final points of GPR are in fact zeroes W_{ok} it follows that they are located in the infinity.

4.3. Determination of asymptotes and asymptotes cross-section point

$$\varphi = \frac{(2K+1)}{n-m}, K=0,1,2,n_{m-1}$$

Here $n = 7$, $m = 0$, and from this it follows:

$$\varphi_1 = \frac{\pi}{7} = 25,7^\circ, \varphi_2 = \frac{3\pi}{7} = 77,14^\circ, \varphi_3 = \frac{5\pi}{7} = 128,57^\circ, \sigma_a = \frac{\sum R_i - P_i}{n-m} = \frac{-4103}{7} = -586.$$

4.4. Determination of segments of real axis which belong to the the flowsheet GPR

Segments of the real axis which belong to the flowsheet of GPR are portions -1820 , $-925j$ and $-433-0$.

4.5. Determination of the joining or separation point of the flowchart of GPR,

$$\sigma_0 = -217,$$

4.6. Determination of cross-section point of the flowchart of GPR with imaginary axis, $W_{kr} = 350$

Determination of the value of amplification factor for $\xi = 0.7$, $K = 52,3 \cdot 10^{12}$

According to the flowchart of GPR, in fig. 10, one may conclude that the system for regulation is conditionally stable and that $K_{kr} = 11325 \cdot 10^{10}$ for damping rate $\xi = 0.7$, $K = 52,3 \cdot 10^{12}$.

Surplus of amplification (for point A) is: $d = \frac{K_{kr}}{K} = 2,16$. Throughput range (for point A) is: $W_0 \approx 150 \frac{\text{rad}}{\text{s}}$. Velocity amplification of the open circuit (for point A) is: $K_v = 1,2 \cdot 10^6$. Velocity static error is: $\varepsilon_{sv} = \frac{1}{K_v} = 0,83 \cdot 10^{-6}$.

By using the block diagram given in fig. 2, for the transfer function of the open circuit W_{ok} , the equation:

$$W_{ok} = K_a \cdot \frac{10 \cdot 0,764 \cdot 433}{S + 433} \cdot \frac{2,8 \cdot 10^4 \cdot 975^2}{S^2 + 1850 \cdot S + 855634} \cdot \frac{1,53}{S^2 + 688^2} \cdot \frac{1}{S} \cdot \frac{0,4 \cdot 1820}{S + 1820},$$

and the program for determination of the response one obtains, from fig. 11, which represents responses of each output values from particular transfer functions if one applies jump function to system input.

Accordingly we have:

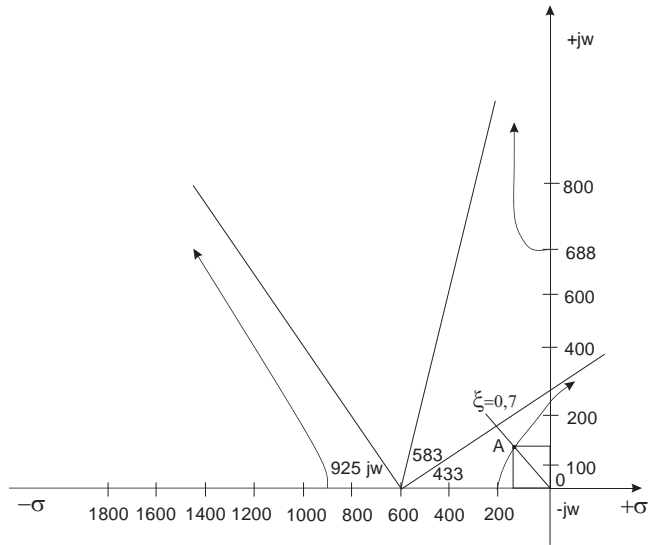


Fig. 10. Flowchart of GPR

$Y_1 = i_{(t)}$ if V_{bx} is the jump function, $Y_2 = Y_{(t)}$ if V_{bx} is the jump function, $Y_3 = \dot{X}_{(t)}$ if V_{bx} is the jump function, $Y_4 = X_{(t)}$ if V_{bx} is the jump function and, $Y_5 = v_{oc(t)}$ if V_{bx} is the jump function.

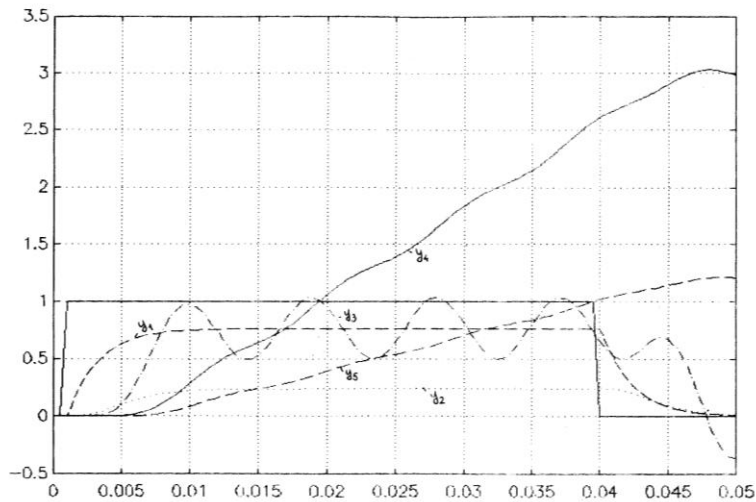
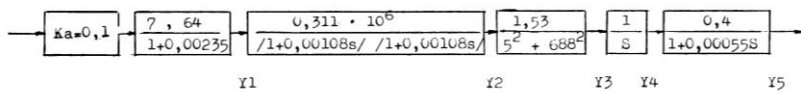


Fig. 11. Determination of response of the System for Automatic Control (SAC) if jump function is applied to system input

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RAZVOJ INTEGRABILNOG ELEKTROHIDRAULIČKOG AKTUATORA ZA ROBOTE

Velibor Karanović¹, Mitar Jocanović², Darko Knežević³, Milija Krašnik⁴

Rezime: U ovom radu, prezentovan je koncept Integrabilnog Elektro Hidrauličkog Aktuatora, koji nudi rešenje određenih problema savremenih robotskih sistema. Takođe ukazuje se i na neke od propusta, koje je po autorovom mišljenju, potrebno razmotriti u cilju ostvarenja maksimalnih radnih performansi IEHA sistema.

Ključne riječi: hidraulika, robotika

DEVELOPMENT OF ELECTROHYDRAULIC ACTUATOR FOR ROBOTS

Abstract: *This paper, presents a stage of developed concept of Integrated Electro Hydraulic Actuator for robotics, which offers solutions to some advanced robotic systems problems. Also, there is pointed on some of omissions, which are necessary to consider if the aim is achivement of better IEHA system performances.*

Keywords: *hydraulics, robotics*

1. UVOD

Jedan od prvih primera uvođenja hidraulike u robotiku je patent industrijskog robota, koji je podneo 1954. godine Džordž Devol [1], a dve godine kasnije (1956) osnovana je kompanija "Unimation" koja ih je serijski proizvodila. Osim robota u industriji, sfera delovanja robotike proširila se i na medicinu, gde su, 60-ih godina prošlog veka, rađena mnogobrojna istraživanja u želji da se pomogne ljudima sa nedostatkom nekog od ekstremiteta. U ovim istraživanjima, elektromehanički pogoni su se tada pokazali mnogo pouzdanijim, kompaktnijim, fleksibilnijim i bezbednijim u radu, te su stoga potisnuli hidraulički iz upotrebe u robotskim aplikacijama. Hidraulički pogon se koristio jedino tamo gde su radni zadaci podrazumevali velika radna opterećenja. Poznata tehnologija tada nije imala rešenja za neke od nedostataka koji su bili od presudnog značaja za dalju upotrebu hidraulike u robotici.

Neki od tih nedostataka i danas predstavljaju prepreku, ali napredna tehnologija omogućava da se veći broj njih svede na minimalnu meru ili eliminiše u potpunosti, tako da prednosti koje hidraulički pogon ima, dolaze do izražaja. Ima nekoliko uticajnih nedostataka: visoka cena, visoki radni pritisci (što uslovljava primenu

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sudova pod pritiskom koji podležu velikom broju ispitivanja kako se ne bi ugrozila bezbednost korisnika), dodatni pogon za rad hidrauličke pumpe (korišćenje elektromotora ili SUS motora čime se povećava prostorno zauzeće), isticanje ulja van hidrauličkog sistema (čime se narušava bezbednost okoline), i velika masa komponenti koja znatno otežava robotski sistem.

U ovom radu biće dat kratak prikaz razvoja i princip rada elektro-hidrauličkog aktuatora. Takođe, u poglavlju diskusija, biće dat stav autora rada u pogledu daljeg razvoja ovog veoma pesperktivnog uređaja, na polju robotike.

2. PREGLED RAZVOJA ELEKTROHIDRAULIČKOG AKTUATORA U POSLEDNJIH PAR GODINA

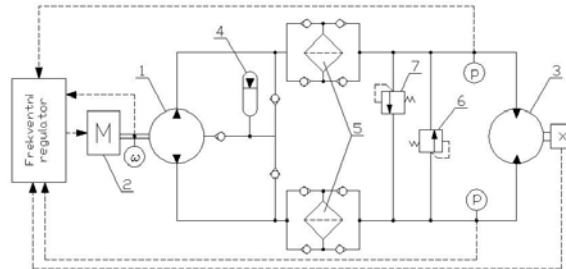
Kao aktuatori u robotskim sistemima čestu primenu imaju elektromotori, pneumatski i hidraulički cilindri i motori. Danas, radi postizanja što boljih radnih performansi, razvijaju se kombinovani pogonski sistemi od kojih je jedan predstavnik i uređaj koji je tema ovog rada.

Poznato je da je tokom 60-ih godina razvijen elektro mehanički pogon koji je bio kompaktan, pouzadan u radu, i koji je imao jednostavan princip punjenja baterija i dr., čime je, u to vreme, bio superioran u odnosu na ostala tehnička rešenja. Zbog toga je godinama kasnije razvijan i danas ima najveću upotrebu kod robotizovanih sistema. Elektromotorni prenosnici, kao osnovni pogon za robotske sisteme, pogodni su jer imaju nisku cenu, visok stepen iskorišćenja i dobru upravljivost u odnosu na ostale pogonske sisteme. Nedostaci upotrebe elektromotora dolaze do izražaja kada se ukombinuju sa zupčastim prenosnicima. Tada se upravljački algoritmi usložnjavaju i postavljaju se novi zahtevi, čije rešavanje često podrazumeva i ugradnju dodatnih elemenata. Prilikom dimenzionisanja, odnosno izbora odgovarajućeg elektromotora za pogon, javlja se još jedan nedostatak. Pri dimenzionisanju obično se usvaja elektromotor koji zadovoljava i u slučaju kritičnih (maksimalnih) opterećenja, zbog čega se javlja problem neoptimizovanog izbora tj. predimenzionisanja, što znatno smanjuje koeficijent iskorišćenja istog. Navedeni nedostaci su neki od osnovnih koji su inicirali razvoj alternativnih pogonskih sistema. Neki od njih su primenjeni u sada javno publikovanim projektima koji su rađeni za vojsku SAD [2, 3, 4].

Pionirski projekat konstruisanja i razvoja potpuno novog elektro-hidrauličkog aktuatora za robote objavili su Habibi S. i Goldenberg A. [2]. Cilj ovog istraživačkog rada bio je razvijanje uređaja i utvrđivanje performansi sistema, kojim se kombinuju prednosti hidrauličkih i električnih aktuatora. Koncept konstrukcije sistema, svodi se na zatvoreni hidraulički krug, u kojem se koristi pumpa dvostranog dejstva, čija se promena protoka postiže promenom broja obrtaja pogonskog elektromotora (slika 1).

U hidrauličkom sistemu, na slici 1., koristi se pumpa dvosmernog dejstva (1). Frekventni regulator koji upravlja pogonskim elektromotorom (2), nakon obrade signala o izmerenim pritiscima (p), brzini obrtanja vratila na ulazu u pumpu (ω), kao i signala o ostvarenoj poziciji izvršnog elementa (x), povećava ili smanjuje broj obrtaja vratila elektromotora, odnosno veličine protoka u sistemu, tako da se ovim dobija pumpa promenljive radne zapremine. U slučaju zamene usisne i potisne strane, motor menja smer obrtanja. Uloga akumulatora (4), je da prihvati višak fluida iz drenažnog voda u slučaju naglog porasta pritiska u pumpi, i spreči pojavu kavitacije u pumpi usled nedovoljnog dotoka ulja u usisni vod pumpe. Filteri (5) se koriste radi održavanja projektovane klase čistoće radnog fluida, definisane prema najosetljivijoj komponenti

(na nečistoće), ugrađenoj u sistem. U ovakvim sistemima neizostavni su ventili za ograničenje pritiska (6, 7) koji reaguju u slučaju naglog porasta pritiska u sistemu. Hidrocilindar sa jednostranom klipnjačom (3) ima konstrukciju kojom je obezbeđen niz prednosti, pri kretanju klipnjače u oba smera, kao što su: ista maksimalna brzina i sila; iste dinamičke karakteristike, što doprinosi jednostavnijem upravljanju hidrocilindrom; iste zapremine radnih komora.



Sl.1 Šema Elektro Hidrauličkog Aktuatora (EHA)(1 – pumpa, 2 – elektromotor, 3 – simetrični aktuator, 4 – akumulator, 5 – filter, 6, 7 – ventil za ograničenje pritiska)

Među radove od značaja za napredak u razvoju EHA koncepta i značajnijeg uvođenja hidrauličkih sistema u robotiku, ubraja se i rad Kargova [3]. Rad je doprineo plasiranjem koncepta minijaturizacije hidrauličkih komponenti, korišćenih u projektu razvoja EPPH (Externally Powered Prosthetic Hand) sistema. Kompletan pogonski i upravljački sistem, projektovani su tako da mogu stati u metakarpalni deo šake koja nije veća, ni manja od prirodne veličine ljudske šake. Zatim, istraživanju primene hidraulike u robotskim sistemima doprineo je i rad Kaminage [4]. Njegovo istraživanje imalo je za cilj unapređenje upravljivosti robotskom šakom i prevazilaženje nedostataka kao što su manjak snage za obavljanje zadatka (tipova hvata), držanje u poziciji i složeno održavanje mehanizama. U ovom projektu predlažu se koncepti sintetizovanja pasivnog žičanog mehanizma i aktivnog hidrostatičkog pogona, zatim primena principa kompaktnosti i modularnosti kojima se obezbeđuju jednostavno održavanje u slučaju otkaza nekog dela sistema. Akcentuje se i poboljšanje upravljivosti sistemom (tačnije povratne upravljivosti⁵), sa stanovišta primene hidrostatičkog prenosa energije.

3. INTEGRABILNI ELEKTRO-HIDRAULIČKI AKTUATOR (IEHA)

Dalji korak u razvoju koncepta kombinovanog pogonskog sistema, prikazanog na slici 1., predstavlja Integrabilni Elektro Hidraulički Aktuator (IEHA). Uređaj je zamišljen kao minijturni agregat koji se direktno ugrađuje na izvršni element i u suštini obavlja i funkciju agregata i upravljačkog elementa. Kao nešto što je relativno novo u oblasti primene aktuatora u robotici, IEHA je predstavljen široj naučnoj javnosti u radovima [8, 9]. U nastavku rada biće prikazana njegova struktura i princip rada.

⁵ Termin koji se koristi u stručnoj literaturi engleskog govornog područja jeste "backdrivability".

Struktura IEHA

Osnovnu strukturu IEHA uređaja čine elektromotor, mikropumpa, mikroventil, razvodnik, rezervoar i hidraulički aktuator. Za vršenje kontrole i sinhronizacije rada komponenata upravljačkog sistema sa povratnom petljom, u IEHA uređaj ugrađeni su senzori pozicije (na mikroventilu i hidrauličkom aktuatoru), i senzori pritiska. Princip rada je takav da mikropumpa uz pomoć elektromotora pretvara električnu energiju u hidrauličku. Da bi se upravljalo raspoloživom količinom hidrauličke energije, koristi se mikroventil, čiji rad određuje vrednost protoka, zahvaljujući mogućnosti promene vrednosti ekscentriciteta mikropumpe, koja je radijalno-klipnog tipa.

Ugradnja IEHA podrazumeva njegovo postavljanje u samom zglobu, čime se obezbeđuju bolje performanse i umanjuju nedostaci klasičnog hidrostatičkog prenosa energije. Zahvaljujući tome, svaki IEHA predstavlja autonomnu jedinicu koja se dimenzioniše prema kritičnoj veličini radne sile i radne brzine u zglobu. Pad pritiska je smanjen na minimalnu meru kao i mogućnost isticanja ulja van sistema. Da ugradnja IEHA bude još pogodnija, isti mora zauzimati što je moguće manji prostor i biti jednostavan za upravljanje. Ispunjavanjem prethodno pomenutih uslova, IEHA postaje veoma atraktivan za primenu u robotici.

Mikropumpa i mikroventil

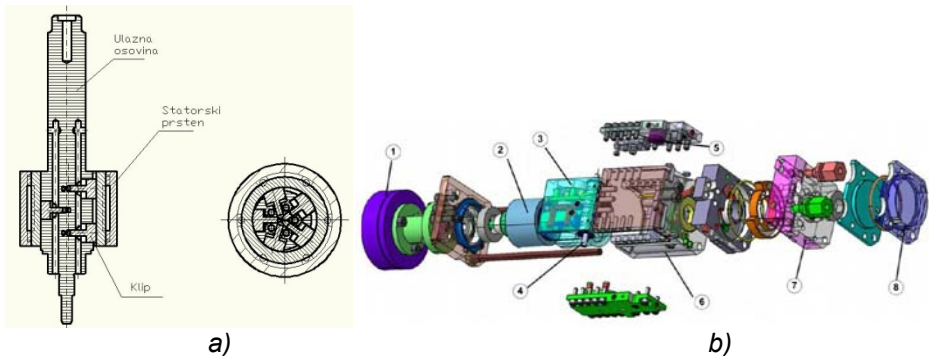
Osnovu rada IEHA predstavljaju rad mikroventila i mikropumpe. Ove komponente čine nerazdvojni sklop koji prilagođava generisanje energije potrebama potrošača.

Mikropumpa je modifikovana klipno radijalna pumpa, minijaturnih dimenzija. Pumpa je takve konstrukcije da ima radijalno raspoređene klipove u nekoliko nivoa uzduž ose rotacije. Na svakom nivou, klipovi su fazno pomereni jedni u odnosu na druge, kako bi se dobio ravnomerniji protok, a time i manje oscilacije pritiska na potisnom priključku pumpe.

Izlazno vratilo elektromotora (1) i vratilo pumpe (slika 2.) su povezani spojnicom i obrću se konstantnim brojem obrtaja. Klipovi, koji se nalaze u žljebovima vratila mikropumpe, kreću se translatorno unutar žljeba (zavisno od veličine ekscentra) i jednim krajem kližu po unutrašnjoj površini "plivajućeg" statorskog prstena, stvarajući tako usisni i potisni pritisak u radnim komorama. Menjanjem ekscentriciteta e , tj. razlike u distanci između osa vratila pumpe i statorskog prstena (3), dolazi do promene dužine hoda klipa, tj. promene veličine protoka u sistemu. Proporcionalno povećanju parametra e povećava se protok. Ako je vrednost e konstantna, protok ostaje nepromenjen, ali pritisak raste srazmerno sili koja se savladava hidrauličkim aktuatorom. Promenom smeru pomeranja statorskog prstena mogu se dostići i negativne vrednosti parametra e , kada dolazi do redukcije pritiska u sistemu kao i promene usisne i potisne strane, pri čemu smer i brzina rotiranja vratila elektromotora ostaju nepromenjeni. Ovakvo rešenje pojednostavljuje upravljanje elektromotorom. Podešavanje parametra e vrši se elektro-hidraulički, pomoću mikroventila (4) koji je instaliran u statoru (3) i koji je upravljani elektromagnetom (5).

Mikroventil ima ulogu regulatora kapaciteta mikropumpe, odnosno uređaja kojim se podešava vrednost ekscentriciteta. Na slici 3. uprošćeno je prikazan sklop mikropumpe sa upravljačkim mikroventilom, a u nastavku će biti opisan njihov rad.

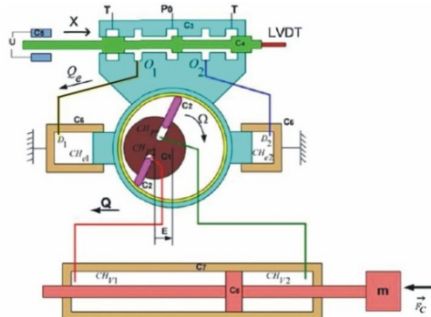
Aktiviranjem elektromagneta, klip mikroventila pomera se u desnu stranu, čime se ulje pod pritiskom usmerava od priključka P_0 ka O_1 odnosno komori CH_{e1} . Pri tome



Sl.2 a) Konstrukcija mikropumpe; b) Eksplozivna šema (1 – elektromotor, 2 – mikropumpa, 3 – stator mikropumpe, 4 – mikroventil, 5 – elektromagnet, 6 – kućište IEHA, 7 – razvodnik, 8 - rezervoar)

se druga komora CH_{e2} povezuje preko O_2 sa T priključkom i omogućava ulju da protiče od upravljačke komore ka rezervoaru. Posledica ovoga je pomeranje statorskog prstena u desnu stranu čime se menja vrednost e . Na slici 3. može se uočiti da mikroventil ima mehaničku spregu sa statorskim prstenom. Za ilustriranje ove veze koristi se sledeći opis: ako se sa t_0 i e_0 (gde je e_0 ekscentricitet u trenutku t_0) definiše trenutna pozicija klipa mikroventila, i pri tome ako klip treba pomeriti u poziciju X , onda je u trenutku dostignute zadate pozicije, rastojanje između referentne tačke klipa i statorskog prstena definisano sa $X-e_0$. Kod ove pozicije klipa dolazi do usmeravanja ulja pod pritiskom u odgovarajuću upravljačku komoru, tako da se plivajući prsten pomera i pri tome prati smer u kojem se kretao klip mikroventila. Posledično dolazi do smanjenja razlike u odstojanju referentnih tačaka klipa i prstena, tj. $X-e_t$ (gde je e_t ekscentricitet u nekom trenutku t) sve dok razlika ne bude jednaka nuli. U momentu kada je $X-e_t=0$, priključci P i T su blokirani kao i prsten u svojoj trenutnoj poziciji.

Da bi ostvario ovaj vid upravljanja, na klipu mikroventila ugrađen je senzor koji meri poziciju klipa, i kojim se zatvara upravljačka petlja za upravljanje elektromagnetom. Pored pomenute, postoji i zatvorena petlja za upravljanje intenzitetom radne sile, tj. vrednošću radnog pritiska u sistemu, koja podrazumeva dva pritiska senzora postavljena na priključcima cilindra. Senzori, mere vrednost pritiska u radnoj komori hidrocilindra i šalju signal upravljačkoj jedinici. Izmerena vrednost se



Sl.3 Uprošćen izgled sklopa mikropumpe i mikroventila

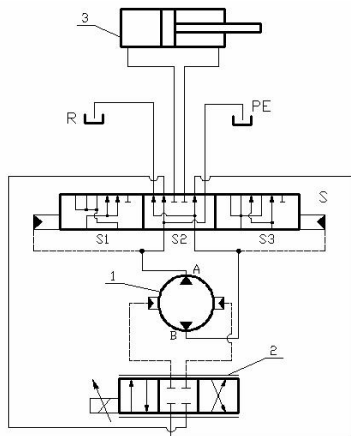
poredi, u upravljačkoj jedinici, sa zadatom vrednošću i ako postoji odstupanje šalje se korekcionni signal, čime se podešava nova vrednost ekscentra.

Razvodni ventil

Upotreba razvodnika u ovom sistemu je varijantno rešenje za slučaj korišćenja ne simetričnog aktuatora. Pod pretpostavkom da su pri radnim hodovima u oba smera različite vrednosti brzine i intenziteta sile, nije praktično uvek koristiti simetričan aktuator. Kod nesimetričnog aktuatora, treba obratiti pažnju na razlike u vrednostima zapremine fluida koje napušta jednu radnu komoru cilindra i zapremine koja ulazi u drugu radnu komoru.

Sistem prikazan na slici 4., ima formu otvorenog hidrauličkog kruga. Pumpa (1) obezbeđuje potisak fluida u liniju A ili liniju B, u zavisnosti od toga koji je zahtevani smer kretanja izvršnog elementa (3). Hidraulički razvodnik (S) ima za cilj da usmeri tok fluida u klipnu ili klipnjačinu komoru cilindra i rezervoar (R). Komponenta (PE) podrazumeva rezervoar u koji otiče fluid usled internog isticanja u komponentama. U zavisnosti od razlike pritisaka u linijama A i B, razvodnik zauzima jednu od tri pozicije.

U poziciji S_2 razvodnik se nalazi kada su pritisci u linijama A i B jednaki ($e=0$, $Q=0$). Tada je onemogućeno bilo kakvo kretanje klipa cilindra. Poziciju S_1 razvodnik zauzima kada je pritisak u liniji A veći od pritiska u liniji B. U ovoj poziciji fluid se potiskuje ka klipnjačinoj komori i klip se pri tome pomera u levu stranu. Ulje iz klipne komore, ističe preko razvodnika u rezervoar R koji je povezan sa usisnom stranom mikropumpe. Pozicija S_3 simetrična je po funkciji radnoj poziciji S_1 . Linije A i B u ovom slučaju zamenjuju svoje uloge, tako da pumpa usisava fluid iz rezervoara R i klipnjačine komore cilindra i potiskuje ga ka klipnoj komori cilindra.



Sl.4 Hidraulička šema IEHA uređaja

4. DISKUSIJA

Prikazano tehničko rešenje predstavlja koncept koji opravdava dalja istraživanja i rad na njegovom razvoju, zahvaljujući činjenici da do sada objavljena laboratorijska ispitivanja IEHA imaju pozitivnu ocenu.

Prednosti IEHA su što se njegovom primenom na predviđenom mestu (tj. na samom zglobu) minimiziraju gubici u prenosu fluidne energije i eliminiše potreba za

korišćenjem cevovoda i crevovoda. Ovim je izbegnuta i potencijalna opasnost od preplitanja crevovoda u radu mašine, koja za posledicu mogu imati porast pritiska i hidrauličke udare. Postavljanjem IEHA direktno na cilindar ili hidromotor, povećava se dinamičnost, tj. upravljivost sistema i smanjuje broj potencijalnih mesta na kojima može doći do isticanja ulja van sistema. Pri korišćenju simetričnih cilindara i hidromotora dvosmernog dejstva, upotrebom IEHA eliminiše se potreba za razvodnim i protočnim ventilima. Kao prednost uređaja može se navesti i kompaktan sklop minijaturnih hidrauličkih komponenata koji ima veoma dobru integrabilnost što ga čini atraktivnim za primenu u robotskim sistemima.

Pored navedenih prednosti postoje i nedostaci koje treba pomenuti. Mikropumpa hidrauličkog sistema opisanog u radu, predstavlja redizajniranu konstrukciju klipno radijalne pumpe, sa ciljem da zadovolji potrebe sistema u pogledu kapaciteta, maksimalnog dozvoljenog radnog pritiska i upravljivosti. Sistem upravljanja radnom zapreminom pumpe ima zadatak da reguliše vrednost raspoložive snage sistema prema potrošaču i tako ostvari maksimalan mogući stepen iskorišćenja. Pozitivna osobina kod pumpe sa regulacijom kapaciteta, jeste što štiti pogonski elektromotor, odnosno produžava njegov radni vek. To je omogućeno zahvaljujući regulisanju veličine kapaciteta u pumpi mikroventilom. Sve što elektromotor po startovanju treba da radi, jeste da obrće vratilo motora konstantnom brzinom. Sa druge strane pumpa ima složenu konstrukciju, koja dodatno poskupljuje cenu izrade. Minijaturizacijom komponenti tolerancije izrade su veoma male, u rangu proporcionalnih i servo komponenata (od 1 do 5 μm), što znači da je kvalitet obrade površina visoke klase. Kada je konstrukcija sklopa složena i kvalitet obrade površina na visokom nivou, treba obratiti pažnju na održavanje i kondicioniranje fluida za prenos energije. Usled kontaminacije fluida nečistoćama, dolazi do pojave mehanizama habanja koji su jedan od mogućih i čestih razloga otkaza hidrauličkih sistema. Kontaminacijom radnog fluida, dolazi i do promene njegovih karakteristika, naročito viskoznosti koja je veoma bitna za rad hidrauličkog sistema. U radu [8, 9] nije naznačena klasa čistoće, kao ni fluid koji se koristi. Bez obzira na to, znajući da su zazor i mikrokomponentama IEHA sistema u rangu servohidrauličkih komponenata, može se preporučiti klasa čistoće fluida. Po NAS standardu, kojim se definiše klasa čistoće ulja u odnosu na sadržaj čvrstih čestica, za IEHA preporučljiva bila bi klasa čistoće NAS 6, za koju je neophodna ugradnja filtera, kako bi se radni vek IEHA i fluida održao na projektovanom nivou, a rad sistema odvijao bez ikakvih smetnji. Bitno je znati i gde će se filter ugraditi, zbog mogućeg problema sa kavitacijom u slučaju njegove ugradnje u usisnu granu pumpe, a nedovoljnog dotoka ulja.

Trebalo bi obratiti pažnju i na to da u sistemu nije predviđena ugradnja ventila za ograničenje pritiska. Ventil za ograničenje pritiska služi kao zaštita sistema od prekoračenja maksimalno dozvoljenog radnog pritiska. Konkretno u IEHA sistemu su ugrađeni senzori pritiska, koji reaguju na spoljne uticaje i šalju signal upravljačkoj jedinici koja smanjuje ili povećava kapacitet pumpe, a time i radni pritisak, regulisanjem veličine ekscentra. To znači da prilikom nekog poremećaja u radu sistema, senzori treba da registruju porast pritiska, centralna jedinica obradi signal i na odgovarajući način upravlja pumpom. Dakle porast pritiska i njegovo regulisanje zavisi od rada senzora, centralne upravljačke jedinice i pumpe što je vrlo diskutabilno po pitanju pouzdanosti kontrole koja zavisi od više elemenata nego u slučaju kada bi bio ugrađen ventil za ograničenje pritiska koji direktno reguliše ovaj poremećaj.

Još jedan element diskusije je i način na koji se upravlja ekscentrom u pumpi. Da bi došlo do promene ekscentra iz nultog u neki položaj, u pumpi je potrebno da postoji predpritisk. Logično je da kada je ekscentar u nuli, protoka u sistemu nema. Kada se želi podesiti neka vrednost ekscentra, na elektromagnet koji upravlja mikroventilom šalje se signal. Nakon toga dolazi do pomeranja klipa mikroventila i sa njegovog pritisknog priključka ulje se usmerava ka A ili B strani pumpe. Međutim pošto pre toga u sistemu nije vladao nikakav pritisak, jer nije bilo potiska ulja unutar sistema, javlja se situacija u kojoj je sasvim jasno da, bez obira u koji radni položaj da se uključi ventil, neće doći do promene stanja u pumpi. Ova pojava nije pojašnjena u radovima [8, 9], a bitna je sa stanovišta funkcionalnosti. Moguće je da konstrukcija pumpe obezbeđuje da ekscentar zapravo nije u nuli već u nekoj poziciji koja daje minimalan protok u sistemu, koji pravi minimalne gubitke, i koji je dovoljan da se, u situaciji kada se mikroventil prebaci u neki od radnih položaja, postigne odgovarajući pritisak koji će proizvesti pomeranje statorskog prstena pumpe i postići potrebnu vrednost ekscentra.

5. PRIMERI MOGUĆE PRIMENE IEHA U ROBOTSKIM APLIKACIJAMA

Primeri potencijalne primene IEHA koncepta su raznovrsni. Bilo kakva robotska aplikacija da je u pitanju, mogućnost ugradnje je garantovana obzirom da uređaj ima male gabarite, da je modularan i jednostavan za upravljanje.

Raznovrsnost robotskih aplikacija se uvećava konstantno i česte su u oblasti medicine, industrije, tehnologija rukovanja materijalima, vojnih aplikacija, poljoprivrede itd. U nastavku su na slikama, koje slede, dati neki od primera moguće primene ovog interesantnog koncepta. Na slici 5. a, prikazan je robot (HortiBot) koji ima primenu kao daljinsko upravljano sredstvo za negu organski gajenog povrća. Na slici 5. b, prikazan je teleoperativni sistem za rukovanje masivnim materijalima u kompleksnom i neuređenom okruženju. Na slici 5. c, prikazan je izgled varijante egzoskeleta napravljenog za potrebe vojske. Egzoskelet je robotski sistem koji pojačava snagu i izdržljivost korisnika. U nastavku na slici 5. d, prikazan je industrijski robot Motoman UP6 koji može postići velike radne brzine, koji je kompaktan i zahteva mali prostor za instalaciju. Nudi superiorne performanse za aplikacije robota kod zavarivanja. Na slici 5. e, prikazana je primena robotskog sistema u medicini na primeru ručne proteze, ali koji se često koristi i za izradu proteza za donje ekstremitete. Poslednji, ništa manje važan, prikaz primene robota na uređajima za podmorska istraživanja, dat je na slici 5. f. Podmorski roboti predstavljaju jedan od osnovnih sredstava rada na naftnim platformama za podmorska bušenja i eksploataciju naftnih ležišta.



a)



b)



c)



d)



e)



f)

Sl.5 Hidraulička šema IEHA uređaja

6. PRAVCI DALJEG ISTRAŽIVANJA

Izvesno je da razvoj robotike zahteva i razvijanje naučnih oblasti koje nalaze svoju aplikativnu primenu u robotskim sistemima, pa time i hidraulike koja tu definitivno opravdava svoje mesto. Pozitivni rezultati u do sada objavljenim radovima, u pogledu testiranja hidrauličkih aktuatora za robote, ističu potrebu za konstantnim praćenjem i prilagođavanjem hidrauličkih sistema i komponenata, potrebama raznovrsnih robotskih aplikacija. Kada je u pitanju primena hidraulike u robotici, sigurno je da će se pravci daljih istraživanja usmeravati na:

- razvoj minijaturnih hidrauličkih komponenata i sistema,
- razvoj kompaktnosti i integrabilnosti hidrauličkih sistema za robotske aplikacije,
- razvoj upravljačkih sistema za kombinovane elektro-hidrauličko-mehaničke aktuatore,
- razvoj postupaka održavanja minijaturnih hidrauličkih sistema.

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SIMULACIJA HIBRIDNOG TRIGENERACIONOG POSTROJENJA FORMIRANOG ZA POTREBE STAMBENOG OBJEKTA

Dragoljub Živković¹, Marko Mančić², Dragan Milčić³

Rezime: Struktura trigeneracionog postrojenja, koje može istovremeno da proizvodi toplotnu, električnu i rashladnu energiju, zavisi od raspoloživosti lokalnih resursa i energetske potrebe stambenog objekta. Predmet ovog rada je sinteza i simulacija hibridnog trigeneracionog sistema koji koristi solarnu energiju i prirodni gas za potrebe jednog stambenog objekta, primenom programa TRNSYS. Na osnovu dobijenih rezultata godišnje časovne simulacije osnovnih energetske potrebe stambenog objekta, određeni su struktura i proizvodni kapaciteti sistema. Hibridni trigeneracioni sistem čine: sistem pločastih solarnih toplotnih kolektora, akumulator toplote sa vodom, absorpciona toplotna pumpa i motor sa unutrašnjim sagorevanjem sa pogonom na prirodni gas. Simulacija časovnog ponašanja kompletnog hibridnog trigeneracionog sistema pokazuje da li ovako formirani sistem može da zadovolji osnovne potrebe datog objekta.

Ključne riječi: hibridna trigeneracija, sinteza sistema, energetske potrebe objekta, simulacija godišnjih performansi

SYMULATION OF A HYBRID TRIGENERATION SYSTEM DESIGNED FOR DEMANDS OF A RESIDENTIAL BUILDING

Abstract: *Structure of a trigeneration system, capable of simultaneous production of heating, cooling and power, is defined by availability of local resources and energy demands of a small residential building. The subject of this paper is synthesis and simulation of a hybrid trigeneration plant which utilizes solar energy and natural gas to meet energy demands of a small residential building, using TRNSYS software. Based on the obtained results of the annual hourly simulation of energy demand of the building, structure and production capacities of the system are defined.*

Hybrid trigeneration system consist of: system of flat plate solar thermal collectors, heat storage with water, absorption heat pump and a cogeneration unit based on a natural gas fired internal combustion engine. Finally, simulation of annual behavior of the complete hybrid trigeneration plant indicates whether the designed system is capable of meeting basic demands of the given building.

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Key words: solar hybrid trigeneration, system synthesis, building energy demand, annual performance simulation

1. UVOD

Pojam trigeneracije opisuje proces konverzije energije sa ciljem kombinovane proizvodnje toplotne, rashladne i električne energije. Upotreba trigeneracionih sistema za istovremeno grejanje, hlađenje i proizvodnju električne energije daje mogućnost za značajno poboljšanje ukupne efikasnosti sistema i smanjenje emisije gasova staklene bašte [1,2].

Trigeneracioni sistemi su složeni energetski sistemi koji koriste prednosti kombinovanja više različitih tehnologija za proizvodnju energije [3]. Primena jednog energetskog sistema zavisi od realnih lokalnih potreba, dostupnih resursa kao i opravdanosti i isplativosti. Pored upotrebe fosilnih goriva, sve veću ulogu dobijaju hibridni sistemi koji koriste i obnovljive izvore energije (OIE). Od posebnog interesa je simulacija i analiza ponašanja ovakvih sistema, za šta je moguće koristiti veliki broj danas dostupnih softvera [4].

U ovom radu je izvršena sinteza trigeneracionog postrojenja za podmirivanje energetskih potreba jednog stambenog objekta, gde su lokalno dostupni resursi solarna energija i prirodni gas. Struktura malog trigeneracionog postrojenja je određena pregledom karakteristika dostupnih podsistema i njihove međusobne kompatibilnosti, sa ciljem formiranja strukture sistema koji može da zadovolji zadatu funkciju. Simulacija godišnjeg toplotnog opterećenja jedne porodične kuće u režimima grejanja i hlađenja izvršena je primenom softvera TRNSYS [4], dok je profil potrebne električne snage uzet po pretpostavci. Strukturu hibridnog trigeneracionog postrojenja koje koristi solarnu energiju i prirodni gas u ovom radu čine sledeće komponente: motor sa unutrašnjim sagorevanjem, pločasti solarni termalni kolektori, akumulator toplote sa vodom i absorpciona toplotna pumpa. Nakon sinteze sistema, izvršena je časovna simulacija rada postrojenja kako bi se utvrdila njegova sposobnost da zadovolji osnovne potrebe datog objekta.

2. STRUKTURA HIBRIDNOG TRIGENERACIONOG POSTROJENJA

U pogledu strukture, može se smatrati da se trigeneracioni sistem sastoji od niza kombinacija podstruktura (blokova) koji mogu međusobno da stupe u interakciju. Trigeneracioni sistem se može podeliti na sledeće blokove tj. podstrukture [3]: (1) kogeneracioni blok, koji može biti zasnovan npr. na motoru sa unutrašnjim sagorevanjem (SUS), gasnoj turbini, stirling motoru, gorivoj ćeliji i sl; (2) rashladni blok, koji može da sadrži električne, absorpcione ili adsorpcione čilere/toplotne pumpe, u zavisnosti od mogućnosti za povezivanje sa kogeneracionim blokom; (3) akumulator energije, toplotne (za grejanje i/ili hlađenje) ili električne energije; (4) konzumno područje koje može a ne mora da bude u vezi sa spoljašnjim energetskim mrežama (električna mreža, toplifikaciona i sl.).

Za sintezu trigeneracionog sistema, potrebno je razmotriti lokalno dostupne resurse, mogućnosti njihove eksploatacije, radne karakteristike pojedinih komponenata i sagledati moguće energetske tokove u sistemu, uključujući i potrebne temperaturne nivoe radnih medijuma u sistemu.

Mogućnosti primene gorivih ćelija, stirling motora, motora SUS, za primenu u domaćinstvima u Kanadi su razmetrane pomomoću TRNSYS softvera, a dobijeni rezultati uključuju ekonomsku izvodljivost, procenu ukupnih emisija, detaljno modeliranje generatora i eksperimente na terenu [5]. Kako gorive ćelije i stirling

motori, po mišljenju autora, još uvek nisu u dovoljnoj meri zastupljeni, naročito na domaćem (srpskom) tržištu, kogeneracioni podsistem bi u domaćim uslovima mogao biti zasnovan na gasnoj turbini ili gasnom motoru SUS [6, 7]. Mikroturbine pružaju efikasnost proizvodnje električne energije od oko 30%, mogućnost korišćenja više vrsta goriva, a ukupna efikasnost kogeneracionog sistema sa mikroturbinom ide i preko 80%. [6]. Prednosti primene mikroturbina su (u odnosu na klipne motore SUS): veličina, mala težina, manji broj pokretnih delova, bolji kvalitet otpadne toplote, manje potrebe u pogledu održavanja i manji nivo buke i vibracija. Ipak, kod sistema manjih snaga, motori SUS imaju bolju efikasnost [6,8], a njihovo korišćenje je i ekonomski i finansijski isplativije [3,9]. Zahvaljujući nižim cenama investicija, oni se koriste za snage manje od 30kW te su pogodniji za manje kogeneracione (trigeneracione) sisteme. Otpadna toplota kod njih može dostići temperature i do 160 °C i pritiske pare do 20bar [6], što zadovoljava potrebe grejanja i hlađenja prostora. Temperatura vode za hlađenje bloka motora je obično 85-90°C, dok je temperatura vazduha za hlađenje (ili pare niskog pritiska) 100-120°C, što se može koristiti kao toplota za toplovodno grejanje, pripremu sanitarne tople vode ili za hlađenje pomoću sorpcionih uređaja [6].

Otpadna toplota kogeneracionog bloka se koristi direktno za grejanje ili za hlađenje prostora primenom toplotom pogonjenih čilera ili toplotnih pumpi [14]. Zahtevi u pogledu kvaliteta otpadne toplote su određeni ulaznim karakteristikama rashladnog uređaja i zahtevima konzuma u zimskom režimu. Za korišćenje niskotemperaturnih izvora energije, mogu se koristiti toplotne pumpe koje koriste toplotni izvor i adsorpciju pare ili sorpciju gasa, za promenu temperaturnog nivoa dostupne toplotne energije [11,12]. Na osnovu pregleda performansi različitih radnih parova, ulaznih i izlaznih temperatura i efikasnosti hlađenja, različitih radnih parova u adsorpcionim i absorpcionim rashladnim uređajima za potrebe manjeg stambenog objekta pogodna je absorpciona toplotna pumpa LiBr-voda, sa temperaturama na ulazu i izlazu 80-90°C i 6-7°C [11].

Za upotrebu drugog dostupnog resursa, solarne enerije, neophodna je primena solarnih prijemnika. Toplotna energija dobijena na ovaj način se koristi direktno za pripremu tople vode ili za hlađenje pomoću toplotom pogonjenih rashladnih uređaja, ili se vrši akumulacija ove energije pomoću akumulatora toplote [13]. Na osnovu karakteristika pločastih, stacionarnih paraboličkih koncentrišućih i vakumskih solarnih kolektora, uslova lokacije datog objekta i potreba konzuma, odabrani su pločasti solarni kolektori, koji su ujedno cenovno i najpristupačniji [14].

Primena akumulatora toplote povećava raspoloživost solarnog sistema, a kako je u pitanju trigeneracioni sistem, otpadna toplota kogeneracionog bloka se može koristiti i za zagrevanje akumulatora toplote. Za potrebe grejanja i klimentizacije objekta, najpogodnija je upotreba vode kao radnog medijuma za niskotemperaturnu akumulaciju u opsegu od 25°C do 90°C [14].

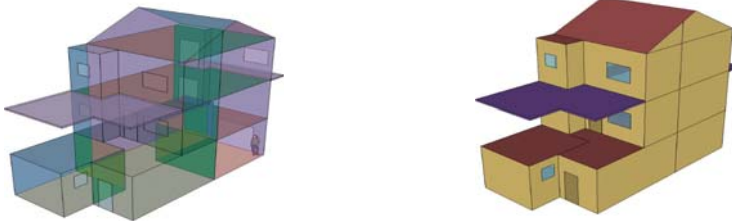
Na osnovu analize dostupnih komponenata, definisana je sledeća struktura malog trigeneracionog sistema za potrebe stambenog objekta: (1) kogeneracioni blok zasnovan na gasnom motoru SUS, (2) absorpciona toplotna pumpa Li-Br – voda, (3) polje pločastih solarnih prijemnika, (4) senzibilni akumulator toplote sa vodom. Kada je doneta odluka o strukturi postrojenja, pristupa se simulaciji konzuma, tj. u ovom slučaju energetske potrebe datog stambenog objekta.

3. SIMULACIJA ENERGETSKIH POTREBA MALOG STAMBENOG OBJEKTA

Sistem radi u “bivalentnom” režimu, što podrazumeva upotrebu dodatnog postrojenja za vršna opterećenja, što nosi niz prednosti kako u pogledu smanjenja troškova investicije i njihove isplativosti, tako i u pogledu ekonomičnosti rada [15].

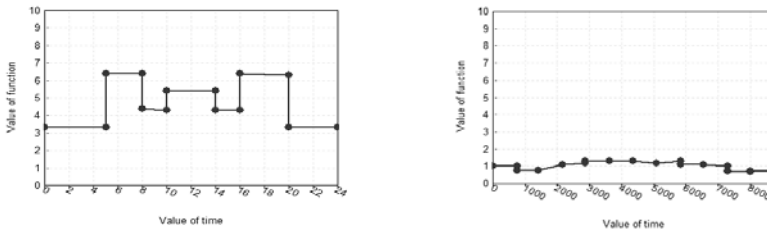
Primenom “Meteonorm” vremenskih podataka za Beograd [16], izvršena je simulacija toplotnog (i rashladnog) opterećenja datog stambenog objekta [17,18], koji je povezan na elektrodistribucionu mrežu, pomoću TRNSYS softvera. Kako su u pitanju statističke vrednosti časovne promene temperature, minimalna $-10.13\text{ }^{\circ}\text{C}$, a maksimalna $35.44\text{ }^{\circ}\text{C}$, jasno je da projektni uslovi definišu strože kriterijume za izbor opreme.

U ovom radu objekat je simuliran kao višezonski (slika 1), podeljen na 3 zone: (1) negrejani deo, (2) prvi sprat unutrašnje temperature 22°C i (3) drugi sprat, unutrašnje temperatura 20°C . Omotač zgrade je modeliran od materijala iz biblioteke programa, kao objekat sa masom.

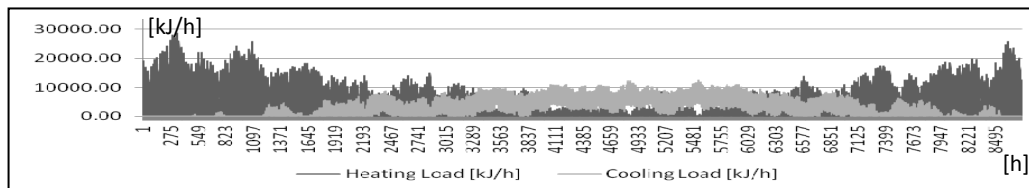


Slika 1. Geometrija objekta u Trnsys 3D plug-in-u za Google sketchup

Energetske potrebe datog objekta simulirane su sa vremenskim korakom od 1h, za period od godinu dana tj. 8765 sati, uzeti po pretpostavci: angažovana električna snaga se menja po istoj funkciji svakog dana, a procentualno se menja svakog meseca (slika 2). Rezultati simulacije predstavljaju srednje časovne vrednosti u toku jedne godine.



Sl.2. Električno opterećenje u kW: dnevna promena (levo) i godišnja promena (desno)



Sl.3. Toplotno opterećenje objekta u režimu grejanja (Heating Load) i hlađenja (Cooling Load)

Karakteristike omotača objekta definiše „u-vrednost“, koja za dati objekat iznosi: $0.726\text{ W/m}^2\text{K}$ za krovnu i međuspratnu konstrukciju ispod negrejanog tavana

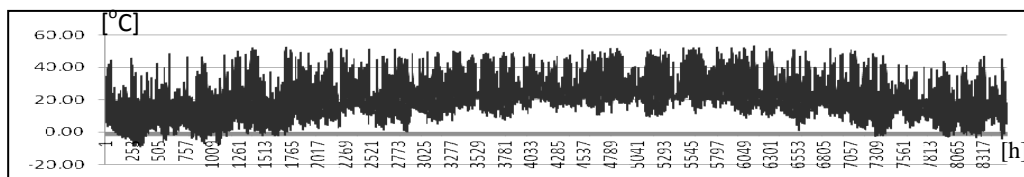
debljine 38cm, $1.1532 \text{ W/m}^2\text{K}$ za podnu konstrukciju sa parketom, debljine 48cm i $0.202 \text{ W/m}^2\text{K}$ za spoljašnje zidove debljine 45cm. Koeficijent solarne absorpcije spoljašnjih zidova i stolarije je 0.6, a faktor izliženosti suncu za slobodne fasade je 0.5. Stolarija je aluminijumska, dvostruka sa faktorom rama 0.15. „U-vrednost“ stolarije je $2.83 \text{ W/m}^2\text{K}$ a „g-vrednost“ 0.75%. Višezonski objekat je zgrada u nizu sa jednim stanom, pri čemu su južna i severna fasada izložene uticaju ambijenta, dok su sa istočne i zapadne strane su zidovi na dilataciji sa susednim objektom.

4. SINTEZA I SIMULACIJA HIBRIDNOG TRIGENERACIONOG POSTROJENJA

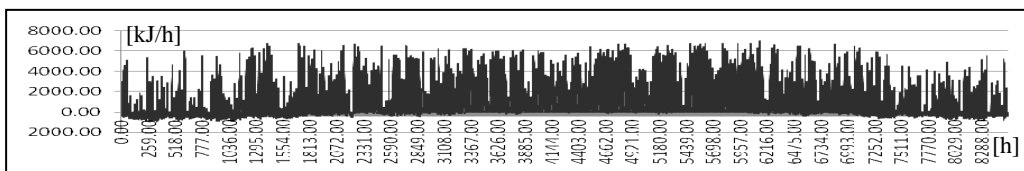
Sinteza i simulacija postrojenja izvršena je pomoću softvera TRNSYS, primenom standardne bilblioteke komponenata. Kako bi se utvrdio potencijal za primenu solarne energije, urađena je simulacija godišnje prosečne proizvodnje toplotne energije primenom ovih kolektora za snabdevanje objekta toplom vodom tokom cele godine. U tabeli 1. dati su ulazni parametri simulacije. Rezultati su prikazani na slikama 4a i 4b.

Tabela 1. Glavni ulazni parametri simulacije

Radno vreme sistema	06h-20h	Površina prijelnika	2,4m ²
Nominalni protok pumpe	60 kg/h	Protok vode kroz kolektor	60kg/h
Temp. vode na ulazu u pumpu	20°C	Efikasnost	80%
Protok vode na ulazu u pumpu	60kg/h	Temp. vode na ulazu u kolektor	20°C
Broj prijelnika	10	Nagibni ugao	45°



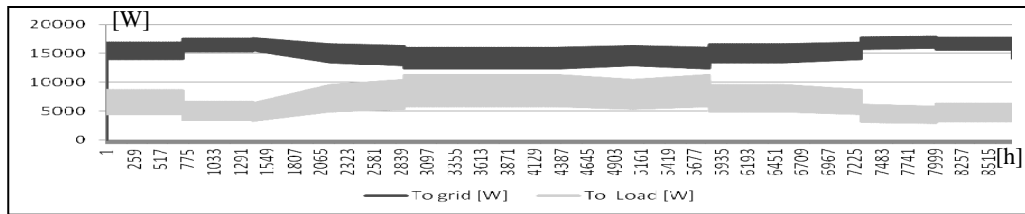
Sl.4a. Promena temperature na izlazu polja solarnih prijelnika u toku godine



Sl. 4b. Toplotna snaga solarnog sistema

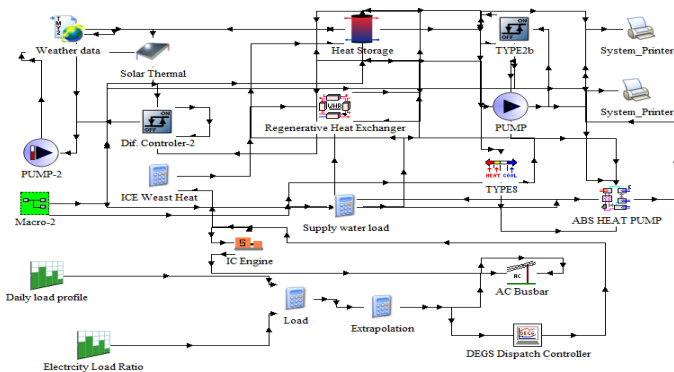
Maksimalna temperatura na izlazu kolektora je $53.52 \text{ }^\circ\text{C}$. a maksimalna izlazna snaga 7020 kJ/h . Količina toplote koja se dobija poljem solarnih prijelnika nije dovoljna za pripremu tople vode za podmirivanje potrebnog toplotnog opterećenja.

Simulacija kogeneracionog bloka je rađena za kogeneracioni sistem koji je zasnovan na vazdušno hlađenom motoru od 20kWe sa pogonom na prirodni gas, čija se otpadna toplota preko kaskadnog regenerativnog razmenjivača toplote koristi za dogrevanje akumulatora toplote.



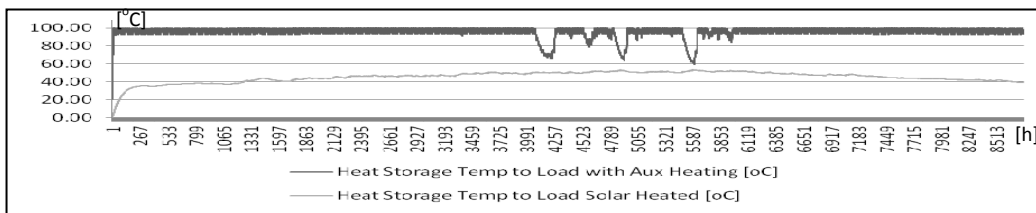
Sl.5. Simulacija proizvodnje električne energije: snaga angažovana za lokalno opterećenje (To Load) i predaju elektrodistributivnoj mreži (To Grid)

Simulacija pokazuje da motor radi sa opterećenjem ispod 50% u većem delu godine za podmirivanje lokalnih potreba za električnom energijom. Ako motor radi sa nominalnim opterećenjem, moguća je predaja viška električne energije elektrodistributivnoj mreži (slika 5).



Sl. 6. Šema simuliranog trigeneracionog hibridnog postrojenja u TRNSYS softveru

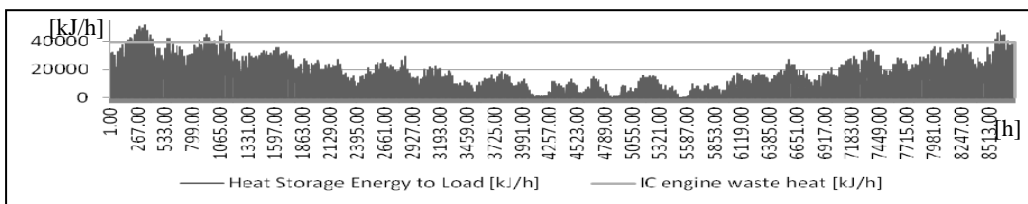
Zagrejana voda iz solarnih prijemnika ide do toplotnog akumulatora sa vodom zapremine 20m^3 . Maksimalna radna temperatura akumulatora je 95°C . Rad pumpe i cirkulaciju vode u sistemu kontroliše diferencijalni kontroler sa histerezisom, podešen na $\pm 2^\circ\text{C}$. Kontroler prati temperaturu na izlazu iz akumulatora toplote.



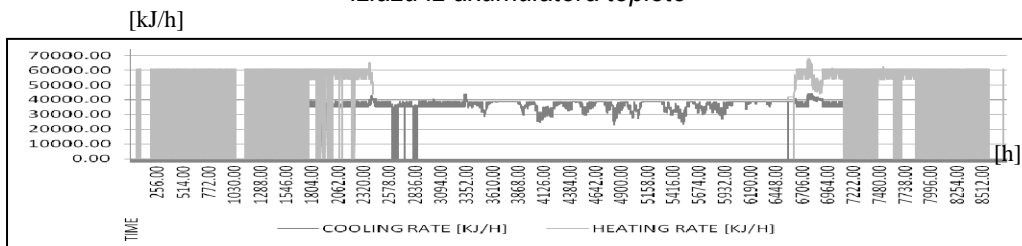
Sl.7. Temperatura na izlazu iz akumulatora toplote: sa zagrevanjem gasnim dogrejačem (Aux Heating) i bez upotrebe dogrejača (Solar Heated)

Topla voda iz akumulatora se koristi za pogon Li-Br/voda toplotne pumpe nominalne snage 15 kW, čija je minimalna temperatura na ulazu 75.6°C . Akumulator po potrebi dogrevaju dva unutrašnja gasna zagrejača ukupne snage 20kW, čiji rad kontroliše diferencijalni kontroler sa histerezisom, podešen na $+5/-2^\circ\text{C}$. Šema simuliranog sistema predstavljena je na slici 6, a dostupna otpadna toplota u nominalnom režimu rada motora SUS i toplotno opterećenje na izlazu iz akumulatora toplote su predstavljeni na slici 8. Absorpciona toplotna pumpa kontrolni signal dobija od termokontrolera, koji na osnovu zadate temperature objekta, temperature i vlažnosti ambijenta po potrebi uključuje i isključuje toplotnu pumpu. Rezultati simulacije rada toplotne pumpe dati su na slici 9.

Zagrevanje akumulatora toplote otpadnom toplotom motora SUS, vrši se preko kaskadnog regenerativnog razmenjivača toplote sa sledećim pretpostavkama: temperatura izduvnih gasova je 120°C, protok izduvnih gasova je 10kg/h, temperatura izduvnih gasova na izlazu iz rekuperatora je 100°C, efikasnost rekuperacije je 60%. Kaskadni regenerativni razmenjivač toplote koristi i toplotu povratnog voda toplotne pumpe. Na slici 9. prikazana je dostupna otpadna toplota motora SUS sa efikasnošću razmene toplote od 0.6, za rad u nominalnom režimu i toplotno opterećenje na izlazu akumulatora toplote.



Sl.8. Dostupna otpadna toplota motora SUS (ICE waste heat) i isporučena toplota na izlazu iz akumulatora toplote



Sl.9. Produkcija Li-Br toplotne pumpe u režimu grejanja i hlađenja

5. ZAKLJUČAK

U ovom radu je izvršena sinteza i simulacija hibridnog trigeneracionog sistema sa pogonom na prirodni gas sa mogućnošću upotrebe solarne energije. Rezultati simulacije solarnog sistema pokazuju da je neophodno dogrevanje akumulatora toplote, što se ostvaruje upotrebom otpadne toplote gasnog motora SUS i primenom gasnih dogrejača akumulatora toplote. Ovakva struktura sistema može da isporučiti toplu vodu dovoljne temperature za pogon odabrane Li-Br toplotne pumpe i nudi fleksibilnost u radu. Proizvodnja električne energije usvojenog motora SUS znatno prevazilazi pretpostavljenu potrošnju električne energije ovog objekta. Posledica ovoga je da motor radi u režimu nižih opterećenja i manje efikasnosti, ili u nominalnom režimu sa viškom proizvedene električne energije.

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University of East Sarajevo
Faculty of Mechanical Engineering

Conference on Mechanical Engineering Technologies and Applications

Session V ***RENEWABLE ENERGIES AND*** ***ENVIRONMENTAL PROTECTION***



ZNAČAJ ANALIZE ENERGETSKIH LANACA PRI PROIZVODNJI ENERGIJE IZ BIOMASE

Srdan Vasković¹, Petar Gvero², Vlado Medaković³, Davor Milić⁴

Rezime: U radu su predstavljeni osnovni pojmovi o energetskim lancima baziranim na biomasi. Šta predstavlja energetski lanac i koji su njegovi sastavni dijelovi? Takođe, zašto je potrebno vršiti analizu energetskih lanaca po pitanju njihove efikasnosti, ekonomičnosti i ekološkog aspekta. Analizom energetskih lanaca dobijaju se mogućnosti izbora "najboljeg" lanca zavisno od uslova u kojima energetski lanac funkcioniše. Da bi se proces vrednovanja energetskih lanaca baziranih na biomasi ubrzao i omogućila njihova efikasna analiza potrebno je razviti dobar model.

Ključne riječi: biomasa, energetski lanac, efikasnost, snabdijevanje, model

THE IMPORTANCE OF ANALYSIS ENERGY CHAINS BASED ON BIOMASS FOR ENERGY PRODUCTION

Abstract: *This paper presents the basic concepts of energy chains based on biomass. What is the energy chain and what are its components? Also, why is it necessary to perform the analysis of the energy chain in terms of their efficiency, cost and environmental reasons. Analysis of energy chains gives choice of "best" chain depending on the conditions for each energy chain function. The development of an adequate model is the best solution for this kind of analysis.*

Keywords: biomass, energy chain, efficiency, supply, model

1. UVOD

Biomasa predstavlja uskladištenu solarnu enregiju u procesu fotosinteze u obliku hemijskih jedinjenja koja formiraju strukturu biljaka. Za vrijeme sagorijevanja biomase, kiseonik iz atmosfere se spaja sa ugljenikom u biomasi i kao produkti sagorijevanja dobijaju se ponovo CO₂ i voda. Ovo je osnovni razlog zašto se ovako dobijena energija smatra CO₂ neutralnom. Međutim, izvjesne količine emisija CO₂ dešavaju se upravo od fosilnih goriva koja se koriste prilikom prikupljanja, proizvodnje i transporta biogoriva. Značajne količine upotrebljive biomase nastaju prilikom sječenja šuma kao ostatak od sječe i primarnom i sekundarnom preradom drveta u drvnoj industriji. Proizvodnja energije iz biomase definisana je odgovarajućim energetskim lancem. Način na koji se iskorištava energija iz odgovarajućeg energenta počev od

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tehnologije za prikupljanje energenta pa sve do sistema za proizvodnju energije (sistemi za transformaciju energije iz jednog oblika u drugi), ali i do samog tržišta energijom predstavlja energetski lanac.

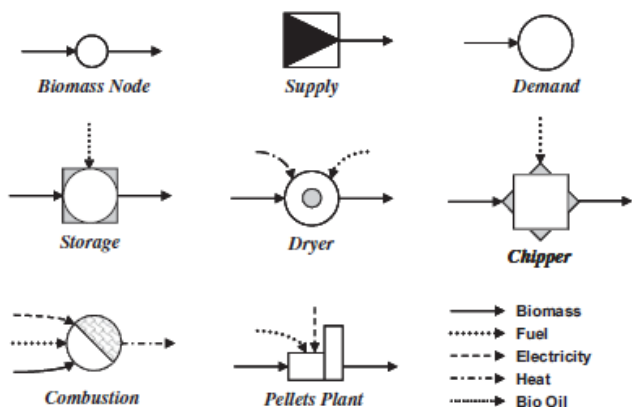
2. STRUKTURA ENERGETSKIH LANACA BAZRANIH NA BIOMASI

Energetski lanac uključuje više faktora čijim razmatranjem i dovođenjem u funkcionalnu zavisnost ostvaruje se mogućnost analize efikasnosti samog lanca i procesa proizvodnje energije. Da bi se detaljno ocjenio i vrednovao proces proizvodnje energije iz biomase potrebno je opisati i analizirati što veći broj elemenata energetskog lanca i postaviti ih u međusobnu zavisnost. Opšti koncept strukture jednog energetskog lanca baziranog na biomasi, sastojao bi se od modeliranja sledećih elemenata:

1. Modeliranje funkcije priraštaja šumske biomase na godišnjem nivou u okviru jedne lokalne zajednice,
2. Izbor tehnologije iskorišćavanja u sječini i razvoj funkcije prikupljanja i privlačenja transportnom putu uz ekološki prihvatljivo iznošenje količine ostataka od sječe iz šume (ukoliko se koristi),
3. Definisane funkcije transporta sirovine iz šume ili iz postrojenja za preradu drveta do postrojenja za pripremu biomase za korišćenje,
4. Modeliranje postrojenja za usitnjavanje i predpripremu biomase,
5. Definisane funkcije sušenja i skladištenja drvene biomase kao gotovog goriva za spaljivanje,
6. Definisane funkcije transporta pripremljene biomase do postrojenja za proizvodnju energije,
7. Modeliranje tehnologije i postrojenja za proizvodnju energije,
8. Modeliranje distribucije energije ili transporta energenata do potrošača,
9. Modeliranje korisnika energije i energenta iz biomase,
10. Modeliranje tržišta energijom kao glavnog faktora poremećaja na ekonomičnost energetskog lanca.

Naravno, svi prethodno nabrojani elementi su samo grubo pomenuti, njihovom detaljnijom analizom i opisivanjem sa što više faktora i zavisnosti može se doći do tačnijeg, preglednijeg i sistematizovanog opisa energetskog lanca za proizvodnju energije iz biomase. Proces modeliranja energetskih lanaca je aktuelan u današnje vrijeme kao i formiranje različitih scenarija što nastaju kao izlazni rezultati iz modela. Obrađivan je od strane više autora u navedenoj literaturi, uglavnom težište svih radova se svodilo na analizu troškova za snabdijevanje sa biomasom, analizu i predviđanje potreba za nekim energentom u projektovanom razdoblju, itd.. Pretežno pristup analizama proizvodnje energije iz biomase imao je najviše ekonomsku dimenziju sa stanovišta varijabilnih troškova, prilikom funkcionisanja lanca, npr. cijena troška transporta drvnog čipsa ili peleta po toni, potrošnja energije za proizvodnju tone peleta, itd.. Obrađivani su najčešće djelimično dijelovi energetskih lanaca. Nisu istovremeno uzimati pristupi analize preko ekonomskih, ekoloških i energetskih pokazatelja energetskih lanaca kao i same barijere koje se pojavljuju tokom uspostave energetskog lanca. Neke od aktuelnih referenci date su u sledećim radovima [1,3,4,5]. Tako je npr.. Li Y. 0,2006, modelirao infrastrukturu za prikupljanje biomase. Na Sl.1. dat

je simbolički prikaz elemenata lanca modeliranih u prethodnom radu kao i uvođenje opšteg pristupa analizi energetskih lanaca baziranih na biomasi. Dizajniranje regionalne mreže snabdijevanja šumskom biomasom radili su Gronalt, M. i Rauch, P., 2007. Linearni model za snabdijevački lanac biomasom s transportom, skladištenjem i pripremom definisali su Van Dyken, Bjorn H. Bakken, Hans I. Skjelberd O,2009.



Sl 1. Simbolički prikaz nekih elemenata energetskog lanca [1]

3. PREGLED ISTRAŽIVANJA ENERGETSKIH LANACA BAZIRANIH NA BIOMASI

Istraživanja struktura energetskih lanaca za proizvodnju energije iz biomase su relativno novijeg datuma. Uglavnom povećani interes za ova istraživanja pojavio se sa globalnim problemima kao što su: proces globalnog zagrijavanja, poskupljenjem cijena goriva zbog smanjenja rezervi fosilnih goriva, težnjom za smanjenjem zavisnosti od snabdijevanja fosilnim gorivima uz korišćenje domaćeg resursa biomase, zagađivanje životne sredine, itd. Prisutno je niz radova koji obrađuju ovu tematiku, a neki od novijih radova su dati u literaturi: [1,3,4,5,6,7], itd.

U zemljama u razvoju, oko 22% korišćene energije se dobija iz biomase, međutim radi se o tradicionalnom načinu korišćenja sa veoma niskim stepenom iskorištenja i povećanim emisijama zagađujućih materija. Mnogi scenariji predviđaju u budućnosti značajan porast učešća energije iz biomase [2].

Istraživanja koja se tiču komponovanja snabdijevačkih energetskih lanaca i uopšte korišćenja biomase kao energenta su novijeg izdanja. Optimizacija snabdijevačkih lanaca biomasom uglavnom se vrši prema distancama transporta i vlažnosti biomase koja se transportuje. Opis modeliranja regionalne strukture snabdijevanja šumskom biomasom kao gorivom u zavisnosti troškova transporta opisali su Gronalt, M. i Rauch, P., 2007, [3].

Model linearnog snabdijevačkog lanaca biomasom koji uključuje, transport, skladištenje i pripremu biomase obrađen je od strane Silke Van Dyken, Bjorn H. Bakken, Hans I. Skjelberd, 2009, [4]. Glavno težište ovog rada nalazi se u iznalaženju linearne zavisnosti između sadržaja vlage u biomasi i energetske moći biomase i ekonomskih pokazatelja, posebno je obrađen slučaj pasivnog sušenja biomase u procesu skladištenja.

Planiranje i logistika u korišćenju drvene biomase za proizvodnju energije (Frombo, F., Minicardi, R., Robba, M., Rosso, F., Scaille, R., 2009, nalazi se u referenci [5]. Varijable odlučivanja u ovom pristupu su kapacitet postrojenja i prikupljena biomasa sa odgovarajućeg područja dok je ciljna funkcija suma svih troškova.

Produktivnost i troškovi mehanizovane sječe i prikupljanja drveta u energetske svrhe obrađeni su od strane Roser, D., Sikanen, L., Asikanen, A., Parikka, H., Vaatainen K., 2011, [6]. U radu je urađena analiza i pregled troškova koji javljaju u različitim kombinacijama proizvodnje drvnog čipsa kao energenta za slučajeve proizvodnje (kod postrojenja, uz put, na terminalu) shodno transportnim dužinama.

Analiza troškova transporta snabdijevačkih lanaca energetskim drvetom na duže distance u Finskoj [7]. U radu su analizirani načini transporta pomoću kamiona za drveni čips, transport baliranih ostataka sječe pomoću kamiona ili voza, transport rasutog ostatka itd.

Dakle, zaključuje se da većina radova u oblasti analize energetskih lanaca za proizvodnju energije iz biomase obuhvata samo analize pojedinih vrsta energetskih lanaca. Pored toga u tim analizama se pojavljuju nepotpuni lanci koji ne uključuju sve elemente sa kojim se zaokružuje tok lanca od sirovog resursa biomase do postrojenja za proizvodnju energije. Posebno se otvara priča kod izbora tehnologije za proizvodnju energije, toplotne i/ili električne. Da bi se dobila potpuna slika o energetskom lancu prije svega potrebno je da bude u potpunosti analiziran. Za analizu primjene izvjesnog energetskog lanca na nekom prostoru i pod odgovarajućim uslovima potrebno je da pored svih potrebnih podataka za opis energetskog lanca postoji i pregled potencijala i barijera njegove primjene. Ocjena prihvatljivosti primjene energetskog lanca treba da bude donešena na bazi višekriterijumskog vrednovanja.

4. PRISTUP ANALIZI ENERGETSKIH LANACA NA BAZI BIOMASE

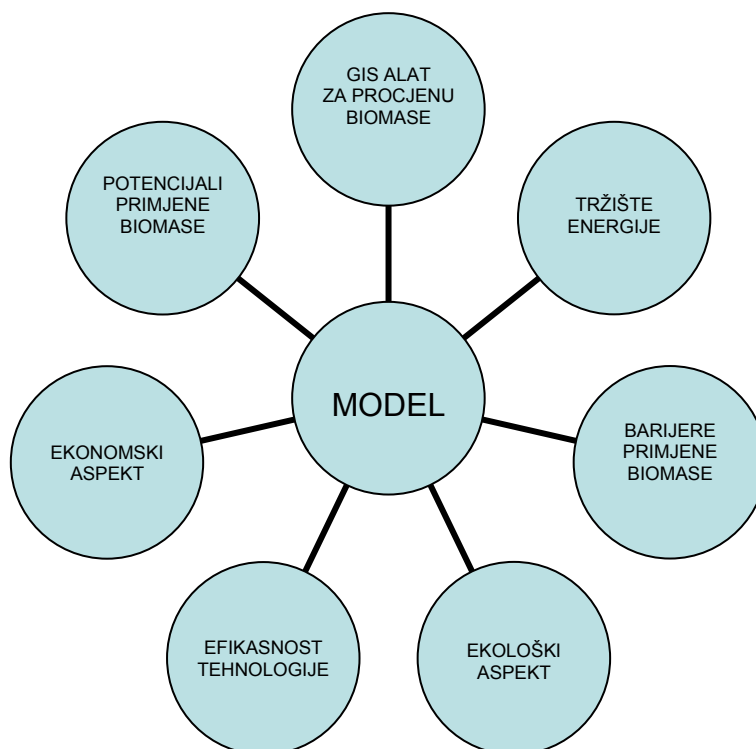
Analiza pomenutih energetskih lanaca može se vršiti prema konceptu „3E“, *Energy - Economy - Ecology*, tako što će svaki element lanca biti pojedinačno analiziran. Za konačnu ocjenu efikasnosti i efektivnosti energetskih lanaca mogu se koristiti sva tri parametra od pomenutog koncepta. Prema energetskom pristupu konceptu „3E“ uzima se u obzir faktor iskorišćenja svakog člana energetskog lanca,

$$\mu = \frac{\text{Dobijena energija}}{\text{Uložena energija}}$$

i kao rezultat dobija se konačna efikasnost energetskog lanca.

Ekonomska analiza prema konceptu „3E“ odnosi se na troškove investicije u tehnologiju neophodnu za funkcionisanje energetskog lanca, operativne troškove lanca kao i mogući period otplate sredstava. Ekološki aspekt analize pomoću koncepta „3E“ pomenutih energetskih lanaca uzeće u obzir emisije CO₂ koje se ostvare tokom funkcionisanja lanca, tj korišćenjem fosilnih goriva u procesima sječe, prikupljanja, transporta kao i pri proizvodnji samog postrojenja za usitnjavanje, presovanje i dobijanje energenata od drvene biomase (čips, pelet, briket). Konačan ishod čitave analize je formiranje modela za izračunavanje vrijednosti efikasnosti, ekonomičnosti i ekološke prihvatljivosti energetskih lanaca za odgovarajuće uslove i tehnologije pri korišćenju biomase u svrhu proizvodnje energije a sa vanjskim uticajem promjenjivih faktora tržišta energije i energenata. Modelom bi se trebalo da obuhvati i mogućnost modeliranja potencijala i barijera pri korišćenju biomase u energetske svrhe za

područja primjene na kojima se može testirati. Za potpunu ocjenu energetskih lanaca putem modela potrebno je imati u vidu i potencijale i barijere primjene biomase. Na Sl.2. prikazani su osnovni faktori koji trebaju biti uzeti u obzir tokom analize energetskih lanaca baziranih na biomasi. Ovakav pristup analize potrebno je koristiti prilikom razvoja modela za ocjenu kvaliteta energetskog lanca. GIS⁵ (alat za procjenu dostupne količine biomase na odgovarajućoj oblasti)



Sl.2. Pristup razvoju modela za ocjenu kvaliteta energetskog lanca

5. ZAKLJUČAK

Energetski lanci za proizvodnju energije i energenata iz biomase imaju veliki broj faktora o kojima se treba voditi računa tokom procesa njihovog projektovanja i uspostavljanja. Razvojem adekvatnog modela moguće je na kvalitetan i brz način doći do značajnih podataka u procesima projektovanja sistema za proizvodnju energije iz biomase. Zbog neprestanog tehnološkog razvoja i stjecanjem novih saznanja u području korišćenja biomase u energetske svrhe, neophodno je razviti takav model kojim će se osigurati njegova univerzalnost i nadogradivost u pogledu primjenjene tehnologije ali i njegovog područja primjene.

⁵ Geografic Information System

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RECIKLIČNOST - ZNAČAJAN ZAHTJEV PRI PROJEKTOVANJU I KONSTRUISANJU U METALSKOJ INDUSTRIJI

Stojan Simić¹

Rezime: U prošlosti su pri projektovanju i konstruisanju proizvoda u metalnoj industriji prioritetni zahtjevi bili eksploataбилnost i tehnološkičnost proizvoda. U novije vrijeme zbrinjavanje dotrajalih proizvoda za projektante, konstruktore i proizvođače predstavlja dodatni zahtjev koji se mora uzeti u obzir. Ovaj zahtjev se prvenstveno odnosi na recikličnost, a podjednako je značajan u svim fazama životnog ciklusa proizvoda.

U radu se sveobuhvatno razmatraju parametri značajni sa aspekta reciklaže u metalnoj industriji na koje treba obratiti pažnju pri projektovanju, konstruisanju i izradi proizvoda, kao i uštede koje se mogu postići u materijalnom i energetskom pogledu reciklažom proizvoda na kraju životnog ciklusa. Recikličnost proizvoda u metalnoj industriji je zahtjev od izuzetnog značaja na koji se mora obratiti posebna pažnja u toku faze projektovanja i konstruisanja.

Ključne riječi: recikličnost, metalna insustrija, projektovanje i konstruisanje.

RECYCLABILITY-SIGNIFICANT REQUEST FOR DESIGN AND CONSTRUCTION IN THE METAL INDUSTRY

Summary: In the past, for design and construction of products in the metal industry priority requests were exploitability and technologically of products. In recent years, disposal of old products for designers, constructors and manufacturers presents an additional requirement that must be taken into account. This demand is primarily related to recyclability and is equally important in all stages of the product life-cycle.

In this paper are comprehensively discussed all parameters that are important in the metal recycling industry, that should be paid attention when designing, constructing and manufacturing the product, as well as the savings that can be achieved in terms of energy and material by recycling of products at the end of its life-cycle. Recyclability of the products in the metal industry, is high important reques on which must paid special attention during the design and construction.

Keywords: recyclability, metal industry, design and construction.

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1. UVOD

U značajnoj mjeri metalska industrija, na direktan ili indirektan način, opterećuje sve ambijente životne sredine. Pri procesu proizvodnje dolazi do nastajanja otpadnog materijala, tehnoloških otpadnih voda i emitovanja otpadnih gasova u atmosferu. Većina energetskih procesa u metalnoj industriji se odvija sa efikasnošću manjom od 100%, što dovodi do toga da se jedan dio energije nepovratno emituje u životnu sredinu.

Sve do nedavno pri projektovanju proizvoda u metalnoj industriji prioritetni zahtjevi su bili eksploataбилnost i tehnološkičnost proizvoda. U novije vrijeme zbrinjavanje proizvoda na kraju životnog ciklusa za projektante, konstruktore i proizvođače predstavlja dodatni zahtjev koji se mora uzeti u obzir. Ovaj zahtjev se prvenstveno odnosi na recikličnost, a podjednako je značajan u svim fazama životnog ciklusa proizvoda.

U radu se sveobuhvatno razmatraju parametri značajni sa aspekta reciklaže u metalnoj industriji na koje treba obratiti pažnju pri projektovanju, konstruisanju i izradi proizvoda, kao i uštede koje se mogu postići u materijalnom i energetskom pogledu reciklažom proizvoda na kraju životnog ciklusa. Primjenjujući zahtjeve koji se odnose na recikličnost pri projektovanju i konstruisanju u metalnoj industriji postiže se značajno smanjenje količine generisanog otpada u svim fazama životnog ciklusa proizvoda, ušteda energije i očuvanje prirodnih bogastava.

2. ZAHTJEVI PRI PROJEKTOVANJU I KONSTRUISANJU PROIZVODA

Životni ciklus proizvoda započinje projektovanjem i izradom proizvoda, nastavlja se upotrebom, a završava uklanjanjem dotrajalog proizvoda. Sagledavanje proizvoda na ovaj način upućuje na recikliranje [1]:

- prije upotrebe proizvoda (tokom proizvodnje),
- tokom upotrebe proizvoda, i
- nakon upotrebe proizvoda.

Najmanje se problema javlja pri recikliranju tokom proizvodnje, zato što je olakšano sakupljanje, sortiranje (identifikacija), prevoz i prerada otpada. Nije rijetkost da se prerada obavlja na mjestu nastajanja otpada (npr. livnica, prerada plastike i dr.). Na ovaj način se otpad ponovo uključuje u proizvodni proces kao sirovina. Ipak, otpad se najčešće sakuplja kao sekundarna sirovina i odvozi na preradu u fabrike u kojima se proizvode odgovarajući materijali.

Recikliranje tokom upotrebe odnosi se na otpad koji nastaje servisiranjem i održavanjem proizvoda (zamjena dotrajalih dijelova i opreme). Najpovoljnije rešenje je ponovna upotreba dotrajalih delova, za istu ili različitu namjenu, sa ili bez prethodnog regenerisanja, tj. obnavljanja (navarivanjem, metalizacijom, mehaničkom obradom, zavarivanjem, lijepljenjem i dr.). U tim slučajevima radi se o recikliranju dijelova ili sklopova. Mogućnost primjene ovih postupaka zavisi od prikladnosti proizvoda takvom načinu održavanja (pristupačnost i zamjenljivost dijelova, rastavljivost sklopova i dr.). Međutim, danas se uglavnom većina otpada koji je nastao tokom upotrebe prerađuje kao sekundarna sirovina.

Recikliranje nakon upotrebe predstavlja uklanjanje dotrajalog proizvoda. U ovoj fazi nastaje i najveća količina otpada. Problemi se javljaju zbog široke rasprostranjenosti pojedinih proizvoda na tržištu što otežava njihovo sakupljanje, zatim

što različiti proizvođači proizvode iste vrste proizvoda, kao i zbog neprikladnosti proizvoda za recikliranje.

Pri projektovanju i konstruisanju proizvoda potrebno je uzeti u obzir i zahtjeve koji se odnose na recikličnost, a to su prije svega [2]:

- izbor materijala
 - smanjenje vrsta materijala,
 - izbor materijala pogodnih za reciklažu,
 - smanjenje mase materijala,
 - grupisanje materijala problematičnih za reciklažu,
 - označavanje vrste materijala na samom proizvodu,
- pogodnost pri rastavljanju
 - jednostavna zamjena dijelova,
 - davanje detaljnih uputstava za rastavljanje i sastavljanje,
 - primjena razdvojivih veza,
 - izbjegavanje nerazdvojivih veza,
 - tipizacija dijelova,
 - omogućiti prilaz i upotrebu električnih i pneumatskih alata pri rastavljanju.

Na primjer, u industriji motornih vozila potrebno je da proizvođači vozila u saradnji sa dobavljačima materijala, dijelova i sklopova obezbijede:

- ograničeno korišćenje opasnih supstancija u novim vozilima, kako bi se spriječilo da opasne supstancije dospiju u životnu sredinu, čime se olakšavaju uslovi za reciklažu i izbjegavaju obaveze stvaranja posebnih uslova za odlaganje opasnog otpada;
- projektovanje novih vozila uz planiranje jednostavne demontaže, ponovnog korišćenja i regeneracije njihovih komponenata i materijala;
- uputstva za demontažu novih modela vozila u roku od šest mjeseci od trenutka pojave na tržištu;
- pomoć u razvoju tržišta za reciklirani materijal i veće učešće recikliranog materijala u vozilima i drugim proizvodima;
- zabranu korišćenja olova, žive, kadmijuma, šestovalentnog hroma i drugih opasnih materijala u vozilima proizvedenim poslije 01.07.2003. godine.

Radi ocjenjivanja reciklabilnosti dijelova motornih vozila američko udruženje za reciklažu VRP (Vehicle Recycling Partnership) definisalo je sljedećih pet kategorija [3]:

- reciklabilan - infrastruktura i tehnologije su potpuno definisane (npr. blokovi motora);
- potencijalno reciklabilan - infrastruktura nije potpuno definisana (npr. ukrasni dijelovi od plastike);
- potencijalno reciklabilan - tehnologije nisu još komercijalizovane (npr. reciklaža stakla-fibera);

- mogućnost dobijanja energije iz materijala, odnosno proizvoda koji je doživio kraj životnog ciklusa (npr. piroliza gume);
- nema poznatih tehnologija za reciklažu (npr. dijelovi enterijera od kože i dr.).

Projektant bi trebao uvažiti sve vrste i postupke recikliranja. Sa aspekta recikliranja proizvoda potrebno je ostvariti skladnost pri sakupljanju, rastavljanju, čišćenju, provjeravanju, razvrstavanju dotrajanih dijelova i proizvoda, a sa aspekta recikliranja materijala ostvariti skladnost pri sakupljanju, usitnjavanju, razdvajanju i dr. U oba slučaja od izuzetne važnosti je da se ostvari jednostavno rasklapanje proizvoda, odnosno rastavljanje elemenata.

Pri projektovanju proizvoda potrebno je usmjeriti posebnu pažnju na sljedeća načela:

- težiti što manjem utrošku energije u cjelokupnom životnom ciklusu proizvoda;
- u što većem obimu koristiti reciklirane sirovine i materijale;
- primjenjivati tehnološke procese koji proizvode minimalnu količinu otpada, otpadnih gasova i supstancija;
- izabrati materijale koji su relativno lako i jednostavno recikliraju;
- kreativno iskoristiti otpadne materijale u fazi proizvodnje.

U razvoju proizvoda postoji nekoliko trendova koji otežavaju kasnije recikliranje, a to su:

- sve veća kompleksnost proizvoda uz primjenu većeg broja različitih vrsta materijala;
- povećana primjena kompozitnih materijala;
- minijaturizacija pojedinih sklopova.

Sve strožiji zahtjevi koji se odnose na svojstva proizvoda i ekonomičnost izrade, kao i sve veći broj proizvodnih postupaka i materijala čine projektovanje i konstruisanje sve složenijim i odgovornijim. Principi bitni za projektovanje i konstruisanje s aspekta recikličnosti proizvoda:

- Primijeniti što manje vrsta materijala.
- Izabrati postupke praoblikovanja i preoblikovanja koji stvaraju što manje otpada.
- Proizvod nakon upotrebe koristiti bez ili uz minimalnu promjenu oblika.
- Proizvod tako izraditi da se nakon upotrebe ne mora odbaciti, već da se može preraditi i ponovo upotrijebiti.
- Materijale i njihove kombinacije izabrati tako kako bi se najmanje otežavao njihov proces recikliranja.
- Izbjegavati upotrebu supstancija koje u procesu recikliranja nepovoljno utiču na svojstva recikliranog materijala i proizvoda.
- Izbjegavati primjenu prevlaka od plastike, slojeva koji se nanose i spajanje različitih materijala lijepljenjem.
- Standardizovati dijelove, sklopove i proizvode, i normirati priključne mjere. Kodirati i označiti dijelove i materijale koji su pogodni za reciklažu.
- Elektro jedinice sa visokim udjelom bakra trebaju biti lako dostupne i rastavljive. Minimizirati njihov broj i kombinovati ih sa dijelovima sličnog hemijskog sastava.
- Po mogućnosti izraditi proizvod tako da nema površina koje bi mogle biti izložene dejstvu korozije. U zonama gdje postoji opasnost od pojave korozije

izbjegavati oštre ivice, grube i neravne površine. Rastavljive veze tako izraditi da usljed dejstva korozije ne postanu nerastavljive.

- Da se svaki višedjelni proizvod mora moći brzo, lako i bez oštećenja razdvojiti na sastavne dijelove.
- Sa aspekta tribologije potrebno je svesti habanje na najmanju moguću mjeru. Dijelovi koji se troše usljed habanja moraju biti lako zamjenjivi i izrađeni od materijala koji se relativno lako recikliraju.

3. RECIKLIČNOST PROIZVODA

Recikličnost proizvoda je osnovni pokazatelj mogućnosti materijalne iskoristivosti proizvoda na kraju životnog ciklusa. To je bezdimenzioni pokazatelj čija se vrijednost kreće od 0 do 1. Određuje se pomomoću sljedećeg izraza:

$$R = \frac{\sum_{i=1}^n b_i \cdot m_i \cdot r_i}{M \cdot r_{\max}} \quad (1)$$

gdje su:

- b_i , - , - broj ponavljanja i-tog dijela u proizvodu,
- m_i , kg , - masa i-tog dijela,
- r_i , - , - ocjena recikličnosti i-tog dijela,
- r_{\max} , - , - najveća ocjena recikličnosti (max. 5),
- M , kg , - ukupna masa proizvoda.

Prilikom korišćenja ovog izraza u praksi treba obratiti posebnu pažnju na ukupnu masu proizvoda (M) jer istu vrijednost recikličnosti može imati proizvod male mase i visoke recikličnosti, kao i proizvod velike mase i niske recikličnosti. Zato se kao pokazatelj koristi masa proizvoda. Ona predstavlja sumu masa proizvoda, a dobija se mjerenjem mase sklopa ili zbrajanjem masa elemenata. Određuje se pomoću izraza:

$$M = \sum_{i=1}^n (b_i \cdot m_i) , \text{ kg} , \quad (2)$$

Ovaj je izraz od pomoći u situacijama kada dva različita proizvoda imaju isti pokazatelj recikličnosti proizvoda (R). U tom slučaju proizvod veće mase pokazuje veću finansijsku dobit od recikliranja, drugačiji pristup transportu i slično.

Pri utvrđivanju recikličnosti proizvoda bitan pokazatelj je ukupno vrijeme rastavljanja proizvoda (t_{vr}), koje se određuje pomoću izraza:

$$t_{pr} = \sum_{i=1}^n t_i + \sum_{k=1}^g \sum_{l=1}^h t_{kl} + t_{pz} , \text{ s} , \quad (3)$$

gdje su:

t_i	, s ,	- vrijeme odvajanja i odlaganja i-tog dijela,
i	, - ,	- oznaka dijela (1...n),
t_{kl}	, s ,	- vrijeme rastavljanja l-te veze k-tog spoja,
k	, - ,	- oznaka spoja (1...g),
l	, - ,	- oznaka veze (1...h),
t_{pz}	, s ,	- pripremno-završno vrijeme.

Na primjer, za računar PC AT 286 koji je proizveden 1989. godine (masa 16,12 kg, broj komponenti 53, vrijeme rastavljanja 125 s, broj vrsta komponenti 3) recikličnost je 0,74.

4. ZNAČAJ PRERADE METALNOG OTPADA

Gvožđe, čelik, aluminijum, bakar i drugi metali su izuzetno vrijedni otpadni materijali jer spadaju u neobnovljive prirodne resurse. Većina metala se može preraditi i ponovo iskoristiti. Pri proizvodnji novog od otpadnog aluminijuma, umjesto od boksita, može se uštedjeti do 95% energije. Otpadni bakar je izuzetno tražena sekundarna sirovina. Na primjer, prilikom reciklaže otpadnih električnih kablova plastičnu izolaciju treba skinuti mehanički, a ne spaljivati, jer osim što je štetno po životnu sredinu dolazi i do oštećenja metala (bakra). Otpadno gvožđe je kvalitetna sekundarna sirovina za proizvodnju čelika. Pri proizvodnji sirovog gvožđa u visokim pećima otpadno gvožđe se dodaje u odgovarajućem odnosu rudi gvožđa čime se štede primarne sirovine i postiže niža cijena gotovog proizvoda. Tako se na svakih 1000 kg recikliranog čelika uštedi 1150 kg rude gvožđa, 635 kg uglja i 55 kg kreča.

Reciklaža metalnog otpada je izuzetno isplativa zato što se smanjuje količina rude koju treba istopiti i oplemeniti. Metalni otpad je u stvari energetska sirovina zato što štedi značajnu količinu primarne energije, koju treba uložiti pri procesu dobijanja odgovarajućeg metalnog proizvoda iz rude. U tabeli 1. dat je prikaz potrošnje energije pri proizvodnji metala iz rude i otpada.

Tabela 1. *Uporedni prikaz potrošnje energije pri proizvodnji metala iz rude i iz otpada*

Vrsta metala	Potrošnja energije pri proizvodnji metala		Ušteda energije	Iskorišćenje otpada (količinski)
	iz rude	iz otpada		
	MWh/t			%
bakar	13,5	1,7	11,8	87
olovo	9,5	0,5	9,0	95
cink	10,0	0,5	9,5	95
aluminijum	65,0	2,0	63,0	97
magnezijum	90,0	2,0	88,0	98
titanijum	126,0	52,0	74,0	58,5

Upotrebom metalnog otpada kao sirovine za proizvodnju metala smanjuje se potrošnja prirodnih sirovina i ostvaruje značajna uštede energije. U tabeli 2. su

prikazane prednosti upotrebe otpadnog čelika i aluminijuma sa aspekta uštede energije, smanjenja zagađenja vazduha i vode, kao i smanjenja potrošnje vode.

Tabela 2. Uštede koje se postižu reciklažom otpadnog čelika i aluminijuma

Parametar	Čelik	Aluminijum	Jedinica
ušteda energije	47-74	92-97	%
smanjenje zagađenja vazduha	86	95	
smanjenje zagađenja vode	76	97	
smanjenje potrošnje vode	40	-	

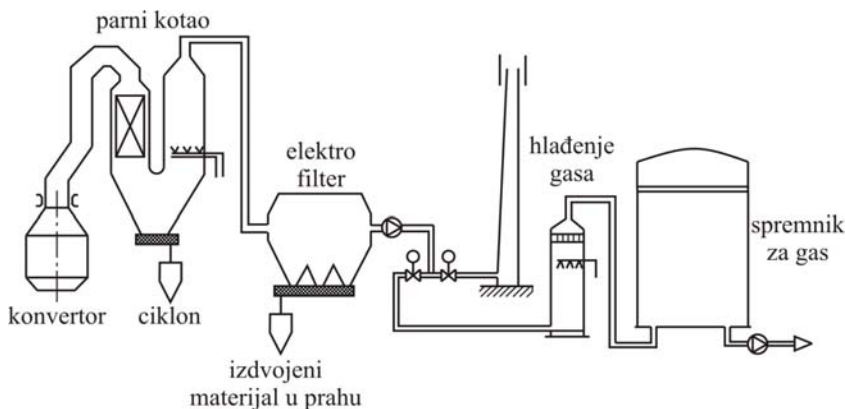
U svijetu se svake godine reciklažom čelika uštedi energija ekvivalentna potrošnji električne energije u 18 miliona domaćinstava u SAD.

Upravljanje čeličnim otpadom od trenutka njegovog pojavljivanja kao sekundarne sirovine do ponovne upotrebe predstavlja kompleksan proces koji se može podijeliti u tri osnovne cjeline:

- sakupljanje, transport i skladištenje,
- priprema za preradu, i
- prerada.

Pri procesu reciklaže posebno treba obratiti pažnju na sistem sakupljanja čeličnog otpada. Čelični otpad treba sortirati odmah na mjestu njegovog nastajanja, zato što miješanjem sa drugim materijalima gubi vrijednost i zahtijeva dodatne troškove pri transportu i skladištenju.

Poseban problem predstavlja reciklaža metalnih legura, kao i materijala kod kojih je urađena površinska zaštita (pocinkovanje, antikorozivna zaštita i dr.). Na slici 1. prikazana je tehnološka šema konvertorske čeličane sa sistemom za odvajanje cinka i ostalih obojenih metala iz rastopljenog čeličnog otpada. Čestice pojedinih metala moguće je akumulirati u ciklonskom izdvajaču i elektrofiltru. U čeličani se na ovaj način može reciklirati i do jedne trećine cinka, koji se nalazio u otpadnom gvožđu i iskoristiti ga kao sekundarnu sirovinu za pocinkovanje čeličnih limova i drugih proizvoda od čelika.



Slika 1. Tehnološka šema postrojenja za izdvajanje obojenih metala iz rastopljenog čelika [2]

Posle čelika, aluminijum je najkorišćeniji metal i trenutno jedna trećina proizvodnje ovog materijala se dobije reciklažom. Dobre osobine aluminijuma, kao i njegovih legura čine da potražnja za njim stalno raste. Aluminijum se danas sve više upotrebljava u automobilske i avio industriji, građevinarstvu, elektrotehnici, pri proizvodnji limenki, folija, višeslojne ambalaže i dr.

Zbog velike potrošnje energije pri proizvodnji aluminijuma iz rude boksita, recikliranje otpadnog aluminijuma se višestruko isplati. Reciklažom aluminijum ne gubi na svom kvalitetu, pa se može bezbroj puta reciklirati. Reciklažom jedne tone aluminijuma uštedi se 8 tona boksita, 4 tone hemijskih preparata i oko 14 hiljada kWh električne energije. Proizvodnjom novog od otpadnog aluminijuma može se uštedeti do 95% energije.

Znatna količina otpadnog bakra se dobija iz sekundarnih sirovina. Izvori sekundarnog bakra su šljaka, kablovi, žica, hladnjaci, mesing, bronza i dr. Postupci proizvodnje sekundarnog bakra zavise od kvaliteta otpadnog materijala. Otpad koji sadrži više od 40% bakra se topi i rafiniše u plamenim i rotacionim pećima. Ukoliko je sadržaj bakra u otpadu oko 5% vrši se topljenje u šahtnim pećima zajedno sa povratnom konvertorskom šljakom, topiteljem i koksom. Proizvod ovog procesa je crni bakar.

5. ZAKLJUČAK

Novi pristup pri izboru materijala, razvoju i konstrukciji proizvoda, osim tehničkih i ekonomskih kriterijuma uključuje i kriterijum recikličnosti. Ponekad su zahtjevi recikličnosti u suprotnosti sa ekonomičnošću i konkurentnošću proizvoda na tržištu, ali su opravdani sa aspekta očuvanja primarnih sirovina, smanjenja potrošnje energije i zaštite svih ambijenata životne sredine.

Tehnološki postupci reciklaže značajno se razlikuju za pojedine grupe tehničkih materijala. Za čelik, čelične livove, lake i obojene metale to su poznati i usvojeni postupci reciklaže. Primjena sve većih količina različitih vrsta polimernih materijala i njihovih kompozita zahtijeva savremene tehnološke postupke za njihovu reciklažu.

U narednom periodu kriterijumu recikličnosti dobijaće sve više na značaju pri projektovanju, konstruisanju i izradi proizvoda u metalnoj industriji.

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ADEKVATNO UPRAVLJANJE OTPADNIM VODAMA ZNAČAJAN SEGMENT UŠTEDE ENERGIJE U RAFINERIJAMA

Stojan Simić¹, Snježana Vujić², Omer Kovač³

Rezime: Rafinerijske otpadne vode međusobno se razlikuju po količini i sastavu, pa je potrebno obratiti posebnu pažnju pri upravljanju njihovim tokovima i izboru postupka obrade. Neophodno je na nivou rafinerije obezbijediti adekvatno upravljanje vodama od početka eksploatacije i korišćenja u tehnološkom procesu, pa do postupka obrade otpadnih voda i ponovnog korišćenja za potrebe procesa proizvodnje, odnosno ispuštanja u recipijent.

U radu su prezentovani postupci, sistem upravljanja tokovima, kao i rezultati koji su postignuti pri obradi otpadnih voda u rafinerijama u industrijski razvijenim zemljama. Primjenom najbolje raspoloživih tehnologija (BAT-Best Available Technique) pri upravljanju rafinerijskim otpadnim vodama u značajnoj mjeri se može ostvariti ušteda energije, odnosno smanjiti troškovi proizvodnog procesa sa jedne strane, a sa druge smanjiti negativan uticaj rafinerijskih postrojenja i procesa na sve ambijente čovjekove životne i radne sredine.

Ključne riječi: rafinerije, otpadne vode, upravljanje, ušteda energije.

ADEQUATE WASTEWATER MANAGEMENT SIGNIFICANT SEGMENT OF CONSERVING OF ENERGY IN REFINERIES

Summary: *Refinery wastewater differ from each other in the composition and amount, so it is necessary to pay special attention to the management of their streams and the choice of treatments. It is necessary to provide an adequate level of water management in refinereis, from the beginning of the exploitation and usage in the production process, to the process of wastewater treatment and re-use for the production process, or discharge into the recipient.*

This paper presents methods, stream control system and the results that have been achieved in the treatment of wastewater in refineries in industrialized countries. By the application of the Best Available Technique (BAT) in the management of refinery wastewater in a significant measure can be achieved energy savings and reduce costs of the production process, as well as to reduce the negative impact of refinery plants and processes on the all ambiance of human life and working environment.

Keywords: *refineries, waste water management, energy saving.*

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1. UVOD

U praksi nije moguće postići potpunu kontrolu zagađujućih komponenata ili njihovu potpunu eliminaciju zbog ekonomsko-komercijalnih razloga, pa je zato najvažnije držati njihovu koncentraciju u granicama tolerancije, odnosno u granicama koje su dozvoljene važećom zakonskom regulativom. Potrebno je kontinuirano vršiti monitoring zagađujućih komponenata, kako bi se preduzele neophodne mjere za njihovo smanjenje i upravljanje na način bezbijedan po čovjekovu životnu i radnu sredinu.

Pri preradi nafte i naftnih derivata koriste se različiti tehnološki postupci i operacije. Kao rezultat tehnološkog procesa dobijaju se gotovi proizvodi i poluproizvodi, ali i štetne komponente koje zagađuju sve ambijente životne sredine. U zavisnosti od tipa opreme i vrste tehnološkog procesa rafinerije proizvode veće ili manje količine zagađujućih komponenata koje se ispoljavaju u vidu aerozagađenja, stvaranja otpada i zagađenja površinskih i podzemnih voda.

U radu su prezentovana svojstva i količine rafinerijskih otpadnih voda, kao i značaj adekvatnog upravljanja vodom tokom cjelokupnog tehnološkog procesa u rafineriji.

2. SVOJSTVA I KOLIČINE RAFINERIJSKIH OTPADNIH VODA

Rafinerijske otpadne vode se stvaraju u toku proizvodnog procesa i sadrže veliki broj različitih hemijskih jedinjenja, koja vode porijeklo iz sirove nafte. Tipični polutanti u rafinerijskim otpadnim vodama su: ugljovodonici, teški metali, fenoli, merkaptani, sulfidi, cijanidi i amonijak. Pri tretmanu rafinerijskih otpadnih voda obično se kombinuje više procesa, radi što efikasnijeg uklanjanja ulja i ostalih polutanata prije ispuštanja u recipijent. Radi pojednostavljenja tretmana otpadnih voda u rafinerijama dolazi do razdvajanja tokova prema porijeklu na procesne, sanitarne, rashladne, zauljene i druge otpadne vode. U rafinerijama je uobičajeno da se tretman otpadnih voda sastoji iz sljedećih faza: izdvajanje ulja iz vode, flotacija i biološki procesi obrade u bazenima sa aktivnim muljem ili u aerisanim jezerima i lagunama. Za završni tretman se koristi filtracija, proces sa aktivnim ugljem ili hemijski tretman.

Za obradu otpadnih voda i pripremu vode za potrebe tehnoloških postrojenja troši se značajna količina energije. Smanjenjem količine vode koja se troši značajno se smanjuje i potrošnja energije.

U tabeli 1. prikazane su moguće uštede energije i vode u pojedinim industrijskim granama.

Tabela 1. *Mogućnosti uštede energije i vode u pojedinim industrijskim granama*

Industrijska grana	Ušteda energije	Ušteda vode	Jedinica
Rafinerije nafte	10-25	20-40	%
Hemijska industrija	10-45	30-60	
Industrija papira	20-30	20-30	
Industrija hrane i pića	25-40	25-35	

Prema mjestu i dinamici nastajanja rafinerijske otpadne vode najčešće se dijele na:

- procesno-tehnološke otpadne vode,

- rashladne vode,
- otpadne vode od pranja aparata i uređaja, cjevovoda i pogona,
- otpadne vode nastale djelovanjem atmosferskih padavina na zaujljene platoe i površine fabričkog kruga,
- fekalne otpadne vode.

Najveći dio upotrebene vode se koristi za hlađenje određenih uređaja u pogonima kao i održavanje njihove radne i tehnološke sposobnosti, dok se nešto manji dio troši za pranje i ispiranje. Rashladne vode nose sa sobom ulje i druge u vodi teško rastvorljive organske komponente. Procesno-tehnološke i hemijski zagađene vode po količini su relativno male u odnosu na rashladne vode, ali su nosioci najveće količine zagađenja jer potiču iz proizvodnog procesa. U zaujlenim vodama, povećana koncentracija organskih supstancija i raznovrsnost sadržaja, utiče na povećanje pH vrijednosti i na povećanje potrošnje kiseonika.

U tabeli 2. je dato koliko pojedini procesi u rafinerijama stvaraju otpadne vode, kao i koje su najčešće zagađujuće komponente u tim vodama.

Tabela 2. Količine i sastav procesnih otpadnih voda u rafinerijama [1]

Proces	Količina otpadne vode po barelu prerađene nafte, L	Zagađujuće komponente
Desalinizacija	7,5-9,5	solii, mulj, glina, čestice korozije, emulgujuća ulja
Destilacija	75-95	sumpor-vodonik, amonijak, suspendovane i rastvorene čvrste čestice, fenoli, sumporna jedinjenja organskog porijekla
Katalitičko krekovanje	55-60	ulje, suspendovane čvrste čestice, amonijak, sulfidi, fenoli, cijanidi
Katalitičko reformisanje	mala količina	naznatan sadržaj sumpor-vodonika i fenola
Izomerizacija	mala količina	hloridi, naznatna količina sumpor-vodonika i amonijaka
Koksovanje	oko 4	voda bazična, visok sadržaj suspendovanih čvrstih čestica, amonijaka i sumpor-vodonika, veliko HPK opterećenje
Visbrejking	7,5	voda bazična, visok sadržaj amonijaka, sumpor-vodonika, fenola, suspendovanih čvrstih čestica, visoka vrijednost BPK ₅ i HPK
Alkilacija	mala količina	voda kisela, znatan udio rastvorenih i suspendovanih čvrstih čestica, visoka vrijednost HPK, mala količina sumpor-vodonika, amonijaka i fenola
Polimerizacija	mala količina	voda bazična, sadrži amonijak i sumpor-vodonik
Proces izdvajanja sumpora, kondicioniranje pare, ostali procesi i međuprocasi	znatna količina	nema značajnijeg uticaja na ukupnu količinu i sastav procesne otpadne vode

Prema podacima US EPA potrošnja vode u rafinerijama se kreće od 1 do 2,5 m³/m³ proizvoda. Prema dostupnim podacima u rafinerijama u SAD dnevna proizvodnja iznosi 3 miliona m³, a potrošnja vode oko 7,5 miliona m³.

Rafinerija se sastoji od niza pojedinačnih procesnih jedinica. Način na koji su te pojedinačne jedinice ugrađene u integrisanu cjelinu može imati značajan uticaj na količinu i sastav otpadnih voda. Rafinerije u regionu su djelimično modernizovane ili su u fazi modernizacije, pa je potrošnja vode smanjena u odnosu na prethodni period i trenutno se kreće od 2,4 do 5,6 m³/m³ proizvoda.

U tabeli 3. dat je pregled količina zagađujućih komponenata iz procesnih jedinica u rafineriji.

Tabela 3. Količina zagađujućih komponenata iz procesnih jedinica u rafineriji

Proces	Ulja i masti	Sumpor-vodonik, merkaptani	Amonijak	Fenoli	BPK ₅ , HPK, TOC	Suspendovane čvrste čestice
Destilacija	50-500	50-500	50-500	manje od 50	50-500	50-500
Hidroobrada		oko 500	oko 500	-	preko 50	-
Visbrejking		50-500	50-500	50-500	50-500	manje od 50
Katalitičko krekovanje		preko 500	preko 500			
Hidro krekovanje		manje od 50	manje od 50	-	manje od 50	-
Bazna ulja				manje od 50	manje od 50	
Balastne vode	manje od 50	-	-	manje od 50	manje od 50	manje od 50
Sanitarna voda	-	-	manje od 50	-	50	50-500

3. UPRAVLJANJE RAFINERIJSKIM OTPADNIM VODAMA

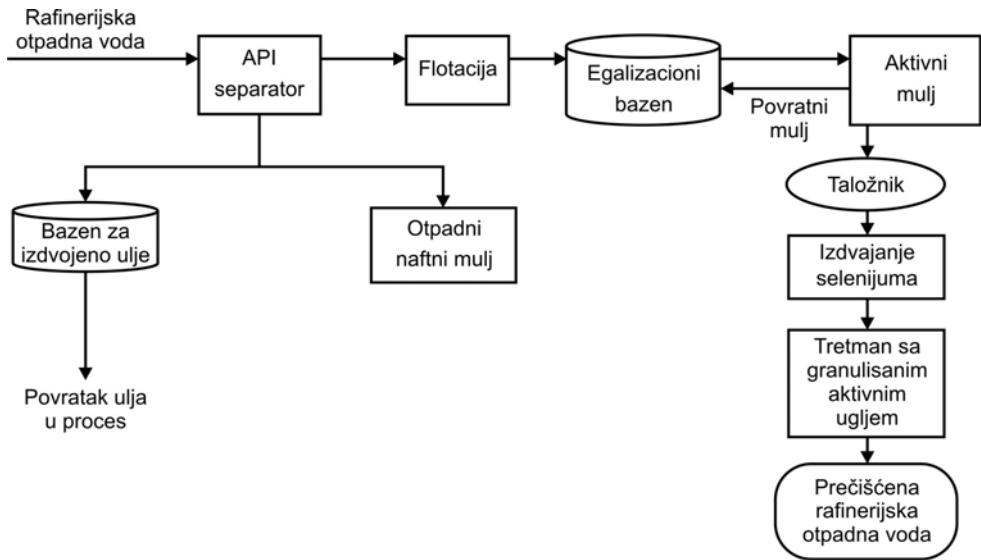
Otpadne vode koje nastaju u rafinerijama sadrže zagađujuće komponente organskog i neorganskog porijekla. U zavisnosti od porijekla otpadne vode neophodno je da tokovi budu međusobno razdvojeni do postrojenja za obradu. Na ovaj način se pojednostavljuje proces i smanjuju troškovi obrade otpadne vode. Na primjer, u rafineriji "ESSO AG" u Ingolštatu (Ingolstadt) izvršeno je razdvajanje tokova sa niskim i visokim udjelom soli, u kombinaciji sa povratnim vodom sa niskim udjelom soli, što zahtijeva dva odvojena sistema za prethodni tretman, kao i dva odvojena biološka tretmana otpadne vode.

Izbor procesa i tehnologije prečišćavanja rafinerijske otpadne vode zavisi od stepena prečišćavanja koji je potrebno postići. Proces prečišćavanja rafinerijskih otpadnih voda mogu se svrstati u nekoliko osnovnih grupa:

- mehaničko prečišćavanje,
- fizičko-hemijsko prečišćavanje,
- biološko prečišćavanje.

Najčešće se vrši kombinovanje procesa iz navedenih grupa u zavisnosti od sastava otpadne vode i željenog kvaliteta prečišćene vode. Kod prečišćavanja rafinerijskih otpadnih voda, koriste se sljedeći osnovni procesi: mehaničko izdvajanje nerastvorenih materijala, taloženje nerastvorenih materijala, koagulacija i flokulacija koloidnih supstancija, biofiltracija sa imobilisanom mikroflorom, biološka aerobna obrada sa aktivnim muljem, biološka anaerobna obrada, taloženje sa hemijskim sredstvima i dezinfekcija prečišćene vode. Za navedene osnovne procesa koriste se pojedine pomoćne operacije: miješanje i aeracija, flotacija (separacija masti i ulja), filtracija i dr.

Na slici 1. prikazana je uprošćena šema sistema za obradu otpadnih voda u jednoj od pet rafinerija "Bay Area" koje se nalaze nedaleko od San Franciska u SAD.

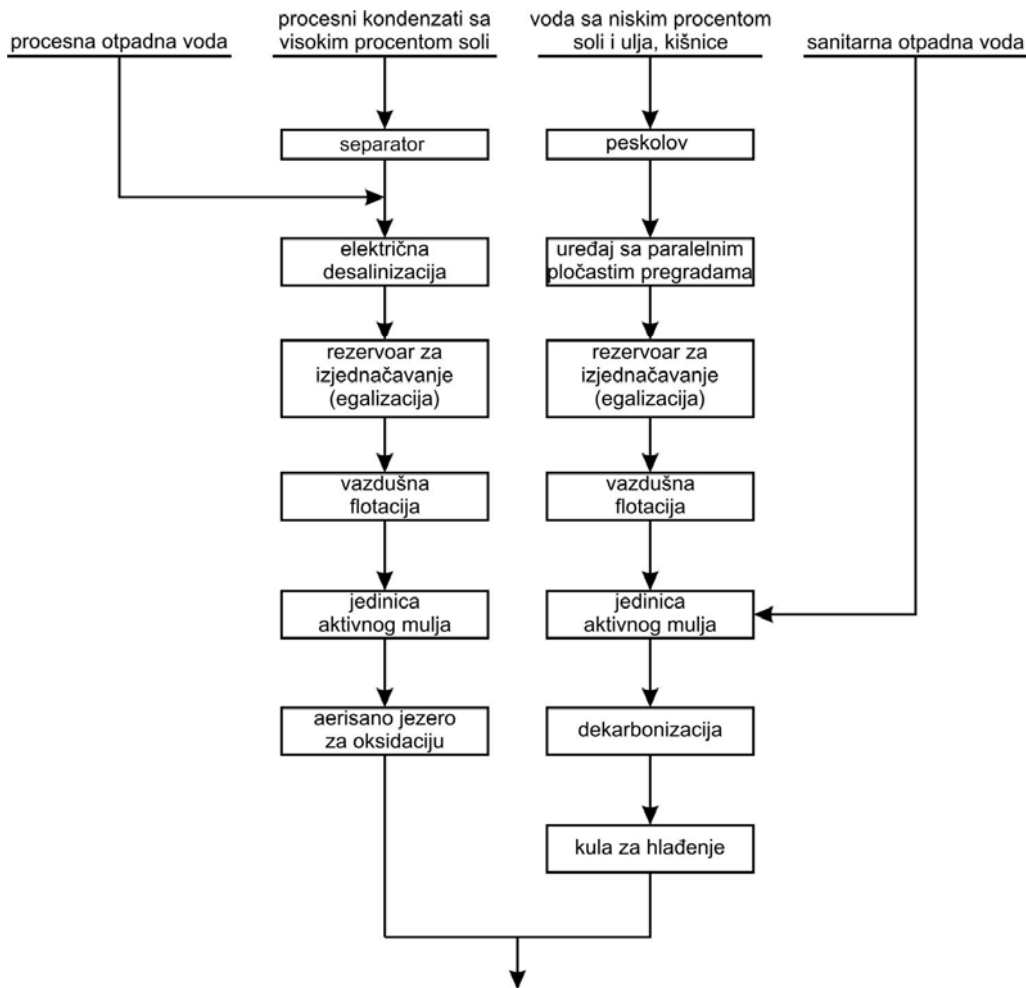


Slika 1. Uprošćena šema jednog od sistema za obradu rafinerijskih otpadnih voda "Bay Area" [2]

Svaku od rafinerija "Bay Area" karakteriše drugačiji redoslijed i kombinacija faza obrade otpadnih voda. Primarni tretman obuhvata procese separacije i vazdušne flotacije. Procesom separacije se uklanjaju suspendovane čvrste čestice, flokule nafte i naftnih derivata koje plivaju po površini vode koja se dovodi u postrojenje na obradu. Flotacijom se iz otpadne vode uklanjaju komponente organskog porijekla. U tri rafinerije bazen u kome se vrši flotacija je potpuno zatvoren i emisija lako isparljivih komponenata iz ove faze obrade se prati u sistemu za kondicioniranje pare. U jednoj od preostale dvije rafinerije bazen za flotaciju, takođe, je zatvoren ali posjeduje četiri oduška kroz koje se u atmosferu emituju lako isparljive komponente, dok druga rafinerija ne poseduje jedinicu za flotaciju. Nakon flotacije u ovoj rafineriji otpadna voda se kroz kanale sa strugačima transportuje u jedinicu za biološku obradu, dok se u preostalim rafinerijama otpadna voda iz separatora ili bazena za flotaciju takođe dovodi u jedinicu za biološku obradu. Sekundarni tretman u dvije rafinerije obuhvata biološku obradu otpadne vode u aerisanim jezerima i lagunama, a u druge dvije biološku

obradu u bazenima sa aktivnim muljem. Preostala rafinerija u okviru jedinice biološke obrade posjeduje i bazen sa aktivnim muljem i aerisano jezero [2].

Na slici 2. prikazana je uprošćena šema toka obrade otpadnih voda u rafineriji "ESSO AG" u Ingolštatu.



Slika 2. Uprošćena šema toka obrade otpadnih voda u rafineriji "ESSO AG" [3]

Prosječan sastav i osobine influenta i efluenta kao i parametri efikasnosti postrojenja za biološku obradu otpadne vode rafinerije "ESSO AG" prikazani su u tabeli 4.

Tabela 4. Efekat prečišćavanja i kvalitet efluenta u rafineriji "ESSO AG" [3]

Parametar	Influent u postrojenju sa aktivnim muljem, mg/L	Ukupni efluent, mg/L	Degradacija ili eliminacija, %
čvrste komponente koje se mogu filtrirati	50-100	16	79
pH	7,2-7,8	7,4	-
BPK ₅	150-200	4	98
HPK	203	70	66
ugljovodonici	5-10	1,1	85
fenoli	5-10	0,09	99
sulfidi	1-2	-	-
merkaptani	1-2	-	-
cijanidi	0,5-1	-	-
hloridi	1000-1600	1000-1600	0

U posljednjih dvadesetak godina prema kvalitetu obrađene otpadne vode BP Rafinerija Kwinana (Kwinana) u zapadnoj Australiji je jedna od vodećih rafinerija u svijetu. Rafinerija BP Kwinana posjeduje savremeni sistem za obradu otpadne vode kojim se postiže izuzetno visok kvalitet obrađene otpadne vode. Za regulisanje procesnih parametara pri obradi otpadne vode u ovoj rafineriji koriste se savremeni uređaji. Parametri koji se regulišu ovim uređajima su: protok vode, temperatura i pH vrijednost vode, sadržaj rastvorenog kiseonika u bazenu sa aktivnim muljem, protok vazduha koji se dovodi u bazen sa aktivnim muljem i količina hemikalija koja se dodaje pri hemijskoj obradi vode. Razvijen je računarski program pomoću kojeg se upravlja velikim brojem podataka, koji se odnose na otpadne vode u rafineriji prije i poslije obrade. Ovi podaci su lako dostupni pa se na osnovu njih prave izvještaji i vrše dodatne kalkulacije u cilju optimizacije procesa obrade otpadne vode. Kvalitet obrađene otpadne vode iz BP Rafinerije Kwinana konstantno se poboljšava. Kada je 1978. godine ova rafinerija puštena u rad sadržaj ulja i masti u prečišćenoj otpadnoj vodi iznosio je 1000 kg/dan, fenola 500 kg/dan, sulfida 600 kg/dan i azota 350 kg/dan. Sa pooštavanjem zakona iz oblasti zaštite životne sredine i potrebom za optimizacijom potrošnje energenata vršena je modernizacija postrojenja za obradu otpadnih voda tako da je 2003. godine u prečišćenoj otpadnoj vodi sadržaj ulja i masti iznosio 1 kg/dan, fenola 0,01 kg/dan, sulfida 0 kg/dan i azota 21 kg/dan [4].

U zavisnosti od tipa tehnološkog procesa, konstrukcionog rješenja opreme i sistema za tretman otpadnih voda u cilju smanjenja zagađenosti i potrošnje vode u savremenim rafinerijama primjenjuju se neki od sljedećih postupaka:

- umjesto vodenog korišćenje vazdušnog hlađenja u tehnološkom procesu;
- za potrebe hlađenja korišćenje obrađene otpadne vode;
- uspostavljanje sistema za povrat kondenzata u energetski proces;
- primjena metode regenerativnog odsumporavanja sa monoetanolaminom, koje proizvode male količine otpadne vode;
- primjena visokotemperaturske regeneracije u procesu katalitičkog krekanja, čime se može značajno smanjiti koncentracija jedinjenja cijanida i organskih jedinjenja sumpora.

Potrebno je naglasiti da se pri obradi rafinerijskih otpadnih voda stvara odgovarajuća količina otpadnog mulja s kojim se mora upravljati na način koji je prihvatljiv sa tehnološkog, ekološkog i ekonomskog aspekta.

4. ZAKLJUČAK

U radu je prezentovano koliko pojedini procesi u rafinerijama stvaraju otpadne vode. Dat je pregled količina zagađujućih komponenata u otpadnoj vodi iz procesnih jedinica.

Prezentovani su postupci obrade, kao i kvalitet obrađene otpadne vode u rafinerijama u industrijski razvijenim zemljama. Navedene su neke od tehničko-tehnoloških mjera koje treba primjeniti u cilju adekvatnog upravljanja tokovima otpadnih voda čime bi se u značajnoj mjeri postigla ušteda energije i smanjili troškovi proizvodnog procesa u rafineriji.

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SMART GRIDS CONCEPT USED IN RURAL AREAS

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Sorin Abagiu⁴, Stan Ivan Felicia Elena⁵

Abstract: This article presents the concept and vision of Smart Grids in Europe, and describes the requirements that such networks as Smart Grids have to perform in order to meet the objectives set by the Lisbon Strategy, namely: Flexibility, Accessibility, Safety, and Economy. It is shown a comparison between existing electricity networks and Smart Grids.

Key words: Smart grid, renewable energy sources energy, Smart Meter.

1. INTRODUCTION

In the last years, the number of power quality problems has grown dramatically. Growth electricity demand and consequently extension of the number and power electric plants along with changing the structure of energy agents and increasing the number of receivers' power led to deterioration power quality parameters, with serious implications for the operating modes and consumer networks.

In this economic period, very difficult and unpredictable, energy consumers face a complex energy situation, which a specialist can understand and manage difficult. Electricity prices are in relatively upward trend in developed countries is likely to continue, due to global trends related to structural changes in the supply of electricity and the increasing need for investment in new technologies and energy sources [1].

Because this new challenges appearance in power system has been launched a new concept called Smart Grids (SG). This concept was launched in 2005 in the European Technology Platform for Electricity Networks of the Future, 7th Framework Programme of the European Commission. The purpose of this platform is to formulate and promote a vision of developing electricity networks in Europe in the near future. In addition, this view is based on research, development and demonstration programs with European and local finance. It wants the transit of energy to future networks to be achieved through an integrated and innovative from the technical, commercial and regulatory [2].

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2. SMART GRIDS – CONCEPT AND VISION

2.1. The concept of "Smart Grids - SG"

The concept of "Smart Grids - SG" is used today more as a marketing term than a technical definition, so there is not yet clear criteria specifying what is "smart" and what is not. [3]

There is no single definition of a type network, 'Smart Grids', nor is there a standard architecture or design for such a network. This complicates things for both utility companies and for designers, but also underscores a huge potential and opportunities in this space [2].

New technologies like, 'Smart Grids' improve control and analysis of power system and have the ability to transform the grid infrastructure from static to dynamic.

However, many institutions offer this concept following definitions:

Definition 1: 'Smart Grids' is a concept for the modernization of electricity networks, which integrates electrical and computer technologies at any point in the network generation to the consumer [3]. From this point of view, Smart Grids' appears as a new generation of energy systems, one in which information technologies make the system, and one general intelligence.

Definition 1': 'Smart Grids' represents the a modernization of the electricity distribution network, which will allow you to monitor, protect and automatically optimize operation of the interconnected elements of central and distributed generator, through high-voltage network and distribution network for industrial users and building automation systems, energy storage installations, finalreceptors and their thermostats, electric vehicles, appliances and other household appliances " [4].

The term "Smart Grid" refers to a modernization of the electricity delivery system so it monitors, protects and automatically optimizes the operation of its interconnected elements – from the central and distributed generator through the high-voltage transmission network and the distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances and other household devices.

Definition 2): Such networks, Smart Grids are electrical networks that can intelligently integrate the behavior and actions of all participants in the generation, transmission, distribution and use of electricity, ensure the sustainable and economic efficiency and security of energy supply power [2].

Definition 3): Such networks, Smart Grids are best defined through their functions that have to be met, especially that the based technologies to achieve these goals are still evolving.

Are proposed seven objectives for a network to become a Smart Grids [5]:

1. Enabling active participation of consumers;
2. To accommodate all generation and storage options;
3. To develop new products, services and markets;
4. To provide power quality for the range of needs of the 21st century economy;
5. Allow optimizing use of assets and efficient operation;
6. To locate incidents, to prevent, to automatically isolate and put back into service;
7. To withstand physical and cyber attacks and natural disasters.

2.2. Vision SG in Europe

In [6] are described the requirements that Smart Grids networks have to perform in order to meet the objectives set by the Lisbon Strategy, namely:

a) **Flexibility.** Electricity networks must provide configurations to maintain continuity in the supply of electricity to consumers in all operating conditions. One way to increase the flexibility of electrical networks is the interoperability by providing compatibility for implementation of electricity market, through effective management of internal network congestion and interconnection lines by improving transport distance and integration of renewable energy sources.

b) **Accessibility.** Electricity networks must allow free access to all users, both consumers and producers. In particular, electrical networks have to provide renewable energy to connect without any restrictions, even if they have specific operating problems (intermittent power products and so on).

c) **Safety.** Secure operation of both producers and consumers, is a requirement for modern electrical networks. In addition, the requirements of a digital society are met by ensuring power quality. Security of electricity supply refers to the operating conditions of the power system. The large number of incidents in recent years, more power systems which led to extensive damage proves that it is necessary to increase the power transfer capacity of the network by increasing reliability and nominal power lines and transformers, respectively, by reserving the sources of production, which include storage systems. In addition it is necessary grid renewal and innovation through efficient management of assets, by increasing automation to improve service quality through the use of remote control systems, etc..

d) **Economic.** Electrical grid infrastructure development should be encouraged through innovation, efficient energy management, competition and technical regulations as any undue expense is reflected on the price of electricity to final consumers.

To achieve these objectives, electrical networks must become more "active", allowing the integration of new technologies. In the future electricity system will be split between centralized and distributed production.

Distributed generators can be aggregated and controlled so as to form virtual power μ -grids or facilitate their integration into the physical system and electricity market.

An example of a SG is shown in Fig.1 where we can see how renewables play an important role in energy production.

Distributed generators are not the only power production sources that will supply the consumers but they will be integrated into the system. Thus, medium and low voltage networks will become "active", having the ability to provide ancillary services. At the distribution network level, which is traditionally oriented power supply and consumer service, new practices and dispatching their real-time network calculations and so on, that there were initially operating activities in the transport network.

At the transport network level it is necessary to develop a new strategy and operational practices that can allow decentralized operation but with centralized control.

The strategic objectives of this vision include [7]:

- Creating a set of tools and a portfolio of proven technical solutions that can be implemented quickly and efficiently in existing networks and which can enable power injections from all energy resources;
- Harmonization of regulations in Europe to facilitate cross-border marketing of energy and ancillary services;

- Establishment of common technical standards and protocols to ensure open access to equipment from any chosen manufacturer;
- Development of computer systems, computers and telecommunications systems, enabling customers innovative services to improve efficiency;
- Creating interfaces between automation and control systems to ensure interoperability of old equipment with modern.

Key elements of the vision include [7]:

- Creating a toolbox of proven technical solutions that can be deployed rapidly and cost-effectively, enabling existing grids to accept power injections from all energy resources;
- Harmonizing regulatory and commercial frameworks in Europe to facilitate cross-border trading of both power and grid services, ensuring that they will accommodate a wide range of operating situations;
- Establishing shared technical standards and protocols that will ensure open access, enabling the deployment of equipment from any chosen manufacturer;
- Developing information, computing and telecommunication systems that enable businesses to use innovative service arrangements to improve their efficiency and enhance their services to customers;
- Ensuring the successful interfacing of new and old designs of grid equipment to ensure interoperability of automation and control arrangements.

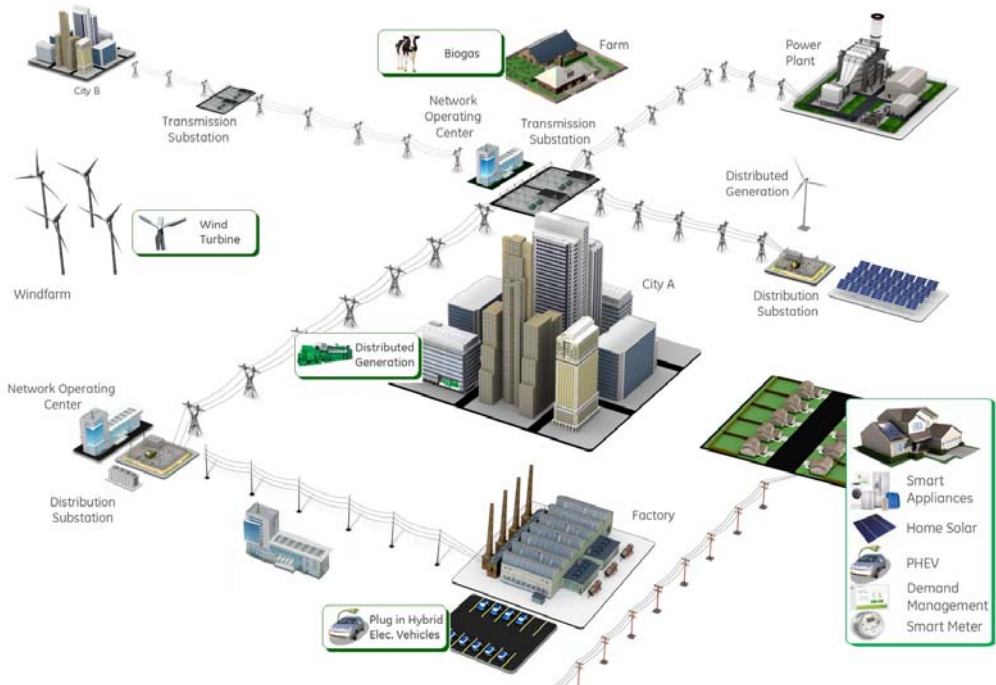


Fig. 1 *Integration of distributed energy sources into the traditional power system [8]*

3. POWER SYSTEMS AND SMART GRIDS

Basic principles of the current network were adopted now more than 150 years: centralized network unidirectional, transmission and distribution system, control system based on production consumption balance.

Networks have been built for a system where electricity comes from large units such as coal power plants or gas, nuclear or hydro.

In the past 20 years, electricity supply networks are increasingly harder face new requirements to: risks related to security, existing schemes at national or regional level in promoting renewable energy production, requests from increasingly numerous service level power supply with availability comparable to that of electronic systems (GSM, Internet, e-banking).

Whereupon under several low power energy sources distributed across the network, but mainly because developing wind power plants, power flow may periodically change direction and control may trouble the frequency and / or voltage.

These new circumstances lead to the necessity to transform the unidirectional model to a network of integrated and interactive (Fig.2).

It is necessary that the network to win "intelligence" and provide two-way communication between producers, distributors and consumers.

In Table 1 are specified key features that electricity networks it should fulfill to satisfy the needs of increasingly demanding customers. In the left column are specified electrical characteristics of existing networks and in the right column, in contrast to the first column, are presented the main characteristics of a Smart Grids network type.

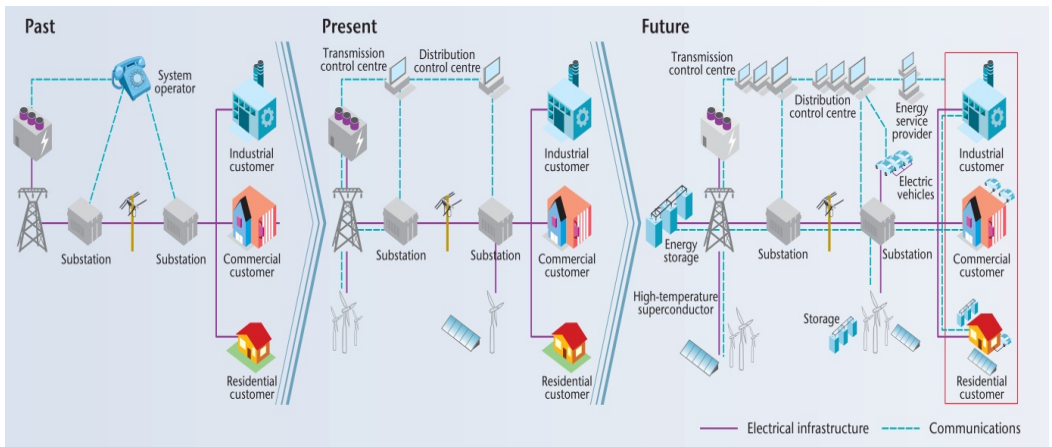


Fig. 2 The electrical networks evolution [9]

Table 1. Comparison between actual electricity networks and Smart Grids [10]

Present electricity networks	The main characteristics	Networks such as SmartGrids
Shall remain answerable to prevent damage. The focus is to protect the assets following system faults.	Self-healing	Automatically detects and responds to current and future problems of transmission and distribution electricity. The focus is on prevention. Minimizes the impact of consumers.

Present electricity networks	The main characteristics	Networks such as SmartGrids
Consumers are not informed and do not participate actively in the power system.	Motivates and includes the consumer	Motivates, involve and activates consumers. Penetration range of demand response.
Vulnerable to malicious acts of terrorism and natural disasters	Resistance to attacks	Resistant to physical and cyber attacks. Less vulnerable to natural disasters. Rapid recovery capabilities.
Focus more on interruptions than quality of electric power. Slow response to power quality problems.	Ensures quality of electricity for 21st century needs.	Quality of electricity meets the industrial standards and consumer needs. Different levels of power quality at different prices.
Relatively small number of large power plants generates most electricity. There are numerous obstacles for interconnecting distributed generators (DER).	Accommodates all generating and storage options. Accommodates all generation and storage options.	A large number of different distributed generation and electric power storage devices used to compensate the generation of large power plants. Technology takes advantage "Plug-and-play". It puts more emphasis on access to renewable sources.
The wholesale markets for electricity working towards to find the best operating model. Do not work well with other markets. Energy transport congestion separates customers sellers	Activates markets	The wholesale markets mature operate together, well integrated at national level and integrated with reliability coordinators. Retail markets flourish where relevant. Minimum congestion for transporting energy .

3.1 Technical requirements for the implementation of Smart Grids

To highlight why it is necessary that the current grid to become a network such as Smart Grids, it is necessary to list the tasks that this network had to fulfill [10]. Thus a network such as Smart Grids must:

- a) To be able to isolate faults and to detect ways to restore power;
- b) To provide the consumer elements enabling active participation in the network;
- c) To ensure high operational safety service, avoiding losses due to interruptions in power supply;
- d) To allow the connection of the distributed generation and storage current systems;
- e) To allow energy markets to expand business;
- f) To ensure efficient operation;

- g) To allow resolving the problems caused by the lack of predictability of distributed renewable.

3.2 Integration of distributed energy resources

Distributed generation (DG - Distributed Generation) and renewable energy sources (RES - Renewable Energy Sources) enjoys special attention in Europe. Both are considered to play an important role in achieving the following two objectives:

- Increased security by reducing the imported fossil fuels energy sources dependence: oil, natural gas and coal;
- Reducing emissions of greenhouse gases, especially carbon dioxide derived from fossil fuel combustion.

The term "renewable energy source" refers to natural sources "eternal" such as sun and wind. Renewable energy systems convert these natural energy sources into useful energy (electricity and heat). RES are often related to electricity, but heat production (solar collector / geothermal) etc. is also possible. In this paper we consider only RES that are used to produce electricity (RES-E).

In accordance with the European Directive on RES-E [7], renewable energy sources include:

- hydropower (large and small);
- biomass (solid biofuels, waste gas, wastewater treatment gas and biogas);
- wind;
- solar energy (photoelectric and photothermal);
- geothermal energy;
- wave and tidal;
- Biodegradable waste.

3.3 Smart Metering Implementation [11]

Advanced metering infrastructure (AMI) and automated meter reading (AMR) must provide the means to measure analyze and communicate energy consumption to a central database for billing, troubleshooting and analysis.

Functions that are intended to be implemented in **Smart Metering**:

- To allow real-time acquisition of voltage, current, frequency, total energy consumption, total cost of energy consumed and payments;
- Storing values measured and recorded at different time periods;
- Bidirectional data communication counter;
- Meters must contain an interface through which to communicate the data contained therein to the doorstep additional devices in real time („*In-Home Displays*”);
- If the source of energy production is located in residential buildings, counter model chosen should take into account the implications which he can have on the system and the energy market;
- Ability to switch between energy suppliers;
- Ability to create a history of energy consumption that is accessible to both supplier and consumer;
- Meters must have multiple functions (electricity, water, gas);

- Ensure consumer protection overvoltage, overcurrent, frequency variations inadmissible by automatic restoration of these parameters;
- To eliminate the possibility of illegal electricity consumption;
- Customer information on energy consumption and by GSM (mobile phone) and *Portal Web*;

4. CONCLUSION

There are several definitions that express the concept of Smart Grids. For this reason is very important to analyze the current state of the power system. It should examine whether the current power system is able to support new requirements of Smart Grids.

A network can become a Smart Grids, this need to perform the functions as described above were. For current power grid to reach satisfying these conditions is necessary to evolve gradually through major segments of the network modernization.

Current energy supply system satisfies of consumers of more than a century. The sudden implementation of new technologies (untested sufficient) would lead to system instability already well known. It can be seen how system integration with power system is critical for a network such as Smart Grids.

Comparative analysis emphasizes the advantages of Smart Grids. The Smart Grids equipped with communication and real-time measurement techniques schemes, allow the improvement of strength, prognosis, and protection against internal and external threats.

ACKNOWLEDGMENT

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UPRAVLJANJE INOVATIVNIM PROJEKTOM OSVAJANJA PROIZVODNJE SOLARNOG FOTONAPONSKOG MODULA

Dejan Krstić¹

Rezime: Obnovljivi izvori energije (OIE) podrazumevaju izvore energije koji se nalaze u prirodi i obnavljaju se u celosti ili delimično, posebno energija vodotokova, vetra, neakumulisane sunčeve energije, biomasa, geotermalna energija i dr. Korišćenje ovih izvora doprinosi efikasnijem korišćenju sopstvenih potencijala u proizvodnji energije, smanjenju emisija „gasova staklene bašte“, smanjenju uvoza fosilnih goriva, razvoju lokalne industrije i otvaranju novih radnih mesta. Tehnički iskoristiv energetske potencijal navedenih OIE u Republici Srbiji, veoma je značajan i procenjen je na preko 4,3 miliona tona ekvivalentne nafte (toe) godišnje - od čega se oko 2,7 miliona toe godišnje nalazi u iskorišćenju biomase, 0,6 miliona toe godišnje u neiskorišćenom hidropotencijalu, 0,2 miliona toe godišnje u postojećim geotermalnim izvorima, 0,2 miliona toe godišnje u energiji vetra i 0,6 miliona toe godišnje u iskorišćenju sunčevog zračenja.[5] Ovaj rad upravo stavlja akcenat na potencijalu sunčevog zračenja, te je i sama ideja inovativnog preduzetništva u pravcu osvajanja proizvoda solarne fotonaponske ćelije, uz praćenje trendova novih tehnologija, koje doprinose sve većem stepenu iskorišćenja i transformacije solarne energije u električnu.

Ključne reči: obnovljiv izvor energije (OIE), sunčevo zračenje, fotonapon, solarni modul

MANAGEMENT OF THE INNOVATIVE PROJECTS FOR CONQUEST OF MANUFACTURING SOLAR PHOTOVOLTAIC MODULE

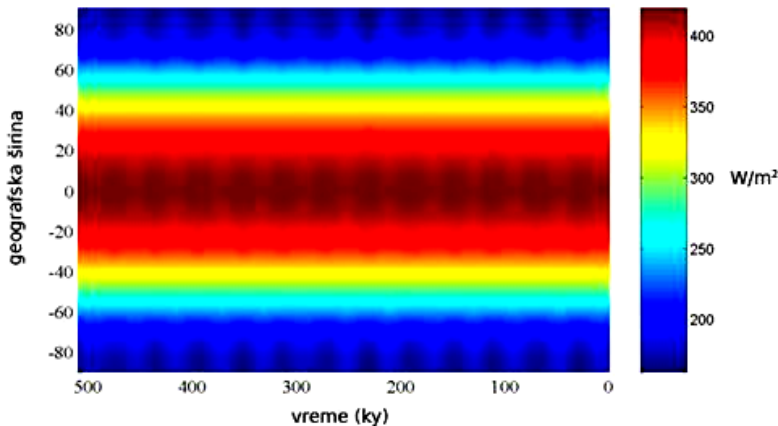
Abstrac: Renewable energy sources (RES) include energy sources which are found in nature and are renewed in whole or in part, particularly the energy of water flows, wind, non-acumulated solar energy, biomass, geothermal and others. Using these sources contributes to the efficient use of their own resources for energy production, reduction of "greenhouse gases", reducing imports of fossil fuels, development of local industry and job creation. Technically usable potential energy envy RES listed in the Republic of Serbia, it is significant and estimated at over 4.3 million tons of oil equivalent (toe) per year - of which about 2.7 million toe per year in biomass utilization, 0.6 million toe per year in unused hidropotential, 0.2 million toe per year in existing geothermal sources, 0.2 million toe per year in wind power and 0.6 million toe per year in the utilization of solar irradiation. This study also emphasizes the potential of solar irradiation, and the idea of innovative entrepreneurship in the conquest of solar photovoltaic cell, following the trends of new technologies that contribute to a higher degree of utilization and transformation of solar energy into electricity energy.

Keywords: renewable energy sources (RES), solar radiation, photovoltaics, module

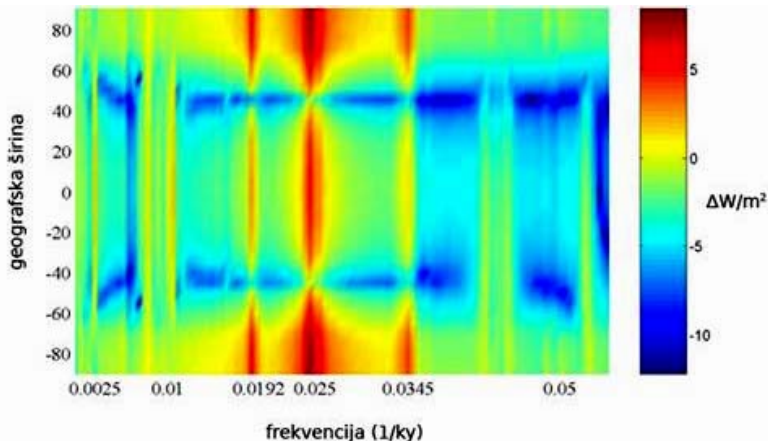
¹ Msc of tech.science Dejan Krstić, Kragujevac, Grupa Zastava Vozila, (e-mail: dejan.krstickg@sbb.rs)

1. UVOD

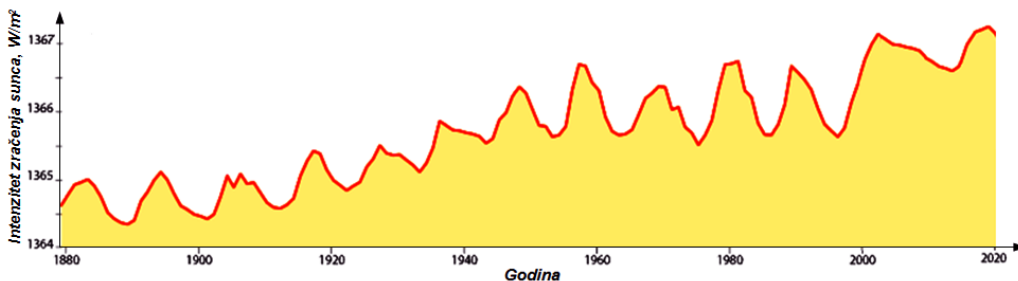
Sunce kao fuzioni reaktor svake sekunde pretvori oko 600 miliona tona hidrogena u helijum pri čemu oslobodi ogromnu količinu energije koju pošalje u Svemir u vidu elektromagnetnog, svetlosnog, toplotnog, rentgenskog i drugih vidova zračenja. Od ukupno $3,8 \times 10^{26}$ W energije koju Sunce zrači u kosmos, Zemlja primi $1,7 \times 10^{17}$ W. Oko 30% primljene energije Zemlja reflektuje nazad u kosmos, oko 47% zadrži kao u toplotu, oko 23% ide na proces kruženja vode u prirodi dok se ostatak „potroši“ na fotosintezu. Različiti su interesi za eksploataciju sunčeve energije. U hladnijim krajevima ona se koristi za grejanje prostora i dobijanje tople vode, dobijanje električne energije a u toplijim krajevima za rashlađivanje prostorija i dobijanje električne energije. Globalno srednje godišnje osunčavanje u vatima po kvadratnom metru (W/m^2) i razlike u osunčavanju ($\Delta W/m^2$), hronološki tokom pola miliona godina, sa periodogramom u zavisnosti od geografske širine je prikazano na slikama br. 1. i br. 2. Na slici br. 1. boje predstavljaju intenzitete osunčavanja (W/m^2), a na slici br. 2. razlike u osunčavanju ($\Delta W/m^2$). [4]



Sl. 1. Globalno srednje godišnje osunčavanje (W/m^2) u zavisnosti od geografske širine



Sl. 2. Razlike globalnog osunčavanja ($\Delta W/m^2$) u zavisnosti od geografske širine



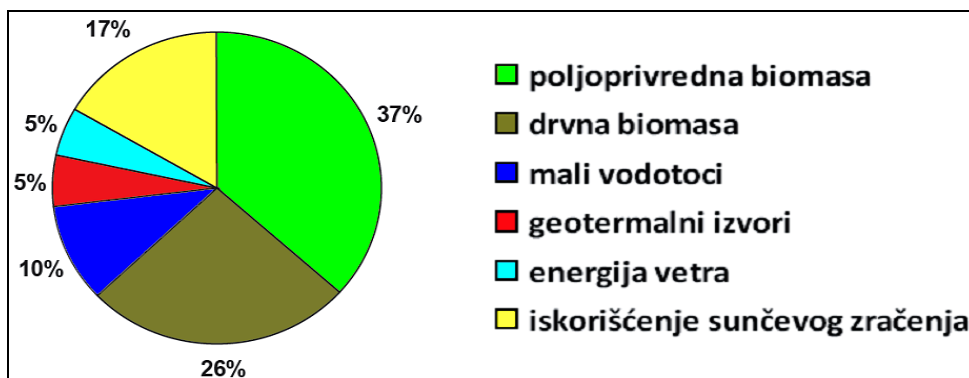
Sl. 3. Hronologija globalnog rasta zračenja sunca (W/m^2) [4]

2. DIREKTIVE 2001/77/EC I 2003/30/EC

Republika Srbija je prihvatila obavezu da donese i realizuje plan primene direktive 2001/77/EC o promovisanju proizvodnje električne energije iz obnovljivih izvora energije i direktive 2003/30/EC o promovisanju korišćenja biogoriva i drugih goriva iz obnovljivih izvora energije. Potencijal OEI u Srbiji je prikazan dijagramom na slici br. 4.

Direktiva 2001/77/EC definiše obnovljive izvore energije (OIE):

- Nacionalni cilj za proizvodnju električne energije dobijene iz OIE
- Program mera za njihovo dostizanje
- Garancije o poreklu - za električnu energiju proizvedenu iz OIE (Guarantee of Origin)
- Pojednostavljenje pravnog okvira za izgradnju i eksploataciju postrojenja
- Obaveza za operatera prenosa i distribucije da preuzimaju i transportuju električnu energiju iz OIE
- Definisane uslova i tarifa za priključenje na mrežu



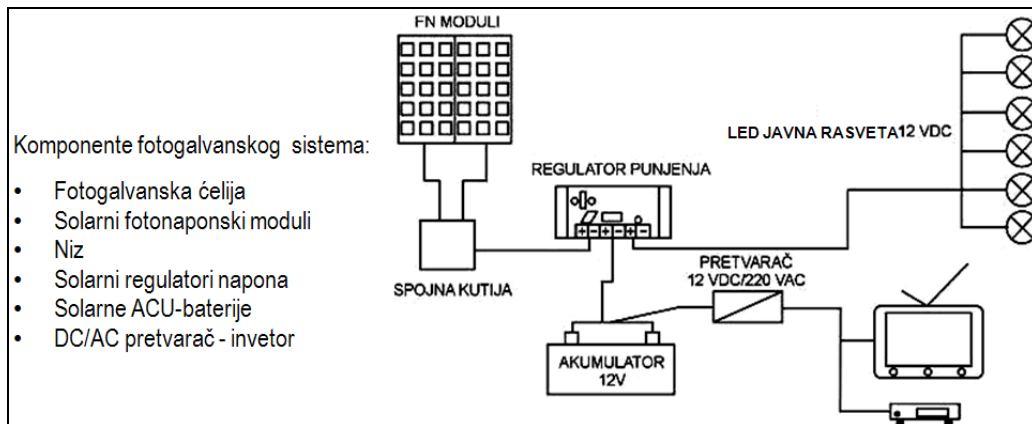
Sl. 4. Potencijal OEI u Srbiji - 3.83 Mt.en.god [5]

3. PREDVIĐEN SISTEM FUNKCIONISANJA FOTONAPONSKE ČELIJE

Fotonaponski sistemi rade na principu pretvaranja dnevne svetlosti u električnu energiju. Fotonaponske ćelije se sastoje od dva različito naelektrisana poluprovodnika između kojih, kada su izloženi svetlu, teče elektricitet. Zatvaranjem strujnog kola između solarnog kolektora i nekog potrošača, npr LCD svjetiljke, struja će proteći i potrošač će biti snabdeven el.energijom, odnosno led diode će zasvetliti. Ovu transformaciju ftonske energije svetlosti u električnu definiše *Efikasnost konverzije*, koja izražava procenat svetlosne energije Sunca pretvorene u elektricitet. Za izračunavanje efikasnosti konverzije fotogalvanskog modula koristi se sledeća formula:

$$\frac{\text{Nominalna maksimalna proizvodnja modula (W)} \times 100}{\text{Površina modula (m}^2\text{)} \times 1000 \text{ W/m}^2}$$

Proračun je dobijen korišćenjem spoljašnjih dimenzija modula sa izostavljenim izbočenjima. Komponente kao što su regulatori punjenja (*charge controllers*), akumulatori i invertori regulišu, akumuliraju i isporučuju električnu energiju krajnjem potrošaču. Zavisno od potrebne snage i obima sunčeve energije, koriste se jedan ili više modula. Regulatori punjenja (*charge controller*) povezuju module, bateriju i potrošače, a osnovna funkcija im je da štite bateriju od prevelikog punjenja ili jakog pražnjenja. Jednosmerna el. energija se pretvara u naizmeničnu (220V) *Inverter*-om, u slučaju potrebe napajanja potrošača koji su napravljeni za rad na naizmenični napon od 220V. Kompletna šema povezivanja fotogalvanskog sistema je prikazana na slici br. 5.



Sl. 5. Šema povezivanja fotonaponskog sistema

Solarni moduli zbog navedenih svojstva i električkih osobina proizvode jednosmernu struju.

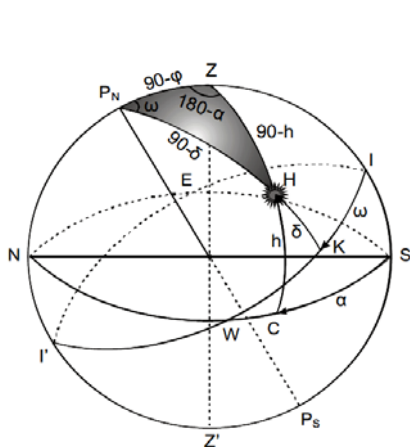
4. NAPADNI UGAO SUNČEVIH ZRAKA NA FOTONAPONSKU ČELIJU

Poznavanje napadnog ugla sunčevih zraka na fotonaponsku ćeliju je veoma važno, jer nam od njene vrednosti zavisi količina zračenja koja padne na površinu. Napadni ugao direktnog solarnog zračenja na površinu fotonaponske ćelije, treba da se orijentiše u odnosu na Zemlju, odnosno da se definiše odgovarajućim solarnim uglovima. Ovi uglovi su prikazani na slici br. 7. Orijentacija i nagib površine fotonaponske ćelije su definisani preko dva ugla i to:

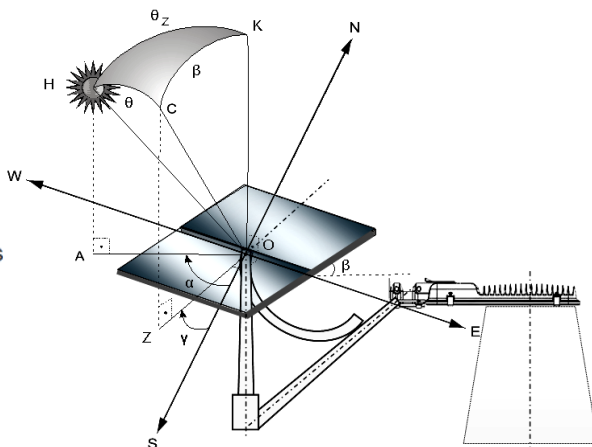
- ugao azimuta površine γ i
- ugao nagiba (inklinacija) β , respektivno.

Ugao azimuta površine γ je ugao između pravca juga i projekcije normale površine na horizontalnu ravan. Ovaj ugao je pozitivan ako je normala zapadno od juga i negativan ako je ista, istočno od juga. Ugao nagiba (inklinacija) β je ugao pod kojim je nagnuta površina fotonaponske ćelije u odnosu na horizontalnu ravan i uzima se kao pozitivan, ukoliko je ta površina nagnuta prema jugu. Pozicija Sunca u odnosu na površinu fotonaponske ćelije se može definisati korišćenjem napadnog ugla solarnih zraka θ . Napadni ugao je ugao između normale na površinu i pravca upada sunčevih zraka. Međusobni odnosi predhodno definisanih uglova se mogu naći pomoću jednostavnih jednačina sferne trigonometrije, primenjujući kosinusnu teoremu na sferni trougao "HKC" (slika br. 6.). Ugao upada snopa zračenja na površinu se može dovesti u vezu preko osnovnih jednačina za ugao nagiba površine fotonaponske ćelije solarnog Zenitnog ugla i ugla azimuta površine. Na slici br. 6., "KO" je normala na horizontalnu površinu, "CO" je normala na nagnutu površinu fotonaponske ćelije i "OZ" je horizontalna projekcija normale na nagnutu površinu fotonaponske ćelije i primenjujući kosinusnu teoremu na sferni trougao "HKC", imaćemo:

$$\cos \theta = \cos \beta \cos \theta_z + \sin \beta \sin \theta_z \cos(\alpha - \gamma) \quad (1)$$



Sl. 6. Trigonometrija nebeske sfere



Sl. 7. Napadni uglovi Sunca na FN ćeliju

Za slučaj nagnute površine fotonaponske ćelije, časovni ugao pri izlasku i zalasku Sunca ω_{st} , je manji od vrednosti ω_s , ukoliko je odgovarajući solarni napadni ugao veći od 90° . Za takvu situaciju časovni ugao ω_{st} se može naći trigonometrijskom transformacijom jednačine (1) za odgovarajući ugao nagiba fotonaponske ćelije. Tako dobijamo odnos napadnog solarnog ugla sunčevih zraka preko geografske širine, ugla nagiba solarne fotonaponske ćelije, ugla deklinacije Sunca i časovnog ugla, koji možemo predstaviti jednačinom:

$$\begin{aligned} \cos \theta &= \sin \delta (\sin \varphi \cos \beta - \cos \varphi \sin \beta \cos \gamma) + \\ &\cos \delta \cos \omega (\cos \varphi \cos \beta + \sin \varphi \sin \beta \cos \gamma) + \cos \delta \sin \beta \sin \gamma \sin \omega. \end{aligned} \quad (2)$$

Ukoliko je površina usmerena ka ekvatoru ($\gamma = 0$), dobijamo:

$$\cos \theta = \sin \delta (\sin \varphi \cos \beta - \cos \varphi \sin \beta) + \cos \delta \cos \omega (\cos \varphi \cos \beta + \sin \varphi \sin \beta), \quad (3)$$

$$\text{Ili } \cos \theta = \sin(\varphi - \beta) \sin \delta + \cos(\varphi - \beta) \cos \delta \cos \omega \quad (4)$$

Upoređujući gornju jednačinu (4) sa solarnim Zenitnim uglom, vidi se da površina usmerena ka jugu ima efektivnu geografsku širinu kao $(\varphi - \beta)$. Časovni ugao pri izlasku i zalasku Sunca ω_{st} za nagib površine fotonaponske ćelije dobija se stavljanjem $\theta = 90^\circ$ u jednačini (4) i rešavanjem po ω .

$$\omega_{st} = \pm \arccos(-\tan(\varphi - \beta) \tan \delta) \quad (5)$$

S obzirom da ω_{st} ne može da ima vrednost veću od ω_s , konačna jednačina za ω_{st} je:

$$\omega_{st}' = \min\{\omega_s, \arccos(-\tan(\varphi - \beta) \tan \delta)\} \quad (6)$$

Uglovi izlaska ω_{sr}' i zalaska ω_{ss}' Sunca u odnosu na nagnutu površinu fotonaponske ćelije koja nije usmerena ka jugu, neće biti simetrični u podne, a mogu se dobiti preko jednačine (3.17), stavljanjem da je napadni solarni ugao $\theta = 90^\circ$. Ovo rešenje daje dve vrednosti za ω u zavisnosti od orijentacije površine fotonaponske ćelije.

Za $\gamma < 0$

$$\omega_{sr}' = -\min\left\{\omega_s, \arccos\left[\frac{a \cdot b - \sqrt{(a^2 - b^2 + 1)}}{a^2 + 1}\right]\right\} \quad (7)$$

$$\omega_{ss}' = \min\left\{\omega_s, \arccos\left[\frac{a \cdot b + \sqrt{(a^2 - b^2 + 1)}}{a^2 + 1}\right]\right\} \quad (8)$$

Za $\gamma > 0$

$$\omega_{sr}' = -\min\left\{\omega_s, \arccos\left[\frac{a \cdot b + \sqrt{(a^2 - b^2 + 1)}}{a^2 + 1}\right]\right\} \quad (9)$$

$$\omega_{ss}' = \min\left\{\omega_s, \arccos\left[\frac{a \cdot b - \sqrt{(a^2 - b^2 + 1)}}{a^2 + 1}\right]\right\} \quad (10)$$

gde je:

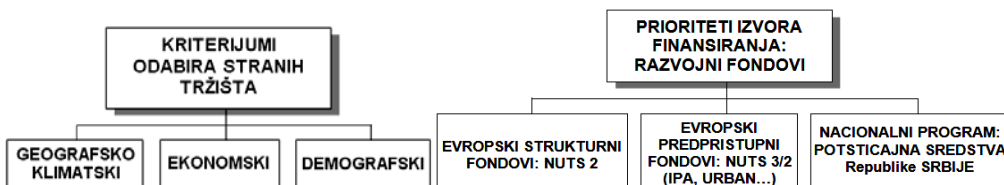
$$a = \frac{\cos \varphi}{\sin \gamma \tan \beta} + \frac{\sin \varphi}{\tan \gamma} \quad (11)$$

$$b = \tan \delta \left(\frac{\cos \varphi}{\tan \gamma} - \frac{\sin \varphi}{\sin \gamma \tan \beta} \right) \quad (12)$$

Svi prethodno proračunom definisani uglovi određuju efekat solarnog zračenja i neophodni su pri montaži fotonaponske ćelije, odnosno pri određivanju ugla nagiba fotonaponske ćelije. Napadni ugao direktnog solarnog zračenja određuje intenzitet dela zračenja koji direktno pogađa površinu fotonaponske ćelije i efikasnost apsorpcije njene površine. Poznavanje ovih komponenti definiše ukupno solarno zračenje na površini fotonaponske ćelije, kao i optimalan nagib fotonaponske ćelije pri njenoj montaži.

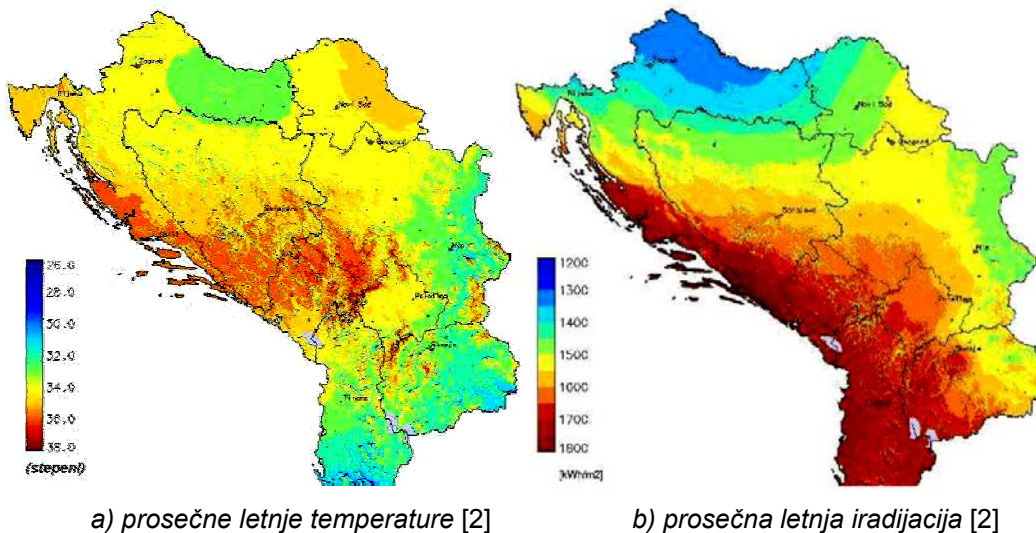
5. MARKENTIŠKA ANALIZA INOVATIVNOG PROJEKTA FN ČELIJA

Potencijal koji pruža sunčevo zračenje u zemljama EU se već koristi u velikoj meri kao solarna energija, i to uz visoku stopu rasta na tržištu. Konkretno, prosečan rast tržišta solarne energije u EU iznosio je u proseku 20% godišnje u periodu od 1999. do 2009. godine. Relevantni uticaji na ciljna tržišta su geografsko-klimatski, ekonomski, i demografski, tako da oni predstavljaju i osnovne kriterijume odabira tržišta, kao što je prikazano na slici 7. Na slici br. 8. su prikazani prioritetni izvori finansiranja projekta. Klimatski pogodnosti prosečnih letnjih temperatura i prosečne letnje iradijacije ciljnih tržišta okruženja su prikazani na slici br. 9.



Sl. 7. Kriterijumi odabira stranih tržišta

Sl. 8. Definisanje prioriteta izvora finansiranja



Sl.9. Klimatski kriterijumi odabira tržišta okruženja;

6. SWOT ANALIZA PROJEKTA PROIZVODNJE FOTONAPONSKIH ČELIJA

Analiza potencijalne tržišne pozicije solarnih fotonaponskih ćelija, odnosno položaja u odnosu na relevantne uticaje, pored pomenutih osnovnih geografsko-klimatskih, ekonomskih, i demografskih kriterijuma, je bazirana i na eksternim steholderima, na osnovu čega je izvedena sledeća SWOT analiza. [1]

<p>S - Snaga (Strength)</p> <ul style="list-style-type: none"> • Ppodsticaj EU za alternativnom energ. • Ekološki aspekt očuvanja okruženja • Značajna ušteda električne energije • Značajna ušteda pri održavanju • Dugoročno rasterećenje budžeta Republike Srbije i lokalnih samouprava • Povećana bezbednost u saobraćaju • Povećana antivandal bezbednost • Mogućnost automatskog upravljanja npr. kod javne rasvete i drugo 	<p>O - Pogodnosti (Opportunity)</p> <ul style="list-style-type: none"> • Strategija Vlade RS pristupanju u EU • Usaglašavanje sa Direktivama EU • Mogućnost finansiranja iz pristupnih fondova EU i ministarstava • Povoljni geo-meteorološki uslovi • Plan rekonstrukcije javne rasvete Srbije • Prilagodljivost primene na postojećoj javnoj rasveti sa mogućnošću automatske koordinacije osvetljenjem u zavisnosti od frekvencije saobraćaja i intenziteta sunčeve svetlosti
<p>W - Slabosti (Weaknesses)</p> <ul style="list-style-type: none"> • Zavisnost od budžeta Republike Srbije i lokalnih samouprava • Nedovoljno razvijena svest o globalnim potrebama za korišćenje alternativnih obnovljivih energenata • Veća cena jedeinice proizvoda fotonaponske ćelije od klasičnih el. izvora • Trenutna politička nestabilnost dela ciljnog tržišta severne Afrike i Bl. Istoka 	<p>T - Pretnja (Threat)</p> <ul style="list-style-type: none"> • Odsustvo podrške ministarstava • Odsustvo podrške lokalne samouprave • Nekorektna javna nabavka u javnom sektoru lokalnih samouprava • Globalna ekonomska kriza • Spor privredni razvoj R. Srbije • Restriktivna kreditna politika • Nelojalna konkurencija • Smanjen kreditni rejting na rang BB -

7. ZAKLJUČAK

Sa tehničko-tehnološkog, organizacionog i logističkog gledišta, projektne analize dokazuju da je moguće organizovati proizvodnju fotonaponskih ćelija u matičnom preduzeću »Feman«, Jagodina. Raspoloživa znanja o tehnologiji izrade i drugim dostignućima ovih specifičnih proizvoda, koji koriste obnovljiv energent sunčeve svetlosti, mogu da se daljom edukacijom, za relativno kratko vreme, dovedu na nivo znanja u razvijenijim zemljama. Razvoj tehnologija i komponentnih materijala fotonaponskih ćelija je dinamičan, i treba pratiti i usvajati sve nove materijale i tehnologije, kako bi proizvod održao konkurentnost. Dugoročno je najekonomičnije korišćenje fotonaponskih ćelija za javnu rasvetu, i istovremeno društveno najkorisnije. Time se pravi ušteda samim građanima, jer se iz budžeta lokalnih samouprava upravo finansira javna rasveta. Pored toga znatno su manji troškovi održavanja, jer je sama solarna fotonaponska ćelija izrađena od postojećih materijala, a instalacije i oprama su jednostavni. Jedna od prednosti je i nezavisni rad, pa je najuočljivija prednost kod dislociranih potrošača.

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ODREĐIVANJE SADRŽAJA TEŠKIH METALA U KORI ČEMPRESA (CUPRESSUS SEMPERVIRENS L.) U OKOLINI KOMBINATA ALUMINIJUMA PODGORICA (KAP) – CRNA GORA

Roganović D.¹, Đurović D.²

Rezime: Ispitivanja sadržaja teških metala (Pb, Cd, Cu, Zn, Ni i Mn) u kori čempresa obavljena su na 12 lokacija u okolini Kombinata aluminijuma u Podgorica (KAP). Uzorci su sakupljeni u aprilu i maju 2012 godine. Promjena (varijacija) u koncentracijama teških metala u kori čempresa na istraživanim lokalitetima je zavisila od industrijske aktivnosti i intenziteta saobraćaja. Rezultati ovih istraživanja pokazuju da kora čempresa može da posluži kao dobar bio-indikator aerozagađenja.

Ključne riječi: Teški metali, kora čempresa, Kombinat aluminijuma (KAP).

DETERMINATION OF HEAVY METALS IN THE BARK OF CYPRESS (CUPRESSUS SEMPERVIRENS L.) IN THE VICINITY ALUMINIUM PLANT PODGORICA (KAP) - MONTENEGRO

Abstract: Investigation of the heavy metals content (Pb, Cd, Cu, Zn, Ni and Mn) in cypress tree bark was carried out on 12 locations around Aluminium plant Podgorica (KAP). On this locations were collected 31 samples of cypress bark. The samples were collected in April and May 2012.. Variations in the heavy metals concentration in the cypress barks have depended on the industrial activities and traffic intensity. The results of this research show that cypress tree bark can be a reliable bioindicator of air pollution.

Key words: Heavy metals, Cypress bark, Aluminium plant (KAP).

1. UVOD

Na području Zetske ravnice nalazi se jedan od najvećih izvora zagađenja, Kombinat aluminijuma Podgorica (KAP). Nalazi se južno od Podgorice, između lijeve obale rijeke Morače i magistralnog puta Podgorica – Bar. Geografski položaj ovog prostora određen je sa 42°26' sjeverne geografske širine i 19°17' istočne geografske dužine, sa nadmorskom visinom od 33 m. Udaljenost postrojenja od gradskog područja iznosi oko 600 m. Površina koju zahvataju svi objekti KAP-a u Podgorici iznosi 825 000 m² i ima oblik pravougaonika. Orijentacija KAP-a je sjeverozapad-jugoistok.

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Glavni otpad KAP-a su crveni mulj u količini od 320 000–420 00 t/god (7,6 % od toga je suvi talog), istrošena katodna obloga sa oko 7000 t/god, PCB i drugi industrijski otpad kao što su mulj iz primarne proizvodnje, vatrostalna opeka i materijali, šljaka, ugljena pjena, istošena katodna obloga, anodni ostatak, dijatomejska i aktivna zemlja, otpaci boja i lakova i drugo [10]. KAP kao posebna tehnološka cjelina zagađuje podzemne vode, rijeku Moraču i dalje Skadarsko jezero

Ispitivanja prisustva teških metala u kori različitih vrsta drveća ukazuju na to da njihove koncentracije u kori ispitivanih vrsta zavise od intenziteta saobraćaja tj. antropogenih izvora zagađenja [13, 9, 15]. Kora preko 40 različitih vrsta drveća je korišćena kao bioindikator tokom različitih istraživanja aerozagađenja u Evropi. Najčešće korišćene vrste su *Acer platanoides*, *Aesculus hippocastanum*, *Fraxinus excelsior*, *Quercus robur*, *Tilia cordata*, *Picea abies*, and *Pinus sylvestris* [12]. Osim kore prethodno navedenih vrsta drveća, za biomonitoring prisustva teških metala se koristi i kora čempresa [15], kao i mahovine i lišajevi, zeljaste biljke itd., [5, 11].

Zagađenje životne sredine Zetske ravnice ne potiče samo od KAP-a već i od zagađivača iz samog grada Podgorice. Tu se prvenstveno misli na kanalizacione otpadne vode, aktivni mulj iz uređaja za prečišćavanje, deponije komunalnog otpada, brojne benzinske pumpe kao i intenzivan saobraćaj.

Imajući u vidu da su u Zetskoj ravnici prisutni brojni izvori zagađenja to je i bio povod da ovo bude područje ispitivanja. Na ovom prostoru su tokom prethodnog perioda vršena istraživanja koja su se bavila kvalitetom životne sredine [14, 10, 2, 8, 1] ali ova istraživanja nisu uključila određivanje sadržaja i prisustvo teških metala i ostalih polutanata u biljkama kao pokazatelja kvaliteta životne sredine.

U Zetskoj ravnici gdje je smješten Kombinat aluminijuma vlada izmijenjena mediteranska klima. Srednja godišnja temperatura vazduha je 15,3^o C. Prosječna godišnja relativna vlažnost vazduha iznosi 66%,

2. MATERIJAL I METOD

Uzorkovanje biljnog materijala: Uzorci kore (5 g težine) sa stabala čempresa su uzeti (oštrim nožem odvojeni djelovi kore od 5 mm) na visini od 1,8 m iznad zemlje a zatim stavljeni u papirne kese i propisno obilježavani. Prosječna starost stabala je oko 50 godina. Uzorci su sakupljeni u aprilu i maju 2012 godine.

Područje na kome su uzeti uzorci obuhvata površinu od oko 5 km² u okolini Kombinata aluminijuma, industrijsko i poljoprivredno naselje sa magistralnim i većim brojem lokalnih puteva (Karta 2). Sadržaj olova, kadmijuma, bakra, cinka, nikla i mangana ispitan je na 31 uzorku.

Priprema uzoraka za analizu: biološki materijal je najprije opran destilovanom vodom a zatim usitnjavan i sušen u provjetrovima, čistim prostorijama, koje nijesu u dodiru sa isparljivim i praškastim materijama koje mogu uticati na promjenu sastava uzoraka. U postupku pripreme suvim spaljivanjem-metodom AY-4, tačno određena količina uzorka kore (1 g), se dobro homogenizuje, a zatim se takav uzorak lagano i pažljivo suši i dimi na grejnoj ploči (rešou) dok se ne ugljeniše (Perkin Elmer-Analytical methods-AY-4). Po prestanku dimljenja, uzorak se stavlja u peć za žarenje kojoj se postepeno povećava temperatura do 450 °C i ostavi 24 sata na istoj temperaturi. Pri tome se, obavezno, vodi računa da se uzorak ne zapali. Po isteku navedenog vremena uzorak se pregleda. Ako je pepeo uzorka bijele boje ili svijetlo žut, dobijeni pepeo je spreman za rastvaranje. Ukoliko je pepeo siv ili ima crnih nesagorjelih čestica, uzorak se doraduje dodatkom 30 % H₂O₂, zagrijavanjem i sušenjem na ploči i dodatnim

spaljivanjem u peći za žarenje. Nakon spaljivanja pepeo se rastvara sa 20 % HCl i prenosi u normalni sud od 25 ml. Ukoliko se pepeo ne rastvara doda se nekoliko kapi koncentrovane HCl. Tako pripremljen uzorak je spreman za analizu.

Slijepe probe se pripremaju na isti način kao i uzorci, dodavanjem svih potrebnih hemikalija u istom odnosu kao kod postupka pripreme uzoraka, ali bez dodatka uzorka.

Određivanje sadržaja olova, kadmijuma, bakra, cinka, nikla i mangana **ICP** metodom - Laboratorijska ispitivanja uzoraka biljnog materijala na sadržaj teških metala (Pb, Cd, Cu, Zn, Ni i Mn) izvođena su primjenom instrumentalne tehnike ICP-OES – indukovana kuplovana plazma-optički emisijski spektrometar.

Standardni rastvori olova, kadmijuma, bakra, cinka, nikla i mangana koncentracije 1000 mg/dm³, proizvođača, LGC korišćeni su za pripremu kalibracionih rastvora. Sve ostale hemikalije korištene u pripremi uzoraka su posebne čistoće sa oznakom “za određivanje rezidua metala” od proizvođača J.T.Baker.

3. REZULTATI RADA I DISKUSIJA

Koncentracije olova u uzorcima kore čempresa kreću se od 4.92 mg/kg na lokaciji Ljajkovići 1, do 33.09 mg/kg na lokalaciji Zabjelo 5 (Tabele 1 i 2). Prosječna koncentracija olova u kori čempresa je 14,10 mg/kg) (Grafik 1). Najveće izmjerene koncentracije Pb tokom istraživanja (Tabela 2) su posljedica blizine magistralnog puta i razgranate mreže lokalnih puteva. Prosječne koncentracije olova u kori drveta *C. japonica* u Nikko-u (Japan) [13] su iznosile oko 150 mg/kg, dok su prosječne koncentracije olova u kori čempresa (*Cupressus sempervirens* L.) u Amanu (Jordan) iznosile od 257,4 mg/kg do 330,3 mg/kg [15]. Koncentracija olova u kori sedam vrsta drveća (Abeokuta, Nigerija) se kretala od 1.9 do 159.8 mg/kg u zavisnosti od intenziteta saobraćaja odnosno antropogenih izvora zagađenja olovom [9]. Kora drveta dobro odražava stanje koncentracije Pb kao posljedica zagađenja, kako od strane saobraćaja, tako i od drugih antropogenih zagađivača [4]. Ranija istraživanja prisustva teških metala u zemljištu na području Zetske ravnice su pokazala povećane koncentracije Pb od maksimalno dozvoljenih [1]. Konstatovane koncentracije olova u uzorcima kore čempresa ukazuju na to da osim bioakumulacije olova koje biljka uzima apsorpcijom iz zemljišta, nadzemni dio biljke je značajno kontaminiran olovom iz atmosfere.

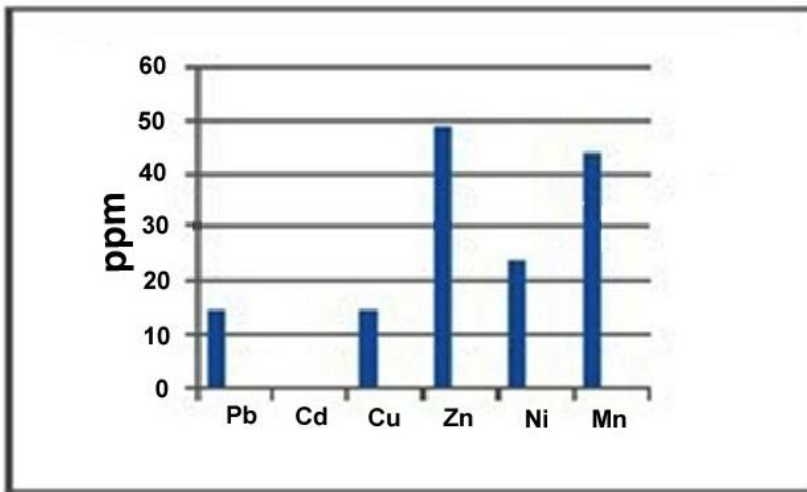
Ispitivanja koncentracija kadmijuma u uzorcima kore čempresa se kreće od 0.01 mg/kg do 0.64 mg/kg (Tabele 1 i 2). Prosječna koncentracija kadmijuma je iznosila 0.42 mg/kg (Grafik 1). Tokom ranijih istraživanja prisustva Cd u zemljištu nijesu konstatovane veće koncentracije od maksimalno dozvoljenih [1]. Imajući u vidu da su u ranija istraživanja pokazala da je kadmijum prisutan i u zemljištu u malim koncentracijama moguće je da je taj sadržaj kadmijuma u kori, posljedica apsorpcije njegovih rastvorljivih soli iz zemljišta putem korjena. Međutim, ne treba isključiti i kontaminaciju nadzemnih djelova biljke kadmijumom prisutnim u atmosferi.

Sadržaj bakra u uzorcima kore čempresa kreće se od 5.27 mg/kg do 30.94 mg/kg (Tabele 1 i 2). Prosječna koncentracija bakra u kori čempresa je iznosila 14.52 mg/kg (Grafik 1.). Istraživanja prisustva Cu na području Zetske ravnice u zemljištu su pokazala povećane koncentracije Cu u zemljištu [1]. Prisustvo povećanih koncentracija bakra u kori čempresa tokom istraživanja, osim obilne primjene bakar-sulfata u poljoprivredi za tretiranje biljaka kao fungicidnog sredstva, je i posljedica blizine KAP-a s obzirom da se ova naselja nalaze na ruži vjetrova (sjeveroistok-

jugozapad i sjever-jug) koja preovladava na ovom dijelu Zetske ravnice. U ranijim studijama je utvrđeno da se ovaj metal emituje u vidu čestične prašine iz pogona za proizvodnju aluminijuma [8], a zatim vjetrom nosi pri čemu zagađuje upravo nadzemni dio biljke koji je uziman za analizu. Istraživanja koncentracija Cu u kori bijelog bora u Finskoj su pokazala izrazito velike koncentracije u industrijskoj zoni topionice, grad Monchegorsk (Cu 867 mg/kg,) i značajno su opadale idući prema zapadu tako da je na distanci od 100 km od Monchegorsk –a, koncentracija bakra iznosila svega 3 mg/kg [12].

Tabela 1: Minimalne, maksimalne i prosječne vrijednosti koncentracija teških metala u kori čempresa u okolini KAP-a

	Ukupno N	KAP		
		Srednja vrijednost	Min.	Max.
Pb	31	14.10	4.92	33.09
Cd	31	0.42	0.01	0.64
Cu	31	14.53	5.27	30.94
Zn	31	48.49	9.13	87.35
Ni	31	23.38	2.31	57.86
Mn	31	43.49	15.47	81.86



Grafik 1: Prosječne koncentracije teških metala u kori čempresa u okolini KAP-a (izražene u ppm)

Tabela 2. Ukupne koncentracije teških metala u kori čempresa na istraživanim lokacijama

Lokacija/mg/kg	Pb	Cd	Cu	Zn	Ni	Mn
Prerada 1	21.25	0.50	19.14	54.32	19.54	49.09
Prerada 2	16.78	0.46	15.79	50.92	16.20	55.32
Prerada 3	20.57	0.49	19.66	55.08	20.89	59.74
Zabjelo 1	17.86	0.35	14.84	65.69	6.49	61.32
Zabjelo 2	11.10	0.01	9.49	19.93	5.68	24.53
Zabjelo 3	11.93	0.16	7.05	40.16	2.31	33.20
Zabjelo 4	14.95	0.16	6.96	44.63	2.36	26.77
Zabjelo 5	33.09	0.34	15.20	79.66	5.00	81.86
Gornja Gorica 1	6.47	0.27	5.27	31.72	7.53	33.48
Gornja Gorica 2	10.71	0.50	6.44	35.35	6.96	29.25
Mojanovići 1	21.33	0.54	24.02	84.40	25.54	75.28
Mojanovići 2	5.72	0.25	9.13	32.62	11.39	48.29
Mojanovići 3	26.19	0.64	30.94	45.53	25.03	49.51
Dahna	12.45	0.63	8.43	54.76	17.59	37.93
KAP 1	13.11	0.41	10.39	47.95	25.41	35.68
KAP 2	13.43	0.47	11.26	56.31	26.31	44.86
KAP 3	17.16	0.52	11.95	57.38	33.58	47.62
KAP 4	16.32	0.57	11.51	57.99	30.90	49.65
KAP 5	23.13	0.63	17.54	64.41	40.77	60.58
Cijevna 1	16.22	0.61	17.93	63.54	32.98	31.55
Cijevna 2	9.37	0.52	17.56	55.56	26.28	35.07
Srpska 1	5.76	0.20	27.15	28.37	31.34	16.74
Srpska 2	10.28	0.34	22.37	43.35	57.86	21.60
Dajbabe 1	10.47	0.50	16.46	87.35	46.81	36.21
Dajbabe 2	5.66	0.26	7.89	38.72	13.82	34.38
Mitrovići 1	12.48	0.53	17.74	9.13	48.18	62.74
Mitrovići 2	23.39	0.57	16.53	65.22	45.79	60.37
Mitrovići 3	9.98	0.25	9.36	23.64	18.87	15.47
Ljajkovići 1	4.92	0.36	6.50	26.12	19,423	31.79
Ljajkovići 2	6.00	0.54	13.71	46.09	20.19	49.08
Botun	9.04	0.47	22.16	37.23	33.65	49.21

Sadržaj cinka u uzorcima kore čempresa kreće se od 9.13 mg/kg do 87.35 mg/kg (Tabele 1 i 2.). Prosječna koncentracija cinka u kori čempresa je 48.49 mg/kg (Grafik 1). Tokom ranijih istraživanja prisustva teških metala u zemljištu na području Zetske ravnice [1], konstatovane su veće koncentracije, ali niže od maksimalno dozvoljenih. Takođe treba imati u vidu da se tačke na kojima su uzeti uzorci kore nalaze na ruži vjetrova (sjeveroistok-jugozapad i sjever-jug) što može biti uzrok kontaminacije cinkom jer je jedna prethodno urađenih studija utvrdila da se veoma velike količine cinka emituju iz KAP-a, naročito iz pogona elektrolize i glinice [8]. Područje Zete je poljoprivredno područje što podrazumijeva primjenu agrotehničkih mjera za gajenje bilja kao što je upotreba mineralnih đubriva čiji je čest pratilac Zn, i insekticida u čiji sastav on ulazi. Istraživanja sadržaja cinka u kori sedam vrsta drveća (Abeokuta, Nigerija) se kretala od 16.5 do 659.1 mg/kg u zavisnosti od intenziteta saobraćaja odnosno antropogenih izvora zagađenja [9].

Ispitivanja sadržaja nikla u uzorcima kore čempresa kreće se od 2.31 mg/kg do 57.86 mg/kg (Tabele 1 i 2), dok je prosječna koncentracija 23.38 mg/kg (Grafik 1), Ispitivanja sadržaja Ni u kori bijelog bora u Finskoj su pokazala izrazito velike koncentracije u industrijskoj zoni topionice grada Monchegorsk-a (303 mg/kg) i značajno su opadale idući prema zapadu tako da je na distanci od 100 km od Monchegorsk –a koncentracija nikla iznosila svega 1.5 mg/kg [12]. Rezultati ispitivanja koncentracija nikla u zemljištu na šest lokacija na teritoriji grada Podgorice u 2009. godini ukazuju na povećan nivo ovog elementa u zemljištu [3].

Sadržaj mangana u uzorcima kore čempresa kreće se od 15.47 mg/kg do 81.86 mg/kg na lokalitetu Zeta (Tabele 1 i 2) dok je prosječna koncentracija 43.49 mg/kg (Grafik 1). Možemo konstatovati relativno veliko prisustvo mangana u kori čempresa na istraživanim lokacijama. Kako se u bezolovni benzin dozira aditiv na bazi mangana (MMT) koji služi za povećanje oktanskog broja, može se pretpostaviti da je to uzrok relativno visokog sadržaja ovog elementa. Ranija istraživanja prisustva Mn u zemljištu na području Zetske ravnice su pokazala povećane koncentracije [1].

4. ZAKLJUČAK

Sadržaj olova na istraživanim lokalitetima ukazuje da koncentracije ovog elementa u kori čempresa zavise prije svega od intenziteta saobraćaja kao i od sadržaja u zemljištu i da koncentracije olova u kori opadaju u zavisnosti od udaljenosti stabala sa kojih su uzeti uzorci od magistralnih i lokalnih puteva.

Bakar i cink se emituju iz pogona za proizvodnju aluminijuma i koriste kao zaštitna sredstva u poljoprivrednoj proizvodnji što je i posljedica povećanog sadržaja u kori čempresa tokom ispitivanja. .

Relativno velike koncentracije mangana koje su zabilježene tokom istraživanja ukazuju na pretpostavku da potiče iz izduvnih gasova automobila jer se Mn dodaje kao aditiv u bezolovni benzin za povećanje oktanskog broja.

Rezultati ovih istraživanja pokazuju da kora čempresa može da posluži kao dobar bio-indikator aerozagađenja.



Grafik.2 Karta lokacija na kojima su sakupljeni uzorci kore čempresa

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ANTHROPIC IMPACT WATER QUALITY IN THE PORT MARINE MANGALIA

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Summary: *The human activities developed in and near the harbor Mangalia, influence physico-chemical and biological parameters of the area. Were inventoried the large and small pollution sources, that are present and act in the perimeter of Mangalia harbor. Based on this data we could draw conclusions which reveals the presence or the absence of anthropogenic effects on the environment inside and near the harbor Mangalia. Evaluation and establishing the level and range of pollution of the marine environment, and negative effects due to port and indirect socio-economic activities in Mangalia are done with monitoring activities. Monitoring points were set near the harbor Mangalia between (28,580 -28,640)E and (43,78-43,82)0 N. Following indicators were analyzed for seawater: transparency, temperature, salinity, dissolved oxygen, CBO5, total inorganic nitrogen, phosphates, nitrates, nitrite, ammonia, chlorophyll, heavy metals, total hydrocarbons. Following the tests performed, were visualized the spatial distribution and the dynamics of these indicators between 2000-2009. The conclusion was that in 2009, was observed a diminution in pollution in the port of Mangalia following the measures taken in the context of harmonizing the sustainable development strategies in the coastal and maritime area. The recommendations made in reducing the anthropic impact generated by the anthropogenic pressures with direct effect on the quality of the Black Sea's water near the port of Mangalia is to identify the main anthropogenic pressures on the Romanian coast.*

Key words: *port, impact, pollution, indicator, seawater, anthropogenic, pressure, wastewater treatment, plant*

1. INTRODUCTION

Human activities that take place in excited near the port of Mangalia influence physico-chemical parameters and biological environment of zone. Were inventoried pollution sources (Figure 1a, b) large and small, that are present and act on these data Mangalia. Could draw conclusions which highlight the presence or absence of anthropogenic effects on the environment inside and near the port of Mangalia. Assess and identify the level and degree of pollution of the marine environment and assess the adverse effects due to port activities and indirect socio-economic activities in the town

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of Mangalia is done with monitoring activities. Monitoring points were set near the harbor Mangalia between (28,58⁰ -28,64⁰) E and (43,78⁰-43,82⁰) N.

2. GENERAL INDICATORS

2.1 Evolution of sea water transparency

Evolution of sea water transparency was analyzed based on measured values in the range of 30 March to September 2008, registering values between 2.5 and 10 m. Belongs to the shallow minimum, the 5 m isobath in May and September, and maximum 30 m isobath in July. Evolution of transparency is related to the hydrological regime of the Danube, as confirmed by the evolution of similar salinity but also the persistence of large water carried by the prevailing winds[1].

2.2. Sea water temperature

Sea water temperature in the coastal area south of the major seasonal variations in 3.1...3.5⁰C in February to 25.8 ⁰ in August, according to air temperature oscillations.

2.3.Salinity

Salinity ranged between 13.7 in PSU (Practical Salinity Unit, 1PSU=1 g/kg) (Fig.1a-Port Military Station) and 15.16 PSU (Eastern Embankment station), within normal limits for the salt waters of the Black Sea.This study showed lower salinity in the station due to the influence of lake water military port of Mangalia.

2.4. pH

Is a general indicator of the ecological status of sea water which varies between 8.00 and 8.10, slightly alkaline, corresponding to the normal functioning of biological processes in the aquatic environment.

2.5. Dissolved oxygen

Dissolved oxygen (%) indicator of organic pollution, with water solubility influenced by temperature, showing a good oxygenation of the water inside the port of Mangalia, ranging from 99.05% (Fig.1a-Port Military Station, left) and 120.01% (Fig.1a-Two station Dane, right).



Fig.1a. Port Military and Two Dane [7]



Fig. 1b. Waste treatment station city Mangalia [8]

3. INDICATORS OF ORGANIC POLLUTION

3.1. Chemical Oxygen Demand

COD-Mn, as is the equivalent oxygen content of organic matter in the sample of water, capable of oxidation by a strong oxidant substance (in this case, KMnO_4). In the samples it was between 2.28 mg O_2 / l (Eastern Embankment station Eastern Embankment station) and 4.09 mg O_2 / l (city spill station), indicating a higher intake of organic matter from wastewater treatment plant from Mangalia (Fig. 1b).

3.2. Biochemical oxygen demand

BOD₅, is the amount of oxygen (mg/l) that bacteria use the oxidation of organic matter in water. *BOD₅* concentrations in the samples range was between 2.89 mg/l (Station Two Dane) and 8.65 mg/l (Station port Military). Note that the maximum concentration value exceeds the limit allowed for this parameter "*Norms on surface water quality classification*" in order to establish the ecological status of water bodies, the situation confirmed by oxygen saturation value in this station.

3.3. Inorganic nutrients

Analysis of concentration distribution (mg/l) inorganic nutrients (phosphate, nitrate, nitrite, nitrogen, ammonia and silicate) in samples from stations inside and near the port of Mangalia reveals very low concentrations of nitrite (an intermediate oxidation state of nitrogen) in all stations (Fig.2) and the dominant forms of nitrogen and ammonia. For ammonia, the most easily digestible form, is also observed, with values close to peak in East Embankment station (102.90 μg / l N-NH_4), the Military port (100.80 μg / l N-NH_4). Both mg/l concentrations exceeding 0.1, the maximum allowable standard of quality in coastal seawater in the area of influence of anthropogenic activity [2].



Fig. 2. Sampling stations in the port of Mangalia [5]

3.4. Silicates

Military Port station stands with a maximum, 1211.9 mg/l, which could encourage the growth of diatoms sharp, and station 2 berths with a value (659.7 μ g/l) very close to the minimum (502.0 μ g/l) confirmed the value of density and biomass of the diatom *Skeletonema costatum* maximum.

3.5. Inorganic phosphate

Inorganic phosphate concentrations were generally low values except station spill reaches the city where the value of 70.06 mg/l due to discharges from wastewater treatment plant Mangalia.

Table 1 Annual average concentrations of physico-chemical indicators over Mangalia profile

Indicator / Location	Sea water temperature °C	Salinity PSU	Oxygen cm ³	pH	BOD ₅ Cm ³
Port Military	3.1...25.8	13.7	98.9	8.00	2.89
Eastern Emb.	3.5...25	15...16	119.5	8.10	8.65

Table 2. Another annual average concentrations of physico-chemical indicators over Mangalia profile

Indicator / Location	O ₂ %	COD-Mn mgO ₂ /L	NH ₄ mg/L	PO ₄ mg/L	SiO ₄ mg/L
Port Military	99.05	4.09	100.8.10 ⁻³	70.06	1211.9
Two st.Dane	120.01	-	98.4.10 ⁻³	10.08	659.7.10 ⁻³
Eastern Emb.	124.08	2.28	102.9.10 ⁻³	23.05	502.10 ⁻³

3.6. Heavy metals

Heavy metals (Pb, Cd, Ni, Cr and Cu) were determined in seawater and sediment collected inside the port of Mangalia. Determinations have revealed that heavy metal values in sediments ranged as follows: - 38.13 to 203.09 mg /g Pb (in dry

sediment), from 7.07 to 20.41 mg/g Cd, 25.71 - 89.19 mg/g Ni from 39.05 to 98.91 mg/g Cr, 29.87 to 198,89 g/g Cu, and in seawater in the area, as follows: - 1.29 to 2.77 mg/l Pb, 0.95 to 1.45 mg/l Cd, 0.30 to 1.00 mg/l Ni, 8.33 to 40.67 mg/l Cr 9.95 -11.91 mg/l Cu. Determinations of heavy metals in Mangalia port have revealed higher for Cr and Cu in water and Cd, Ni, Cr and Cu in sediments.

3.7.Total Hydrocarbons

Analysis of total hydrocarbon content in water samples collected in 2008 from the port of Mangalia were found in 100% presence of pollutants, the size of concentrations ranging in the 305-520 mg/l. 100% share in concentrations in excess of 300µg/l process identifies the presence of chronic oil pollution in this area. Spatial distribution of hydrocarbon concentrations in seawater determined port area Mangalia marked effect of pollutant concentration with oil supplied through specific activities in this area. Effect of water contamination by oil is mass storage of petroleum pollutant sediment surface. In the port of Mangalia, the size of the field concentrations ranging 135-964 µg/USG(1 US gallon of water weighs 3.79 kilograms). This confirms the presence of chronic oil pollution process installed in this area [3]. Average load content of polyaromatic compounds has been measured at 680.7 ng/l in sea water and 110.1 ng/USG the sediment surface. In water samples from the East Embankment discharge concentrations of organochlorine pesticides (HCB, lindane, heptachlor, endrin, DDD and DDT) ranged from 30.08 ng/l and 470.06 ng/l.

4. CONCLUSION

1. Physico-chemical parameters and inside water falls near the port of Mangalia, with few exceptions, in the normal range, thus providing the conditions required for sustainable use of coastal marine ecosystems in areas that support impact of discharged waste into the marine environment [4].
2. Advanced degree of diversity of compounds and concentrations determined show significant aspect of the intensive process of changing the existing oil pollutant in the area under the influence of environmental factors.
3. In water samples the concentrations of organochlorine pesticides (HCB, lindane, heptachlor, endrin, DDD and DDT) ranged from ~30.0 ng/l to ~ 470.0 ng/l [5].
4. The greatest densities and biomass were given diatom species *Skeletonema costatum*, present with a constant 100% in all sampling stations [6].

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A NEW TECHNOLOGY FOR SHIP HEAVY FUEL OIL SYSTEM

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Summary: To protect the environment from toxic gas releases(NO_x , SO_x) its better to use fully mineral fuels, including residues. This new technology reduces costs and NO_x releases by 30 %. The paper presents a study on a heavy fuel oil system, aboard a 70 000 tdw ship with 4 crush-mix fuel systems. An crush-mix system can prevent mechanical problems that can appear during the fuel burn, especially during the burn of residual fuel. The structure of the fuel processed in such a system gain a major improvement of the structure. Residues will be reduced up to 80 %, compared with the initial components of the fuel. This reducing fuel residues will make the fuel to have better quality burn, reducing the ash emission, making the mechanical parts exploitation involved in the burn process more durable. Systems that are using inferior quality fuel are polluting the environment with NO_x emissions and slam. This advanced environment-safe heavy fuel oil system reduces the disadvantages and: a) raises the O_2 inside the fuel, reducing NO_x in emission gases; b) effectively removes the abrasive particles; c) reduces ash deposits, eliminating the shore collecting process.

Key words: ship, system, technology, residue, fuel, emission, environment

1. INTRODUCTION

The MARPOL Annex VI demand several reduction of air pollution by ships engines: NO_x , SO_x and ash. On the other side, the market prices of qualitative fuel oils increase spectacularly, so the owners prefer to use residual oils, containing heavy particles and bigger molecules. The result is: low quality burn process, more abrasive metal residues in the fuel, more deposits on burners, injection valves, outlet valves and more sediments in the H.F.O. (Heavy Fuel Oil) separators units.

We present an system which improve H.F.O. quality, and the results obtained on a 70.000 tdw vessel. The system have as qualities:

- Reducing at microns the dimension of all organic particles,
- Increase fuel's oxygen content, in view to ensure NO_x reducing,

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- Better eliminate abrasive particles,
Reducing H.F.O. separators slam-discharge in order to minimize shore collecting.

2. WORKING PRICIPLE

The crush system consist in a stator and a rotor both with helicoidally channels, but with different pitch. Rotor speed is above 3000 / min, and distance of stator 0.05 mm due to the channels. Inside this system appear ultrasonic waves (6000 Hz), pressure and friction forces, capable to deform then crush the molecules. Mean times the system is used to introduce long stability water particles about 2-3 μm between fuel molecules, in order to enrich oxygen (and hydrogen) content - after vaporization – in the engine's cylinder. The 75 μm diameter droplet including central residue is divided in ~13.000 micro droplets 3 μm in diameter, and a separated residues witch can easily by eliminated.

3. THE ADVANCED ENVIRONMENTAL SAFE HEAVY FUEL OIL SYSTEM

3.1 The components

The system [1] consists in four separate parts/units (Figure 1), called A.E.S.H.F.O.S. from ADVANCED ENVIRONMENT-SAFE HEAVY (FUEL OIL SYSTEM). First unit called A.E.S.H.F.O.S.-1-Slam reducer. Second unit of A.E.S.H.-2 called Emulsifier. Unit A.E.S.H.F.O.S.-3 (Finishing) is placed between booster pumps and final M.E. heaters. Unit A.E.S.H.F.O.S.-4 serves as residues regenerators .

3.2. Principle schema of A.E.S.H.F.O.S.

Unit 1-*Slam reducer*, is fitted in closed circulation on the settling tank (21 m³) in order to begin the crush-mix process. Unit 2 called *Emulsifier* continues the crush-mix process and introduces water in the fuel in form of 3 μm very stable particles. This water is provided from the bilge water tank. Then the fuel is separated in a "classic" purifier/clarifying unit. Here are eliminated separate water and heavy fuel fractions - paraffin's, tar and minerals. All this residues are eliminated in a 4.7 m³ Sludge Tank. The separated fuel is stored at 105 °C in a 42 m³ Service Tank, witch assure a 24 h M.E.(main engine) consumption [2]. The separation process never stops in order to ensure multiple circulation and better separation. Unit A.E.S.H.F.O.S.-3-*Finishing* serves as crush-finishing fuel oil. This unit reduces the ash and increases fuel efficiency. Unit A.E.S.H.F.O.S.-4 serves to regenerate residues(waste oil tank, boiler).

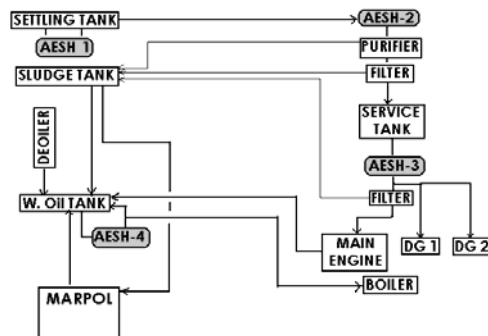


Fig. 1 Principle schema of A.E.S.H.F.O. preparation system.

4. RESEARCH AND RESULTS

4.1 Case studies

We studied the system[2] , collecting results 4 case studies: case I, we study on a 3 days period the A.E.S.H.F.O.S. installation without any mix-crash system(1)(Table 1); case II, records quantities, using A.E.S.H.F.O.S -1and A.E.S.H.-3(Table 2); case III, using A.E.S.H.F.O.S-1 and A.E.S.H.F.O.S-3; increased time between HFO separator automated discharge from 30 min to 60 min(Table 3);case IV, we use the entire system, including A.E.S.H.F.O.S -2(Emulsifier) (Table 4).

Table 1 Case I

Fuel quantity from scavenging syst (liter)	Residues result (liter)	Leaking luboil& fuel (liter)	Burn luboil (liter)	Drained water from residues (liter)	Evaporated water (liter)	Net residues without water (liter)	Bilge cumulated water (liter)
72 000	1000	150	100	450	300	500	1300
72 000	1050	150	100	500	250	550	1400
72 000	1050	150	100	500	250	500	2200

Table 2 Case II

Fuel quantity from scavenging system (liter)	Residues result (liter)	Leaking luboil& fuel (liter)	Burn luboil (liter)	Drained water from residues (liter)	Evaporated water (liter)	Net residues without water (liter)	Bilge cumulated water (liter)
72 000	1000	200	100	600	300	450	2100
72 000	1050	150	100	750	250	300	2200
72 000	1050	200	100	750	300	300	1800

Table 3 Case III

Fuel quantity from scavenging system (liter)	Residues result (liter)	Leaking luboil& fuel (liter)	Burn luboil (liter)	Drained water from residues (liter)	Evaporated water (liter)	Net residues without water (liter)	Bilge cumulated water (liter)
72 000	1050	100	100	450	250	250	1500
72 000	1050	100	100	500	200	250	1600
72 000	1050	150	100	500	250	250	1500

Table 4 Case IV

Fuel quantity from scavenging system (liter)	Residues result (liter)	Leaking luboil& fuel (liter)	Burn luboil (liter)	Drained water from residues (liter)	Evaporated water (liter)	Net residues without water (liter)	Bilge cumulated water (liter)
72 000	1000	150	80	500	250	230	1500
72 000	1050	100	80	500	260	220	1700
72 000	1050	100	80	500	230	220	1300

4.2 Results and interpretations

During the 12 days the residues separately values are presented in Table 5:

Table 5 Resulted values

Day	1	2....6	7....12
Residues separately	1000	1050	750

Graphic interpretation is presented in figure 2:

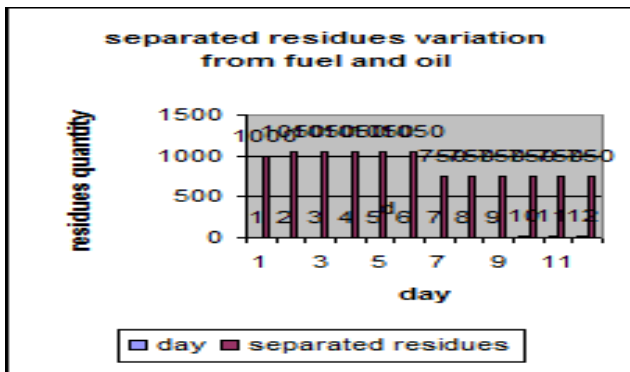


Fig. 2 Separated residues variation from fuel and oil

Daily oil leaks and fuel are presented in Table 6:

Table 6 Daily oil leaks and fuel

Day	1	2	3	4	5	6	7	8	9	10	11	12
oil leaks	150	150	100	200	150	200	100	100	150	150	100	100

Graphic interpretation is presented in Figure 3:

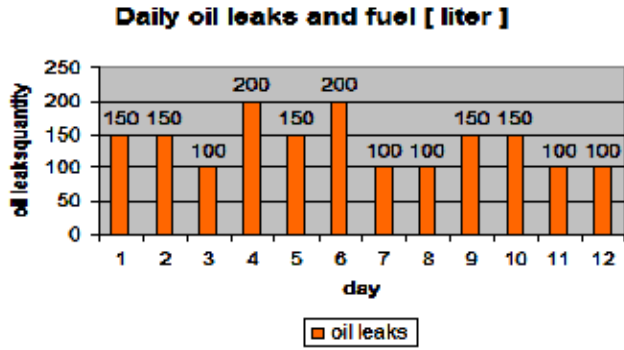


Fig. 3 Daily oil leaks and fuel

Burned oil leaks from sweeping are presented in Table 7:

Table 7 Burned oil leaks from sweeping

Day	1	2	3	4	5	6	7	8	9	10	11	12	
Burned oil leaks from sweeping	100	100	100	100	100	100	100	100	100	100	80	80	80

Graphic interpretation is presented in figure 4:

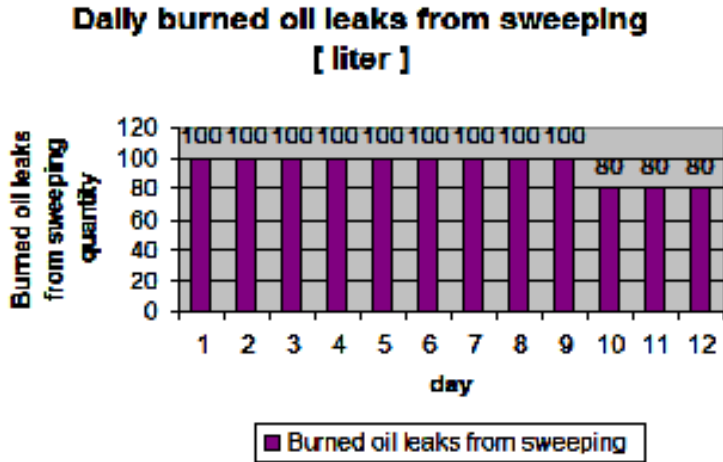


Fig. 4 Daily burned oil leaks from sweeping

Separate water from residues collected values are presented in Table 8:

Table 8 Separate water from residues collected

Day	1	2	3	4	5	6	7	8	9...11	12
Separate water from residues collected	450	500	500	600	750	750	450	500	500	530

Graphic interpretation is presented in Figure 5:

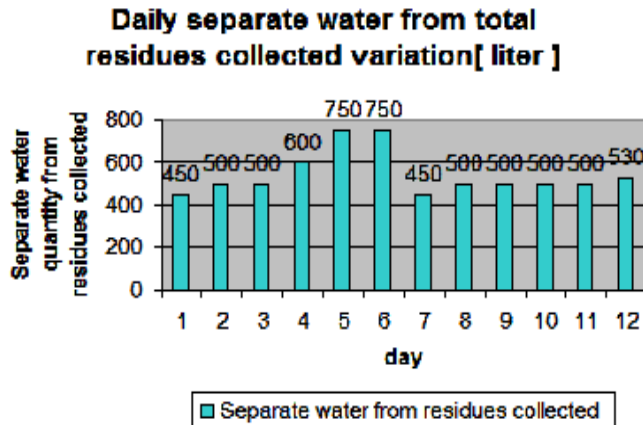


Fig. 5 Daily separate water from total residues collected variation

Water evaporated from all the residues aggregated values are presented in Table 9:

Table 9 Daily water evaporated from all the residues aggregated values

Day	1	2	3	4	5	6	7	8	9	10	11	12
daily water evaporated from all the residues aggregated	300	250	250	300	250	300	250	200	250	250	260	230

Graphic interpretation is presented in Figure 6:

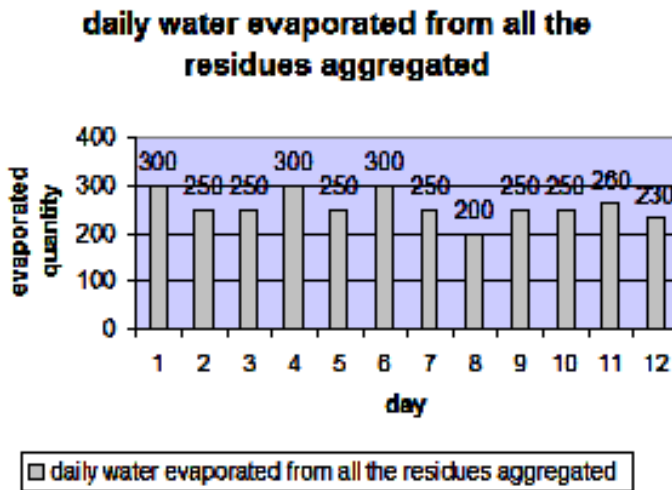


Fig. 6 Daily water evaporated from all the residues aggregated

Residue net without water values are presented in Table 10:

Table 10 *Residue net without water values*

Day	1	2	3	4	5...6	7...9	10	11..12
Residue net without water	500	550	500	450	300	250	230	220

Graphic interpretation is presented in Figure 7:

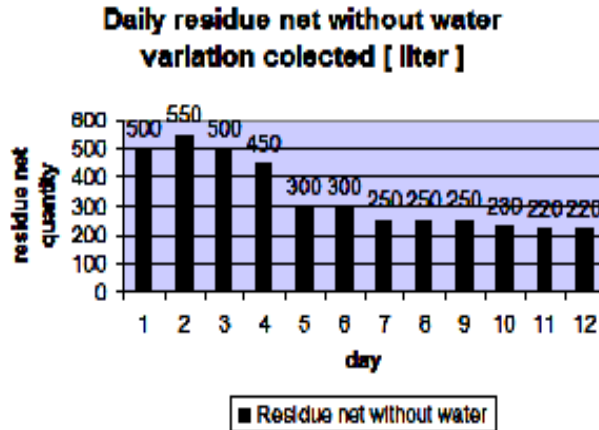


Fig. 7 *Daily residue net without water variation collected*

5. CONCLUSION

- First (Case II) improvement is the 45% reducing of the net residues.
- Second (Case III) improvement is the possibility to double the time between 2nd separator automated discharge because the residues quantity is half reduced. This increase the global life-time of the HFO separator and total separated fuel. In this (Case III) we also observe the decrease of the drained water from residues, and reducing by 15% of the net residues without water.
- Third (Case IV) – Emulsifier introduced- we record a drop of oil leakage from scavenging system (cylinder lubrication oil); also a drop of net residues. We observe too a drop of NO_x and ash.
- At the ME interior inspection we observe the drop of the deposits over the engine parts who interact with the burn gases(injection valves, piston cover, exhaust turbines, scavenging spaces).

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IMPROVEMENT OF ENVIRONMENTAL QUALITY BY SETTING UP THE EXTERNAL VERTICAL GARDEN ON THE EXISTING BUILDING

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Abstract: This paper is presenting the results of the research on developing methods for environmental quality improvement. The method proposed the vertical facade gardens on existing buildings and photo voltage panels, as renewable solar energy application for production of energy which is necessary for pumps work on watering of the garden and energy independency of the building. The method is developed within the preliminary report for Post office building in Kneginje Ljubice street, Belgrade, Serbia. The result is improvement of environmental quality, esthetic effect and environmental protection of particular urban area. The technical solution contains concept of the vertical facade gardens, presented through cross sections and isometric. Independent mini solar power plant for energy supply for watering of the vertical garden is part of the system and it is presented with belonging energy parameters in this papers.

Key words: environment, urban area, buildings, solar renewable energy, vertical facades gardens.

1. INTRODUCTION

The theoretical basics of contemporary methodological approach to sustainable design, environmental quality improvement and specifically designed the mini solar power and vertical gardens on the property address in the Zmaj Jovina Street in the city center of Belgrade are explained in the paper.

This innovative architectural design works on the principle of sustainability, uses renewable solar energy to operate pumps for plants nutrition and hydration and ecological materials. By proposed method the energy efficiency of the building is increased, the visual effect is achieved and a more harmonious relationship between the natural and built environment is established in order to reduce pollution.

"Cities are becoming more widely, causing disruption in the quality of the environment. Man, instead of get to know the nature and the laws that govern it, begun to degrade and pollute it" [1]. In order to establish the lost ecological balance, the cities

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are continuously working on developing modern methods of application of renewable energy sources and landscape design in free urban areas, roofs and facades [2].

2. SUSTAINABLE DEVELOPMENT

On the square in front of the UN building in Geneva, is the vast monument - chair ten feet tall, with a short leg. The monument reminds us of the importance of the concept and definition of sustainable development [3]. The concept of sustainable development could be metaphorically represented as a Renaissance style chair with four solid, stable legs, which represent four equal and equally important components of sustainable development: economic factor, environmental factors, social factors and factor of cultural development.

Equal development of all social factors should lead to sustainable development and its existence. Sustainable development means and includes economic growth. Encouraging responsible long-term progress is necessary. Preservation of natural resources and the environment is imperative for future generations. Social progress expressed through social and cultural development means that all members of society should be responsible to participate in creating their own future. That means decrease of resource waste, reducing pollution and conserving natural habitats [4].

"If you think a year ahead, plant wheat. If you think 10 years ahead, plant trees. If you think 100 years ahead, educate man ", written by an anonymous Chinese poet from 500 g. BC. The concept of sustainability is still an ideal to strive for in all areas of science and human effort [5].

World population is continually growing, natural habitats are daily being more threatened, and economic inequality are rapidly increasing [6]. Sustainability is, generally speaking, the ability to fulfill our own needs, and at the same time not to deprive future generations to meet their own. The resources that can be found at this moment on the globe do not belong only to our generation [7]. Through the design process the amount of energy consumed should be considered. The object is to reduce the required amount of resources during the construction phase as during its use. The "Global Compact" of the United Nations is a key step in creating a recognized standards of corporate social responsibility [8].

Sustainable development "allows people to gain knowledge, acquire values and develop the ability to participate in decision-making ...", which will improve the current quality of life without damaging the planet in the future [9]. The use of the principle of sustainable development is a way of educating future generations, where architecture represents a unique challenge in the sustainability field [10].

3. THE METHOD OF ENVIRONMENTAL QUALITY IMPROVEMENT AND SUSTAINABLE DESIGN

Sustainable construction is defined as the design and responsible management of a healthy built environment, based on energy-efficient use of natural resources and ecological principles [11]. Sustainably designed buildings are designed to minimize adverse impacts on the environment through energy efficiency, the use of natural resources and eco-friendly materials. It includes the following principles: minimizing the use of non-renewable energy sources, use of natural, organic materials, environmental improvement and eliminating or minimizing the use of toxic materials.

Modern sustainable design is linked to a number of specific engineering criteria, which may result in architectural design embedded in the environment. One of

them is the conceptual design of vertical wall gardens at the post office in Zmaj Jovina Street in Belgrade.

4. THE GOAL

The aim of this paper is to teoreticly define ecological principles of energy-efficient and sustainable design, and then to develop its model on a concrete case study of vertical garden on the mail facility at Zmaj Jovina Street, on conseptual design level. From the architectural point of view, the challenge represents the ability to highlight the contrast between the structural stability and permanent changes that are in the nature of plants: the geometric forms of the facade are perceived as a lever which can be revive by the vertical garden. Construction elements and blank facade surface can be covered by photovoltaic panels and plants. Selected vegetation can hide or highlight wall structure. Plant layer can completely or partially cover the building. By using plants that can hide hydraulic drains and outlets, it is posible to create a circular structure without complicated and expensive construction elements.

5. CASE STUDY OF VERTICAL GARDEN AND MINI SOLAR POWER PLANT

5.1 The concept

Mail facility at the corner of Streets Zmaj Jovina and Vase Čarapića was chosen for the application of ecological principles of sustainable architecture by setting vertical garden in order to improve the quality of the environment. The building is located in a very attractive part of the city, in the center of Belgrade, at high frequency Street, and not far from the busiest pedestrian area, Knez Mihajlova Street. The use of organic materials is an important prerequisite for sustainable development [16]. Coffered planting system is used in this specific case of vertical garden. The panels where the soil and plants are installed are made of recycled plastics to improve the environmental characteristics of the entire system, which also has aim of improving the climate characteristics and aerial environments.



Fig. 1. Northeast facade after intervention

The facade made out of concrete, partially covered with marble and glass, has never been rebuilt. Therefore, they fitted into street surrounding with their current appearance. The problem of visual pollution caused by lack of landscape micro environment would be reduced by applying the above mentioned environmental solutions on the move of Zmaj Jovina Street. Bright colors of vegetation throughout the year, regardless of seasons, would fill the space, solve visual pollution and reduce the problem of transport pollution as well.

Given that this is a public facility, this structure would be intended for all city residents. Bearing in mind that there is no vertical gardens in Serbia at all, this would become a landmark of the city, as one of the most important points of orientation.

Vase Čarapića Street is suitable for the introduction of vegetation because of its urban sustainability such as the purification of exhaust car and public transportation system in one of the busiest parts of the city with numerous regulatory directions. The

problem of sustainability represents the lack of essential element of the street morphology - alley. Highlighting the fact that the post office building is surrounded by residential buildings, the need for this project is at a high level.

Equally important task of the proposed eco-sustainable architectural structure is to spread awareness about the importance of landscape in the city center. Wood, as a symbol of ecology, it is taken as a motive and shaped with vegetation in order to convey a symbolic message.

5.2 The system feasibility

The crucial influence on the choice of the place for vertical garden design was the idea that is located at well analyzed location which is attractive enough and exposed to higher air pollution so it could perform its function of air cleaning.

In the case of vertical garden, at the post office in Zmaj Jovina Street, it is mostly used a coffered system that requires a large surface without holes. Panels are installed one to each other and require a space where they can be placed in enough wide range, to form a system of vegetation elements. On a selected building such surface is focused in the south-east side which is one of the first conditions for the execution of vertical gardens. South side of the world gives essential amount of light that plants need for their development (Fig. 2).

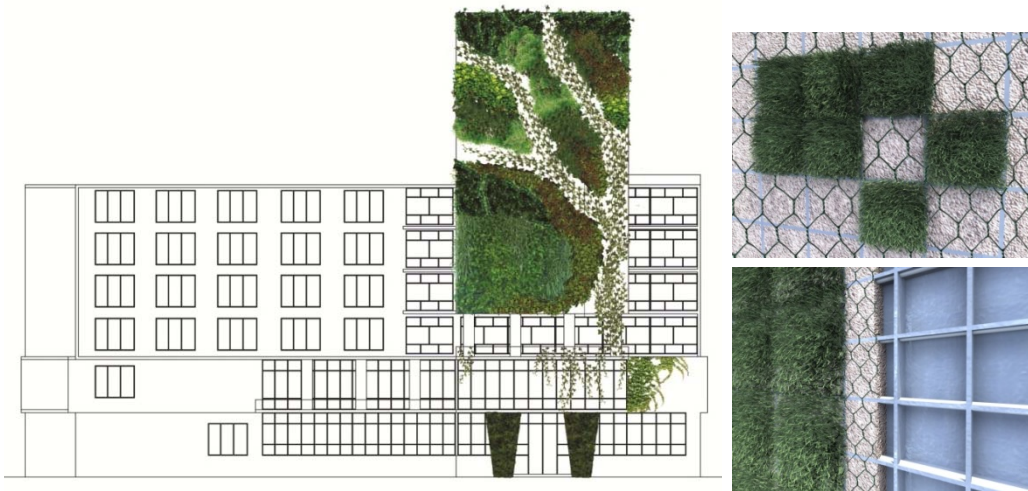


Fig. 2. Southeast facade after intervention with details of facade elements

Besides coffered system in surfaces without openings was used a vine supposed to grow in pots which are attached to the railing of a flat roof. Plants that are used (*Parthenocisus tricuspidata*, *Lonicera Capriforium* L, *Vinca Major Variegata*, *Arabis Albida* Steve, *Hedera helix* L) [13] have the ability to develop in the urban conditions of this area. In addition, they do not require extra work, except for the occasional pruning, primarily to maintain the aesthetic characteristics of vertical garden.

5.3 Visual Effect

The visual effect of vertical garden in this position leaves a strong impression on viewers, which prime objective would be raising awareness about the importance of ecology as a discipline which in the context of the problem of preserving environmental quality becomes more important. Given the high rate of build structures in this part of town, there is no place left for new landscape structures, and it is considered that the establishment of an external vertical garden is good solution for this part of the city (Fig. 3).

Along the far right side of the northeast facade of the building, with a width of 3m, it is planned to set up a compact facade cladding composed by using "Italian ryegrass" grass. The inscription, "Post" that is on the wall, is written by gaps in the vegetation facade.



Fig. 3. Building before and after intervention

On the front southeast facade, at the entrance to the post office are two pillars under the wall that has the symbol of the tree. The proposed conceptual design pillars are covered with grass, achieving unity of structure.

5.4 Sustainability of the system

Following the trend of sustainable development, applied system can be self-maintained with the primary renewable energy source - the sun. For watering plants it is used a so-called "blue water" or rainwater collected on the roof and which is lead to the pipe system implemented throughout the construction of vertical garden. Water circulates by pump, which supplies electricity provided via photovoltaic panels placed on the roof.

Water tank with 50L capacity is placed on the roof, providing direct soaking plant by gravity. 20mm diameter pipe that carries water through the system, go through every niche of coffered system, ensuring continuous watering of plants. Pump that circulates water is small, which is very practical when it comes to its positioning on the roof, in any room on the floor or in the basement. The pump is located on the roof above the vertical garden, thus shortening the path of water flow from the tank to the system. In the event of pump termination the natural water decline provides plant irrigation.

Just below the vertical garden (Fig. 4) is placed drainage system (Fig. 5) in order to collect water which system do not use. The drainage pipe has a longitudinal decline of 1%, collects excess water and use a pump for flow and irrigation and returns

the filtered water back into the tank, where it is provided free circulation of irrigation systems.

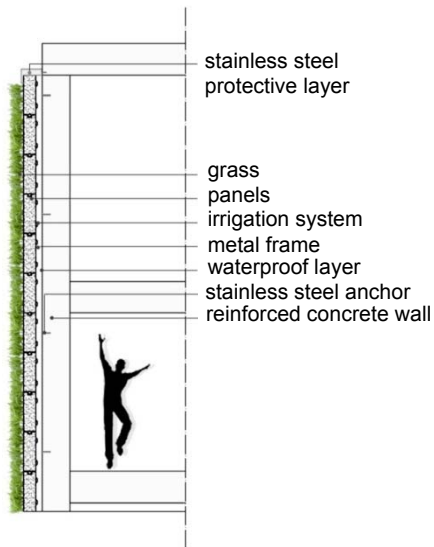


Fig. 4. Vertical garden panels-section

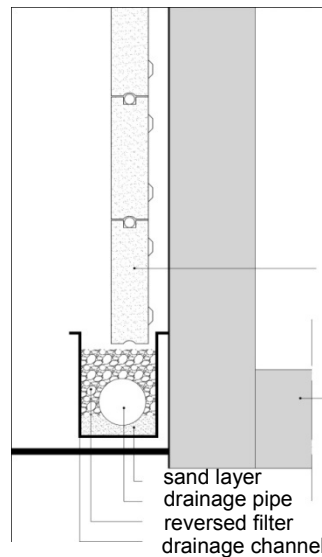


Fig. 5. Drainage water solution

5.5 Technical parameters and features a mini solar power station

The electricity that powers a pump which carries water from the tank to the drainage system to the reservoir is provided by photovoltaic panels placed on the roof. Required panel surface is 2m².

On the roof is a mini solar power plant, consisting of two photovoltaic panels' total power 200Wp, rechargeable battery capacity 140Ah (at twenty hour discharge mode), charge controller and nominal power inverter of 500W.

The use of solar energy has the positive effects from the ecological and economical point of view. Energy importance is reflected in the context of self-sufficiency and independency of the power system. Ecological importance is in reducing global pollution, while economical opportunities are in the discharging electric system for other purposes and not paying the penalty for harmful emissions.

5.6 Utilization

There are no windows or doors on the southeastern wall. Its area is 200 m². The wall surface is in good condition, it is visible from the main, but also from the surrounding streets. Considering that the possible degree of utilization is 100%, compared to the surface without windows, it was decided that the whole facade should be rich by vegetation. The degree of utilization in regard to the total surface is 60%, while 40% of the facade is made of glass. In these surfaces it is not possible to implement vegetation, while all other surfaces without openings are adapted in vertical gardens.

6. DISCUSSION AND CONCLUSION

Analysing 25 German cities it was found that nearly 40% of the public areas are buildings or sidewalks. In some cities, it is even 50%. This percentage has nearly doubled in the past 30 years [14].

Research conducted in highly developed urban areas shows that 90% of respondents believe that the park proximity significantly improves the quality of housing. Design of flat green roofs and facades can be one of the ways that urban areas resist global climate change.

The construction of roofs and facades, as a whole landscape areas with adequate drainage hydro-technical solutions, partially returns nature to the cities. Environment can be converted into a pleasant surroundings, with relatively low costs, creating more humane conditions and higher environmental quality in urban areas.

Green roofs and facades have been known for hundreds of years, to the cold climate of Iceland, Scandinavia and Canada, as in the warm climate of Tanzania. Their contribution to the stabilization of the internal temperature and the energy efficiency of the building is significant.

In urban areas, where significant parts of vegetation on roofs and facades can be found, the air quality has been improved, temperature has been better controlled, life of waterproofing roofs has been prolonged, microclimate has been better created, storm water drainage has been reduced, filtering and quality of storm water have been improved, so as the noise and dust absorption [15].

The process of photosynthesis is an important reason for the mass use of green roofs and facades. Green roofs can be seen as potential areas for sport and recreation, botanical gardens, scientific research and specific ecosystems where insects and birds can live in. Buildings covered in plants are changing their visual effect by creating new flavors, colors and appearance with the change of seasons.

Facade covered in plants suggests that this building is using far less energy for heating and cooling, than other buildings that do not have such systems. A layer of soil and plants keeps the internal temperature at a constant level.

New strategies of urban design in cities with vertical and roof gardens, which are based on the principles of sustainable development, provide a better quality of life for residents, promote sustainable and healthy way of life, while also contributing climate protection.

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Session VI **QUALITY, MANAGEMENT AND ORGANIZATION**



INFLUENCE OF SIZE OF ORGANIZATION AND NUMBER OF INTEGRATED MANAGEMENT SYSTEMS (IMS) ON ORGANIZATION OF IMS PROCESSES

Slavko Arsovski¹, Zora Arsovski², Miladin Stefanović³

Abstract: *IMS's processes are oriented on certification, maintenance and improvement of integrated management systems (IMS). Considering complexity of this tasks, in practice, especially in organizations where these additional activities are assign to specific employee. In further development, with growth in implementation phase, maintenance and improvement of initial IMS, as well as integration with a new management systems, problems grow exponentially. This problem could be solved with selection of appropriate organization of IMS processes. Theoretical background of organization of IMS as well as results of research among 45 organizations with implemented IMS (2 to 4 management systems) is presented. Considering theoretical background as well as authors' practical experience as consultants in development and implementation of IMS, two starting hypothesis were identified: H1: size of organization influences on form of organization of IMS's processes; H2: number of integrated management systems influence on form of organization of IMS processes. The results of research indicates that size of organization and number of integrated management systems influence on form of organization of IMS' processes.*

Key words: ms, size of organization, process

1. INTRODUCTION

Organization of IMS processes are based on three major pillars: (1) organizational theory; (2) concept of TQM and (2) concept of IMS. All of these concepts start from structure of activities of IMS process, and more or less according to politics and strategy of quality that define appropriate organizational structure. Theoretical approach is in many cases confronted with practice, because in number of organizations in practical work insufficient knowledge, financial constraints and insufficient quality of human resources are presented. That is a reason because the number of different organizational solutions of IMS could be found in practice, which are usually explained by diversity of technologies, complexity of business activities and territorial distribution. In this paper the basis of organization of IMS as well as results of research in 45 companies with implemented IMS (2-4 management systems) are

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presented. Having insight in theoretical background as well as authors' practice as consultants in development and implementation of IMS, two starting hypothesis are identified:

- H1: size of organization influences on form of organization of IMS's processes;
- H2: number of integrated management systems influence on form of organization of IMS processes.

Results of research related to 56 enterprises Serbia point that size and number of integrated management systems influence on organization of IMS processes.

2. ORGANIZATION OF IMS PROCESSES

2.1. Theoretical background

In literature that covers organizational issues [1, 2, 3, 4] the most common issues in organizational structure are:

- (1) Socio – economical environment,
- (2) Market environment,
- (3) Technology,
- (4) Business strategy,
- (5) Size of company, and
- (6) Stage in the life cycle of the company (maturity of the company).

In this paper we will consider effects of size of the company and partly market environment and business strategy and their influence on number of integrated management systems.

In definition of organization structure, following principles are respected:

- (1) Division of the work,
- (2) Centralization/decentralization,
- (3) Aggregation of organizational functions, and
- (4) Coordination.

According to division of the work there are horizontal and vertical specializations, according to centralization there are (1) centralized, (2) vertical and (3) horizontally decentralized organizational structure. Usually micro and small enterprises have centralized and medium and large enterprises decentralized organizational structure. In principle of aggregation of organizational functions it is important to mention that lower organizational forms aggregate in higher forms according to following criteria: functional, market and matrix.

Principle of coordination has important place in management theory. According to Mintzberg [5], following coordination approaches differ: internal communication, direct control, standardization of knowledge (inputs), standardization of processes and standardization of outputs. It could be concluded that this principle has important influence on organization of IMS processes.

2.2. Organization in TQM concept

The number of quality gurus and literature in the field of TQM [6, 7, 8, 9, 10, 11, 12] it was pointed on complexity and different forms of organization for fulfillment of quality goals. According to Feigenbaum [8] activities directly connected to quality could be fulfilled through six principles:

- (1) Quality – systems engineering relates quality technology to quality requirements,
- (2) Quality – systems engineering relates this quality technology to quality requirements in an organized form of necessary specific procedures and controls,

- (3) Quality – systems engineering considers the total range of human informational, and equipment factors needed for these procedures and controls,
- (4) Quality – systems engineering specifically establishes the „feedback“ measurements against which the quality system will be evaluated when in operation,
- (5) Quality – systems engineering then structures the necessary quality system objectively and provides for audits of the system, and
- (6) Quality – systems engineering and management provides for the ongoing control of the quality system in use.

Based on those principles for TQM are identified grouped activities of key systems (subsystems):

- 1. Preproduction quality evaluation,
- 2. Product and process – quality planning,
- 3. Purchased – material quality planning, evaluation and control,
- 4. Product and process – quality evaluation and control,
- 5. Quality information feedback,
- 6. Quality training, orientation, and work force development,
- 7. Quality information equipment,
- 8. Postproduction quality service,
- 9. Management of quality control function and
- 10. Special quality studies.

Starting from the fact that 80% quality problems are caused by influences out of traditional quality management, it is important to develop appropriate quality structure. The matrix of responsibilities according to activities is step in that direction (Table 1).

Table 1 – Responsibility matrix

	General manager	Quality manager	Marketing manager	Others managers
The needs and requests of customers			R	
Establish quality policy	R			
Plan the quality system		R		
...

Starting from these activities, duties of quality managers are organized through:

- quality engineering,
- quality information and
- process control engineering

which could be centralized or decentralized, in the function for quality, as well as a part of other business functions (marketing, production, human resources, supply, research and development, management ...). In the case of decentralized system (figure 1) activities of planning of measure and analysis are divided in different organizational units.

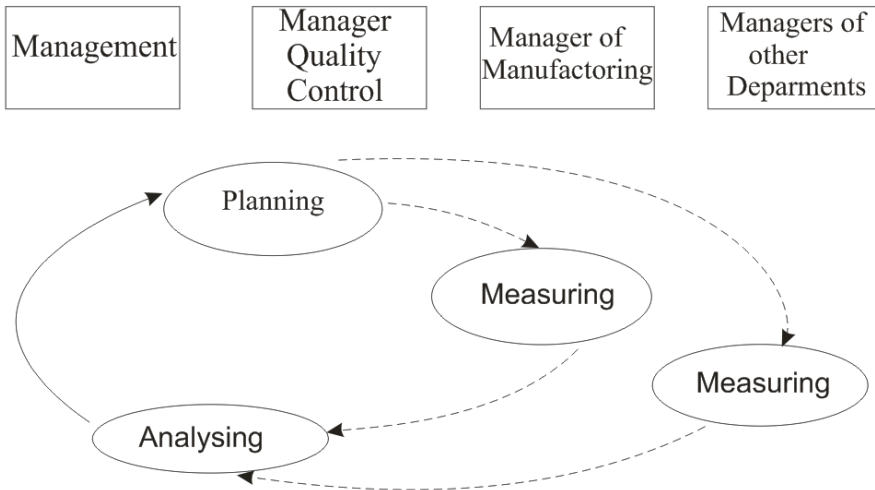


Figure 1. Feedback cycle for decentralized quality control

In centralized form all planning activities, measurement and analysis are under the supervision and control of quality manager. In diversified programs which are realized in several locations, combined approach is dominant. One part of activities is centralized on the company level (quality engineering), and the other mostly connected with operational activities in the field of measurement, prevention and corrective actions are dislocated on distributed organizational unit. In micro and small enterprises executors of processes in the field of quality are under quality manager and quality manager is under supervision of top manager. In large organization quality function is separated and structurally defined to the specific level (Figure 2).



Figure 2. Typical organization of quality function in large enterprises

In the case of more divisional structure, quality function is decomposed horizontally and vertically (Figure 3).

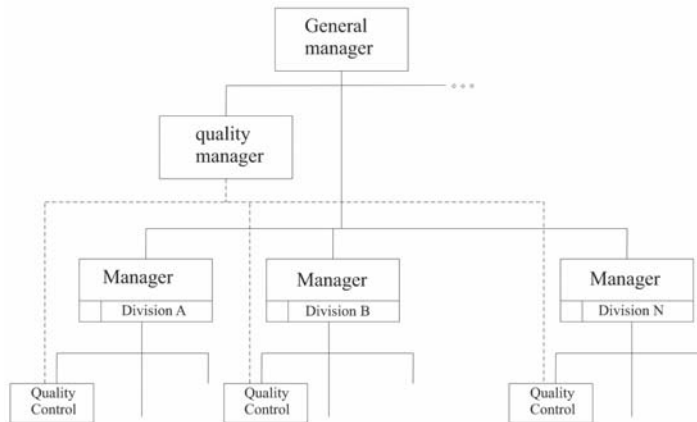


Figure 3. Case of large organization distributed on different locations



Figure 4. Quality triangle

Based on this background Faigenbaum defined quality triangle (Figure 4).

2.3. Organization in concept of quality management and IMS

In the wide scope of literature in the field of quality management and IMS, considering the role of process of quality in fulfilling internal and external demands, according to [13, 14, 15, 16, 17], there is a trend for transition of classical organizational units for quality closer to production, i.e. operation all processes in order to achieve more efficient and effective planning, management and monitoring of key processes. This demands reevaluation of procedures for key processes and involvement of quality managers on that organizational level.

On the other hand, quality managers will be released from operative activities due increase demand for centralization. This result that quality management becomes proves on the higher level covering:

- encouraging and facilitating improvement,
- monitoring and evaluating the process of improvement,

- promoting the „partnership” in relationships with customers and suppliers,
- planning managing, auditing, and reviewing quality management systems,
- planning and providing training and counseling or consultancy,
- giving advice to management on:
 - establishment of process management and control,
 - relevant statutory/legislation requirements with respect to quality,
 - quality and process improvements programs,
 - inclusion of quality elements in all processes, job instructions and procedures.

With increased complexity quality should be understand as strategic business management function which contributes to realization of mission and vision of organization through implementation of quality concepts and appropriate methods and techniques in all other business processes.

According to size of organization [17, p. 369] quality manager and appropriate organizational form are always under questioning. In large organizations quality manager / coordinator is necessary part in centralized planning and implementation of management systems. Also, there is a need for advisor for quality, person responsible for understanding of interfaces, their harmonization, knowledge transfer and to serve as agent of changes, motivator, philosopher, reporter...Deployment of quality function is performed through Quality Board / IMS, team for process management, team for continual improvement of quality (kaizen) and involvement of employees in quality improvement (community of practice for quality). In very large organizations with more management systems, combined functional and executiv approach could be found (Figure 5).

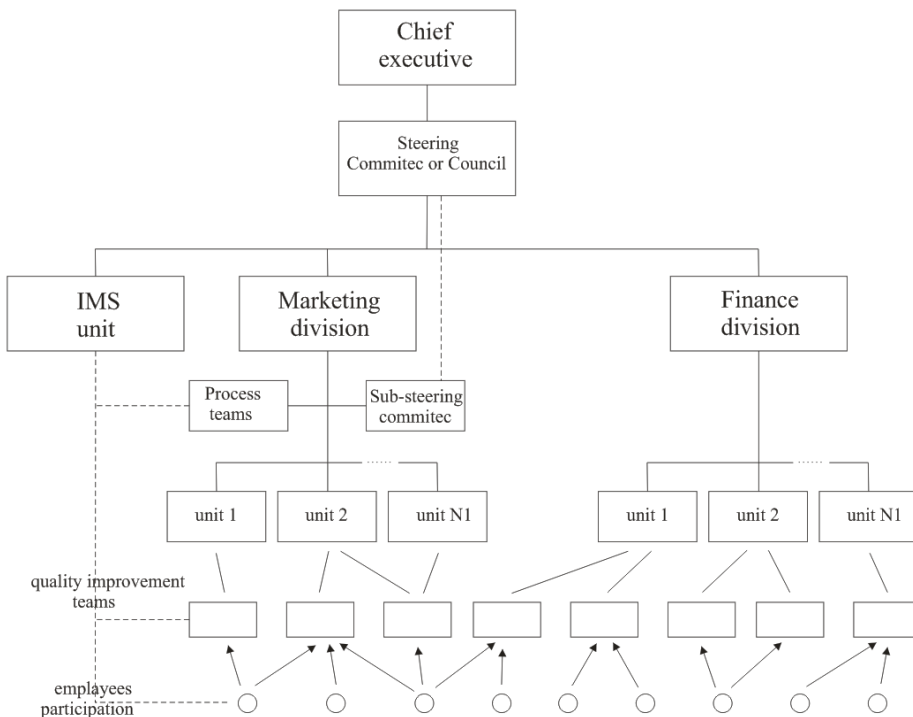


Figure 5. Organization of quality process in typical large organization

The roles of team for processes and team for quality improvement should be separated. The first teams, according to Business Process Management practice, defines structure, responsibilities and goals, activities, inputs and outputs, regulative of processes creating basis for development of process documentation. The second team, with same or similar personal structure, takes care about implementation of methods and tools for improvement of previously defined processes. Both teams function according to concept and practice of team management / engineering which is a part of wider project management concept. Employing this approach quality process becomes creator and very often agent of change in complex business systems.

3. CASE STUDY

In order to prove hypothesis H1 and H2 according to influence of size of organization and number of integrated management systems, research was performed on the sample of 45 Serbian organizations of different size and number of integrated systems. It is important to mention that previous research of authors point to integration problems that influence on different organization of quality function.

Based on the results of research in organization the specific correlations are determinate (Figure 6).

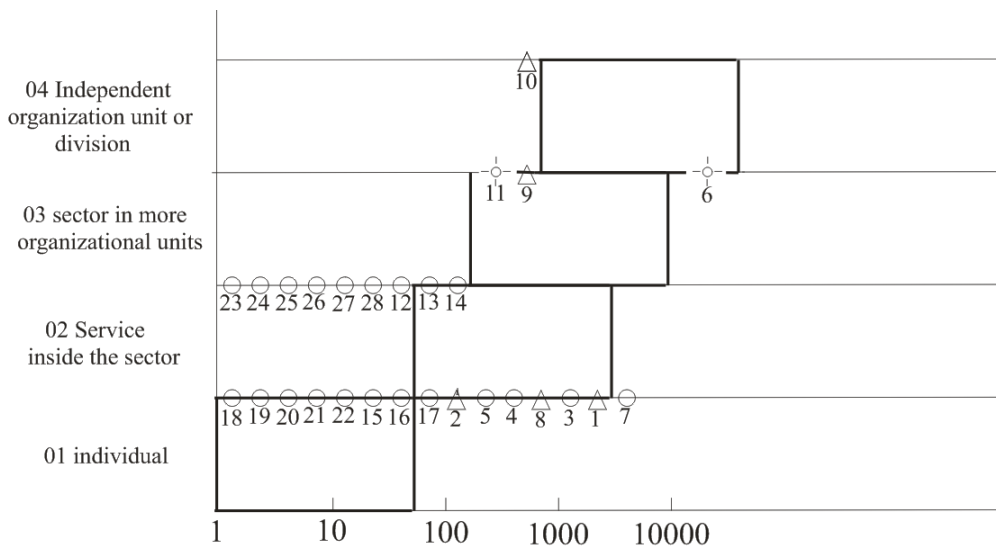


Figure 6. Correlation of organizational form of quality function and number of employees

Based on data presented on the figure 6 we could determinate general correlation between organization level of quality function and size (complexity) of organization as: $ON = f(Z)$, ie. $ON = a_0 + a_1 \cdot \log Z$.

4. CONCLUSION

It is clear that influence of size of organization and number of integrated management systems on organization of IMS processes is very complex and multidisciplinary issue that could be addressed from many different perspectives. In this paper we considered effects of size of the company and partly market environment

and business strategy and their influence on number of integrated management systems.

Based on the presented research the following conclusions are made:

- There is a significant correlation between organizational form of quality function and size of organization,
- There is correlation between organizational form of quality function and number of integrated management systems, and
- Analysis proved constraints based on functional and human resources issues, low implementation of quality philosophy, inter-sector barriers, low commitment and involvement of management and insufficient role of managers as quality leaders.

It is clear that this issue could be addressed from other perspectives which will be topics of further research.

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UTICAJ KVALITETA PROIZVODA NA PROFITABILNOST PREDUZEĆA PRIMJENOM EKSPERTNIH SISTEMA

Rade Ivanković¹, Zdravko Krivokapić², Đurđica Kučinar³

Rezime: U doba globalizacije tržišta, kvalitet proizvoda je najznačajniji faktor konkurentnosti preduzeća. U takvim uslovima, kvalitet proizvoda postaje jedan od značajnih aspekata prilagođavanja preduzeća promjenama u okruženju, a upravljanje kvalitetom jedan od najznačajnijih zadataka menadžmenta preduzeća. U ovom radu je prikazana primjena ekspertnog sistema „ACQUIRED 2.1.“ pri odlučivanju i donošenju odluka u određenim segmentima poslovanja preduzeća; odnosno konkretno, na uticaj kvaliteta proizvoda na pokazatelje uspješnosti preduzeća, kao što su profitabilnost preduzeća i tržišno učešće.

Ključne riječi: Kvalitet, profitabilnost, ekspertni sistemi

IMPACT OF PRODUCT QUALITY ON COMPANY PROFITABILITY BY MEANS OF EXPERT SYSTEMS

Abstract: In the age of globalization of markets, product quality is the most important factor in the competitiveness of enterprises. In such conditions, the quality of the product becomes one of the important aspects of the company to adapt to changes in the environment, while quality management is one of the most important tasks of the company's management. This paper describes the implementation of an expert system "ACQUIRED 2.1." in deciding and making decisions in certain segments of business; more specifically, the impact of product quality on company performance indicators, such as profitability and market share of the company.

Keywords: quality, profitability, expert systems

1. UVOD

Kvalitet proizvoda se, svakim danom, sve više smatra presudnim faktorom konkurentnosti, koji se tiče opstanka i razvoja svakog industrijskog preduzeća, industrijske grane, odnosno industrije kao privredne djelatnosti. Uvođenje sistema

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kvaliteta nije cilj, već sredstvo za ostvarivanje konkurentne prednosti, što je osnovna postavka koncepta upravljanja ukupnim kvalitetom (TQM) u industriji. Kvalitet je jedini faktor koji i kupci i proizvođači smatraju za ključni, bez obzira što i jedni i drugi ponekad imaju različit pogled na njega. [1]

Uticaj kvaliteta proizvoda na rast i razvoj preduzeća podliježe značajnim odlukama menadžmenta od kojih zavisi opstanak preduzeća. Veoma važnu ulogu u odlučivanju i predviđanju poslovanja preduzeća sve više zauzimaju ekspertni sistemi.

Ekspertni sistemi su jedni od najkorišćenijih dijelova vještačke inteligencije u oblasti menadžmenta i odlučivanja. Upotreba ekspertnih sistema je neophodna tamo gdje u jednom ograničenom dijelu oblasti ne postoje algoritamska rješenja i ne postoje potpuno definisana teorijska rješenja, ili tamo gdje postoji teorija, ali praktično nije moguće sve teoretske slučajeve obraditi posredstvom algoritma u zadovoljavajućem vremenskom intervalu.

Ekspertni sistemi se u menadžmentu mogu koristiti da pomažu i u rješavanju usko specijalizovanih problema, evaluaciji i optimizaciji poslovnih eksperimenata ili u rješavanju grupe problema koji se mogu rješavati primjenom određenih tehnika iz raznih naučnih oblasti. Efikasno se mogu primijeniti za planiranje raznih poslovnih i marketinško - logističkih eksperimenata, razvoj metoda izbora najpovoljnijih opcija, predviđanje strukture poslovnog poduhvata, sintezu poslovnog poduhvata i poslovni inženjering i reinženjering. Ekspertni sistemi se posebno i u velikoj mjeri razvijaju i primjenjuju u oblasti upravljanja preduzećima, a posebno se mogu koristiti za čuvanje i upravljanje znanjem. [2]

2. UTICAJ KVALITETA PROIZVODA NA POKAZATELJE USPJEŠNOSTI PREDUZEĆA

Kvalitet proizvoda se definiše kao mjera ili pokazatelj obima, odnosno iznos upotrebne vrijednosti nekog proizvoda ili usluge za zadovoljenje potreba. Neprekidno poboljšanje kvaliteta je možda najmoćniji koncept koji treba da slijedi svako industrijsko preduzeće. To je osnova konkurentnosti preduzeća na tržištu. Kvalitet se smatra svojstvom proizvoda ili usluge koji zadovoljava postavljene zahtjeve. Pojednostavljeno, može se reći da je proizvod ili usluga kvalitetan ako nema nedostataka. Danas se kvalitet poistovjećuje sa profitom, kao najvišim ekonomskim ciljem svake kompanije i uvođenje sistema upravljanja potpunim kvalitetom se smatra opravdanim samo, ako se povećavaju prihodi, smanjuju troškovi i povećava profit.

Prema shvatanjima korisnika, kvalitet proizvoda može biti: [1]

- superioran,
- prosječan,
- inferioran.

U slučaju kada je proizvod *superioran*, profitabilnost preduzeća će biti funkcija visokog tržišnog učešća, viših cijena i lakših uslova pri pregovaranju i sklapanju ugovora o kupoprodaji. Kada je kvalitet proizvoda *prosječan*, cijena mora biti konkurentna, a profit će zavisiti od učešća na tržištu. Ako je kvalitet proizvoda *inferioran*, cijene su obično niske, i oslanjajući se na niske cijene, potrebno je ostvariti veliki promet, a po tom osnovu i uticaj kvaliteta na profit. Međutim, da bi preduzeće znalo da li treba svoje poslove da zasniva na superiornom, prosečnom ili inferiornom kvalitetu proizvoda, treba najprije da ispita kako korisnici proizvoda gledaju na dati

proizvod, da ispita eventualne probleme koje potrošači imaju pri eksploataciji, troškove održavanja konkretnog proizvoda, kao i to kakav nivo kvaliteta odgovara tim potrošačima.

Kvalitet je jedini faktor koji i kupci i proizvođači smatraju za ključni, bez obzira što i jedni i drugi ponekad imaju različit pogled na njega. Troškove definišu faktori poslovanja, dok se cijena formira na osnovu odnosa ponude i potražnje. Važno je da troškovi budu na takvom nivou da preduzeće može profitabilno i konkurentno da posluje sa datom tržišnom cijenom proizvoda.

Konkurentsku sposobnost preduzeća na tržištu u najvećoj mjeri opredjeljuje nivo kvaliteta proizvoda, bez obzira da li se on proizvodi za poznatog ili nepoznatog kupca. Iz tog razloga je veoma važna povezanost između službe prodaje (koja najbolje poznaje tržišne prilike) i službi koje vrše pripremu proizvodnje i koje svojim rešenjima treba da nastoje da što više odoljevaju konkurenciji koja postoji na tržištu. U tom smislu je značajna povezanost tehnoloških sistema gde se konstruktivne zamisli realizuju, sa tržištem datih proizvoda, jer, u protivnom, može doći do porasta troškova za kvalitet, koji bi usloveli i višu cijenu proizvoda, a time i pad konkurentnosti. S druge strane, smanjenje kvaliteta u odnosu na konkurentsku ponudu konkretnog proizvoda, po pravilu, izaziva na otvorenom tržištu progresivno opadanje cijene. Prema tome, potrebno je ustanoviti nivo kvaliteta koji će se uravnotežiti sa cijenom koju tržište nudi za taj kvalitet.

Smanjenje nedostataka na proizvodima (dorade i škarta), a time i povećanje produktivnosti rada radnika, utiče na smanjenje troškova, to jest dovodi do efikasnijeg korišćenja sredstava (imovine) i do povećanja profita. Posmatrano sa stanovišta kvaliteta, oni industrijski proizvodi koji nadmašuju očekivanja kupaca, imaju veću vrijednost od proizvoda konkurenata. Sa povećanjem broja kupovina, povećava se tržišno učešće i rastu prihodi. S druge strane, rast prihoda, bolje korišćenje sredstava i veći profit, doprinose porastu produktivnosti rada. Industrijsko preduzeće može na različite načine postići finansijski uspjeh, ali se dugoročan i zdrav rast preduzeća obezbjeđuje na samo jedan način, i to: kroz povećanje obima proizvodnje i plasmana, i kroz sniženje troškova poslovanja.

Poboljšanje efektivnosti i efikasnosti sistema menadžmenta kvalitetom može pozitivno uticati na finansijske rezultate preduzeća, na primjer:

- interno, smanjivanjem grešaka procesa i proizvoda ili gubitka u materijalu i vremenu, ili,
- eksterno, smanjivanjem grešaka proizvoda, troškova nadoknade u garantnom roku i garancijama, kao i troškova gubljenja korisnika i tržišta. [3]

Da bi preduzeće opstalo na tržištu, ono mora da nađe kupca koji je spreman da plati više nego što je proizvodna cijena konkretnog proizvoda. Razlika između tržišne i ukupne proizvodne cijene predstavlja zaradu, odnosno profit preduzeća, posmatrano u najširem smislu. TQM koncept, pored drugih pogodnosti, omogućava istovremeni porast klase i kvaliteta proizvoda, što vodi ka tome da su kupci spremni da plate veću cijenu za njega, a sa druge strane, dovodi do sniženja proizvodnih troškova, što doprinosi povećanju profita preduzeća.

Ako su naponi na unapređenju kvaliteta u stagnaciji ili opadanju, onda dolazi do obrnutog procesa. Preduzeće doživljava poremećaje, poslovni procesi postaju nestabilni (sa stalnim zastojevima, greškama, škartom), zaposleni postaju demotivisani,

smanjuje se efikasnost i realizacija proizvoda po zaposlenom. U tom slučaju, troškovi poslovanja po realizovanom proizvodu rastu, što uslovljava porast proizvodne cijene proizvoda a, s druge strane, dolazi do opadanja nivoa kvaliteta proizvoda, a time i do pada njegove tržišne cijene. Kao rezultat ovakvih makaza u opadanju nivoa kvaliteta, dolazi do sniženja profita po proizvodu, a ukoliko se pređe kritična tačka i kada proizvodna cijena prevaziđe prodajnu, ulazi se u područje gubitaka.

3. PRIMJENA EKSPERTNOG SISTEMA NA UTICAJ KVALITETA PROIZVODA NA PROFITABILNOST PREDUZEĆA

Ekspertni sistem je jedan od alata u oblasti vještačke inteligencije koji se može uspješno koristiti za ostvarivanje znanja, a razlikuju se od drugih sistema vještačke inteligencije u tome što oni pokušavaju da eksplicitno odnosno nedvosmisleno otjelotvore ekspertize i znanje pomoću softvera. Ekspertni sistemi su takođe označeni kao jedna od najviše komercijalizovanih grana i po broju projekata najviše korišćeni alati vještačke inteligencije [4].

Pod ekspertnim sistemom se podrazumjeva takva vrsta programske podrške ili softvera na računaru, koja u većoj ili manjoj mjeri zamjenjuje čovjeka - eksperta. Ekspertni sistem je u stanju da, na osnovu unesenih podataka i ugrađenih logičkih algoritama (pravila zaključivanja) i tako nastale baze znanja, efikasno pomogne korisniku u rješavanju specifične problematike.

3.1. Ekspertni sistem „ACQUIRE 2.1.”

Ekspertni sistem „ACQUIRE” je apsolutno neprogramski orjentisan. To je alat koji podržava rad u Windows operativnoj sredini. Ima mogućnosti izrade svih elemenata ekspertnog sistema i podržava ulančavanje unaprijed, unazad i kombinovano. Za prezentaciju znanja se mogu koristiti produkciona pravila, akcione tabele ili kombinovana tehnika [5].

Sa kupovinom alata dobija se apsolutno sva neophodna dokumentacija potrebna za edukaciju, detaljan vodič za upoznavanje sa mogućnostima i svim funkcijama ovoga alata. Podržava izradu WEB orijentisanih aplikacija i rada u mrežnoj strukturi. Kao potvrda primjene ovoga alata mogu se navesti i korisnici koji ga efikasno primjenjuju u svojim sistemima i između ostalih to su: Atomic energy of Canada Ltd., British Columbia Assessment Authority, British Columbia Energy, Canadian Space Agency, Consulting and Audit Canada, Council for Scientific and Industrial Research, Metro - McNair Clinical Laboratories i oko sto drugih.

Unutar ovog alata definišu se objekti tokom realizacije ekspertnog sistema u zavisnosti od problema koji treba da se riješi, odnosno u zavisnosti od situacije koju nalažu rezultati. Nakon toga neophodno je dati vrijednosti svakom od objekata i povezati objekte.

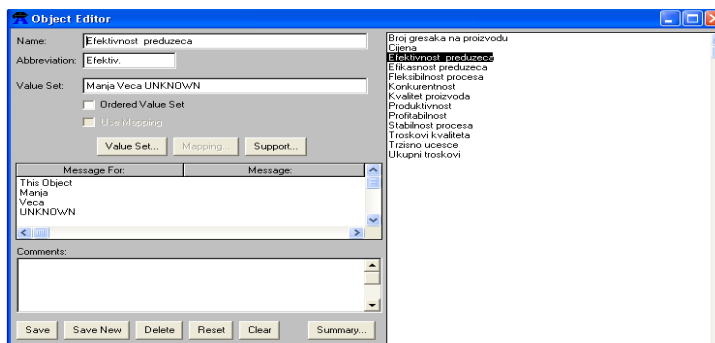
3.2. Primjena ekspertnog sistema „ACQUIRE 2.1.”

U radu je analiziran uticaj kvaliteta proizvoda na profitabilnost i tržišno učešće preduzeća primjenom alata ekspertnog sistema „ACQUIRE 2.1.“. Prvo je neophodno definisati objekte u skladu sa problemom koji se rješav. Za slučaj uticaja kvaliteta proizvoda na profitabilnost i tržišno učešće preduzeća definisani su sledeći objekti:

- kvalitet proizvoda,
- broj grešaka na proizvodu,

- cijena proizvoda,
- troškovi kvaliteta,
- ukupni troškovi,
- efektivnost preduzeća,
- efikasnost preduzeća,
- fleksibilnost procesa,
- produktivnost,
- profitabilnost,
- stabilnost procesa i
- tržišno učešće.

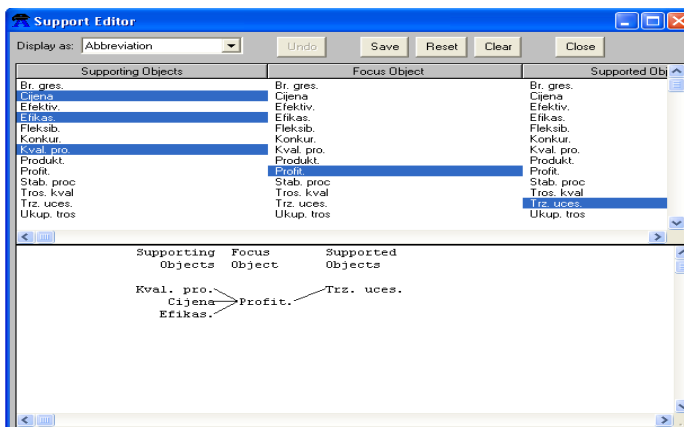
Objekti su definisani u opciji *Object Editor* kao što je prikazano na slici 1.



Sl. 1. Forma za definisanje objekata ekspertnog sistema

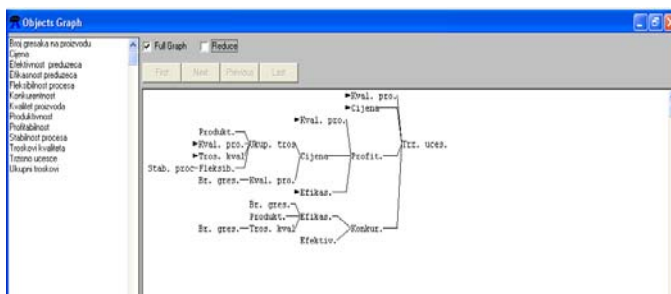
Nakon definisanja objekata, takođe u meniju *Editors*, opciji *Value Set Editor* postavljaju se vrijednosti za definisane objekte. U ovom slučaju, vrijednosti su atributivnog karaktera, odnosno karakterišu povećanje ili smanjenje vrijednosti nekog objekta. Na primjer, kao glavni objekat kvalitet proizvoda je rangiran na tri vrijednosti: inferioran, prosječan i superioran, dok je većina ostalih objekata definisana preko paramenata „manja-veća“ ili „smanjenje-povećanje“.

Sljedeća aktivnost u realizaciji ekspertnog sistema je definisanje povezanosti objekata odnosno njihove međuzavisnosti i stvaranja stabla objekata po kojem će se vršiti odlučivanje, i to u opciji *Support*. Objekti se u dijelu zavisnosti mogu definisati kao „supporting“ objekti ili noseći objekti odnosno objekti koji podržavaju, „focus“ objekti ili oni na koje se usredsređuje aktivnost i „supported“ objekti ili oni koji su podržavani objekti. Upravo u dijelu prozora *Support Editor* se definišu ove međuzavisnosti i to tokom čitave realizacije sistema u zavisnosti od problema koji se pojavljuje i određenog rješenja (slika 2.)



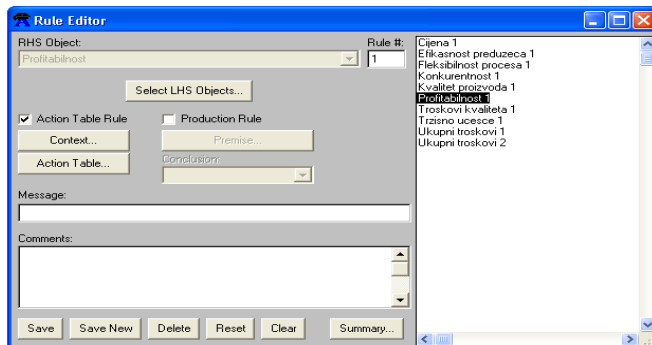
Sl. 2. Forma za definisanje međuzavisnosti objekata

Na kraju se dobija *Object Graph* ili stablo međuzavisnosti objekata po kojem se vrši odlučivanje (slika 3.). Prilikom definisanja međuzavisnosti, postoje slučajevi kada je objekat koji nosi rezultat neke radnje odnosno bolje reći rezultat nekog pravila definisan kao objekat za podršku odnosno kao ulaz u novo pravilo koje se izvršava tek pošto je prethodno pravilo izvršeno. To se može posmatrati kao put ka ostvarivanju meta znanja. Na grafu su ti objekti označeni sa "►" i na taj način se prepoznaju. [5]



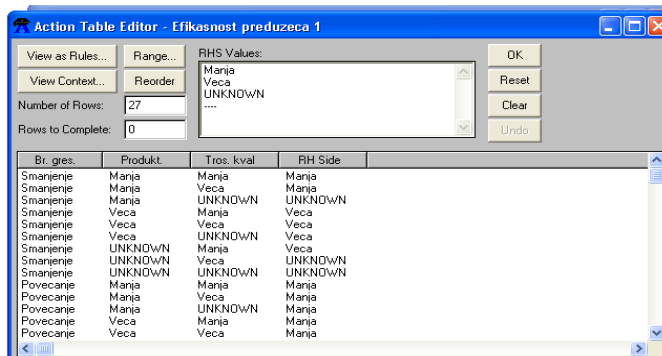
Sl. 3. Stablo međuzavisnosti objekata

Nakon definisanja međuzavisnosti ulazi se u fazu definisanja slučajeva (cases), odnosno grupisanja objekata u zavisnosti od potrebe za izvršavanjem. U okviru slučajeva se definišu stranice ili podgrupe i pripadnost objekata i dodatna podešavanja objekata u okviru ekspertnog sistema. U *Page Editoru* se podešava pripadnost određenom slučaju, u dijelu *Prompt* gdje se unosi tekst koji će se prikazivati na korisničkom displeju, zatim se podešava vrijednost objekata i način unošenja vrijednosti. Nakon toga se na bazi prethodno prezentiranih osnova, ulazi u izgradnju pravila ekspertnog sistema. Ovaj sistem je pravilima baziran i ona su izrađivana primjenom dvije tehnike, i to **akcionih tabela** i **produkcioni pravila** koje su apsolutno kompatibilne i koje su se analizom tehnika za predstavljanje znanja, njihovim specifičnostima i trendova, pokazale kao najprihvatljivije. Ovaj proces se odvija u "rule editoru" programa Acquire (slika 4.)



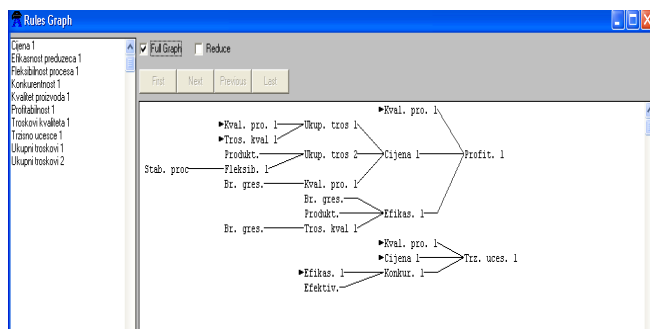
Sl. 4. Forma za izgradnju pravila

Prilikom definisanja pravila selektuje se RHS (eng. Right hand side) objekti i LHS (eng. Left hand side) objekti i u dijelu Action Table se definišu vrijednosti (slika 5).



Sl. 5. Forma definisanja pravila pomoću akcionih tabela

Pravila prikazana pomoću grafikona i njihova međuzavisnost data su na slici 6.



Sl. 6. Forma grafika pravila

Forma grafika pravila pokazuje međuzavisnost pravila, a vidi se da su kao izlazne veličine profitabilnost preduzeća i tržišni utjecaj što je i bila osnovna tema rada.

Dato je deset pravila u kojima se po određenim zakonitostima prožimaju objekti navedeni na početku rada sa programom. Ta pravila su:

1. **Cijena 1** – gdje su kao ulazne veličine dati *ukupni troškovi* i *kvalitet proizvoda* i iz toga slijedi zavisnost cijene od ukupnih troškova i kvaliteta proizvoda;
2. **Efikasnost preduzeća 1** – zavisi od *broja grešaka na proizvodu*, *produktivnosti preduzeća* i *troškova kvaliteta*;
3. **Fleksibilnost procesa 1** – koja je u direktnoj vezi sa *stabilnosti procesa*;
4. **Konkurentnost 1** – zavisi od *efektivnosti* i *efikasnosti preduzeća*;
5. **Kvalitet proizvoda 1** – zavisi od *broja grešaka na proizvodu*;
6. **Profitabilnost 1** – zavisi od *kvaliteta proizvoda*, *cijene* i *efikasnosti preduzeća*;
7. **Troškovi kvaliteta 1** – zavisi od *broja grešaka na proizvodu*;
8. **Tržišno učešće 1** – zavisi od *kvaliteta proizvoda*, *cijene* i *konkurentnosti*;
9. **Ukupni troškovi 1** – koji su zavisi od *kvaliteta proizvoda* i *troškova kvaliteta*;
10. **Ukupni troškovi 2** – u ovom slučaju ukupni troškovi su zavisi i od *fleksibilnosti* i *produktivnosti preduzeća*.

4. ZAKLJUČAK

Ekspertni sistemi danas pronalaze svoju primjenu u skoro svim djelatnostima u kojima klasični programi ne mogu da zadovolje postavljene ciljeve. Pažljivom izgradnjom sistema temeljenog na produkcionim pravilima ili nekog drugog modela baze znanja, ekspertni sistemi su od velike koristi pri odlučivanju. U ovom radu pokazana je mogućnost primjene pri donošenju odluka iz oblasti uticaja kvaliteta na profitabilnost i tržišno učešće preduzeća.

Najveći broj objekata u posmatranom slučaju je zavisan upravo od kvaliteta proizvoda i cijene pa se može reći da su to dva najvažnija i najuticajnija faktora. Između ostalih faktora postoji neraskidiva veza i velika međuzavisnost, pa promjena vrijednosti jednog faktora dovodi i do promjene svih ostalih. U uslovima recesije i svjetske krize pogotovo se velika pažnja posvećuje kvalitetu proizvoda i njegovom unapređenju koji obezbjeđuje veću konkurentnost, a samim tim i veće tržišno učešće, ali je još uvijek cijena presudni faktor i najuticajniji objekat u donošenju odluke.

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PRIMENA ZAHTEVA MEĐUNARODNOG STANDARDA EN 9100:2009 U VAZDUHOPLOVNOJ INDUSTRIJI

Biljana Marković¹

Rezime: Vazduhoplovna industrija predstavlja veoma zahtevan proizvodni sistem, u kome je sistem menadžmenta kvalitetom (QMS) podignut na nivo apsolutnog zadovoljavanja zahteva korisnika. Uspeh na globalnom tržištu podrazumeva kontinuiranu nadogradnju i poboljšanje QMS-a, što u području vazduhoplovstva znači zadovoljavanje zahteva poslednje verzije standarda EN 9100:2009, koji uključuje zahteve ISO 9001:2008, u 100% obimu, (što čini 60% zahteva ovog standarda), kao i specifične dodatne zahteve (40%) u dizajnu, razvoju, proizvodnji, kapacitetu i uslugama u vazduhoplovnoj industriji. Ovaj rad opisuje proces poboljšanja i tranzicije QMS-a za vazduhoplovne kompanije, kroz primenu zahteva standarda EN 9100:2009.

Cljučne reči: QMS, zahtevi korisnika, EN 9100

APPLICATION OF REQUIREMENTS OF INTERNATIONAL STANDARD EN 9100:2009 IN AIRSPACE INDUSTRY

Abstract: Aerospace industry represents a quite demanding production system where Quality Management System (QMS) is upgraded to the level of the absolute satisfaction of customers' requirements. Success on the global market implies continual upgrade and improvement of QMS, which in the domain of aerospace industry represents satisfaction of requirements of the last version EN 9100:2009 Standard. Mentioned standard includes ISO 9001:2008 requirements in total scope (which represents 60% of requirements of this Standard) and additional specific requirements of QMS (40%) in design, development, production, installation and servicing in Aerospace industry. This paper gives description of improvement and transition process of QMS in aircraft companies, through implementation of EN 9100:2009 Standard requirements.

Keywords: QMS, customer's requirements, EN 9100

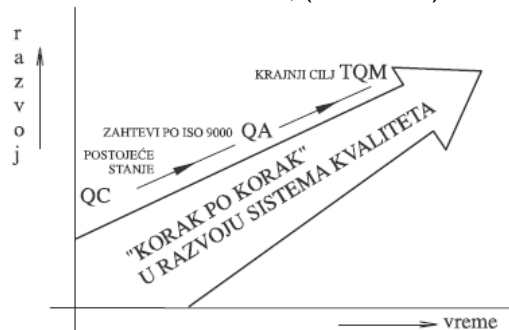
1. UVOD

Vazduhoplovna industrija predstavlja veoma zahtevan sistem, u kome je sistem menadžmenta kvalitetom (QMS) podignut na nivo apsolutnog zadovoljenja zahteva korisnika. Ovo znači da uspostavljen QMS koji zadovoljava zahteve serije standarda ISO 9000 (9001:2008) predstavlja samo potreban, ali ne i dovoljan uslov za

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demonstriranje sposobnosti kompanije da bude konkurentna na tržištu i da zadovolji zahteve potencijalnih korisnika. Uspeh na globalnom tržištu podrazumeva nadgradnju i poboljšanje QMS-a, što u području vazduhoplovstva znači zadovoljanje zahteva standarda EN (AS, JISQ) 9100, koji uključuje zahteve sistema menadžmenta kvalitetom serije ISO 9000 (9001:2008), u 100% obimu, (što čini 60% zahteva ovog standarda), kao i specifične dodatne zahteve (40%) QMS-a u vazduhoplovnoj industriji.

Teorija i praksa sistema menadžmenta kvalitetom (QMS-a) je doživela intenzivan razvoj i promene tokom prethodnih 15 god. Evolucija serije standarda ISO 9000 je uticala na evoluciju dokumenata QMS-a koji moraju zadovoljiti zahteve propisane standardima, opisati procese i približiti teoriju praksi, kako bi njena upotreba bila svrsishodna. Ovo se naročito odnosi na sferu vazduhoplovstva, gdje su zahtevi standarda EN 9100 (AS, JISQ) strožiji i obimniji, po svim tačkama serije ISO 9000. Međunarodni standard EN 9100 pokazuje sposobnost organizacije da dosledno obezbeđuje proizvod, koji zadovoljava zahteve korisnika i odgovarajućih propisa, zadovoljstvo korisnika efektivnom primenom QMS-a, uključujući kontinuirano poboljšanje sistema, te kao takav nema alternativu, (Slika br.1.).



Sl. 1. Razvoj sistema kvaliteta

2. PERIOD PRELASKA (TRANZICIJE)

30-mesečni tranzicioni period za sistem menadžmenta kvalitetom (QMS) vazduhoplovne i odbrambene industrije (Aviation, space and defence industry AS&D) počeo je 1.1. 2010. god. U Americi su dokumenta QMS-a, koja se odnose na ovu oblast, označena kao AS 91XX, publikovana na sledeći način:

- AS 9100:2009, Rev C – Zahtevi za AS&D organizacije (publikovano u januaru 2009. god.);

- AS 9110:2009, Rev A - Zahtevi za vazduhoplovne organizacije koje se bave održavanjem, (publikovano u junu 2009.god.);

- AS 9120:2009, Zahtevi za AS&D distributere (publikovano u junu 2009. god.)

Vreme od kad su AS&D standardi izdati u junu 2009. god. pa do početka tranzicionog perioda, dopustilo je AS&D korisnicima da postanu bliži sa novim i revidiranim (izmenjenim) AS (EN) 91XX zahtevima, pre nego dođe do njihovog uvođenja, prema izmenjenoj šemi izdatoj u martu 2010. god. Tim za standrad 91XX je razvio materijal za podršku, koji uključuje štampani materijal, prezentaciju izmena, najčešće postavljana pitanja, razjašnjenje i reference članaka, koji se mogu pronaći na međunarodnom IAQG (International Aerospace Quality Groupe) website-u (www.iaqq.org).

Period tranzicije, koji je počeo 1.1. 2010. god., sa odobrenim materijalom za obuku proveravača, završen je, kao proces, u aprilu 2010. god. Posle toga, svi proveravači iz ove oblasti su morali biti uključeni u odobrenu obuku za proveravače, koja je počela 1.5. 2010. god., nakon čega su registraciona tela započela akreditaciju prema novim zahtevima, a tek nakon toga su organizacije mogle biti sertifikovane prema revidiranim AS (EN) 91XX QMS standardima i ponovo napisanom standardu AS (EN) 9101, (Slika br.2.).

Od svih proveravača sertifikacionih tela (vazduhoplovni proveravači i proverivači sa iskustvom u vazduhoplovstvu) je zahtevano da pohađaju i polože IAQG odobrenu obuku, priritetno, radi kompletiranja sertifikacione provere prema verziji 2009 standarda AS (EN) 91XX. Odobrena obuka uključuje online module standarda AS (EN) 91XX za obuku i 4-dnevnu obuku vođenu od strane trenera (predavača).

Cilj IAQG odobrene obuke je obrazovanje proveravača o zahtevima standarda AS (EN) 91XX i AS (EN) 9101 metoda za proveru, kao i smanjenje varijacija u pogledu provera. Od svih sertifikacionih tela i njihovih proveravača je zahtevano da završe obuku pre jula 2011. god., ukoliko žele da nastave izvoditi AS&D provere.

Neki važni datumi unutar 30-mesečne tranzicione šeme bili su:

- 1.7. 2011. Od ovog datuma organizacije su mogle biti inicijalno sertifikovane prema revidiranim AS (EN) 91XX standardima. Nakon ovog datuma organizacije više nisu mogle biti inicijalno sertifikovane prema prethodnim verzijama AS (EN) 91XX standarda.
- 1.7. 2012. Od ovog datuma organizacije su morale završiti njihovu AS (EN) 91XX tranziciju, putem nadzornih ili resertifikacionih provera.



Sl. 2. AS (EN) 91XX plan tranzicije

3. NOVINE U PROCESU PROVERE

AS (EN) 9101 standard za proveru, koji je obavezujući za korištenje tokom perioda provere od treće strane, je potpuno izmenjen (ponovo napisan) od strane internacionalnog tima od 13 članova, iz 6 različitih zemalja, 8 kompanija članica IAQG i 4 sertifikaciona tela.

Njihov cilj je bio da revidiraju standard AS (EN) 9101 u skladu sa revizijama AS (EN) 91XX i ISO 17021, preispitaju sadržaj standarda, identifikuju svaku dodatnu

potrebu korisnika i rekonstruišu standard prema procesno zasnovanom pristupu provere i procene u organizacionim sistemima QMS-a.

Revidirani AS 9101 standard zamenjuje prethodne verzije standarda AS (EN) 9101 – Vrednovanje QMS-a, AS (EN) 9111 – Vrednovanje QMS-a za organizacije koje se bave održavanjem i AS (EN) 9121 – Upitnik i check lista za vrednovanje QMS-a.

Prethodna verzija ovog standarda vodila je ka neželjenim rezultatima, jer je kočila procesni pristup, fokus proveravača je bio na popunjavanju check liste i oduzimala vreme na nepotrebne stvari, van same provere.

U cilju dodatne usaglašenosti sa zahtevima, glavna tema ponovo napisanog standarda AS (EN) 9101 je vrednovanje efektivnosti procesa. ISO 9001:2005 definiše efektivnost kao produžetak planiranih aktivnosti koje su realizovane i planiranih rezultata koji su postignuti. Izveštaji o procena efektivnosti procesa se koristi kao dokument procesa realizacije proizvoda, koji uključuje detalje procesa, metode efektivnosti procesa i vrednovanje efektivnosti procesa.

Osnovni način merenja efektivnosti QMS-a je zadovoljstvo korisnika. Imajući to na umu, AS (EN) 9101 uključuje i dodaje fokus na merenje performansi i korištenje povratne sprege od korisnika, razmatrajući organizacione performanse, koje se koriste kao ulaz (input) za procesno zasnovane provere. Priroda check liste iz prethodne verzije AS (EN) 9101 je uklonjena iz ponovo napisanog AS (EN) 9101, preko sistema bodovanja i definisanja ključnih karakteristika.

Od sertifikacionih tela se zahteva da koriste AS (EN) 9101 radi zapisivanja dokaza nalaza (objective evidence record – OER), na njihovoj vlastitoj dokumentaciji, koja ide u susret zahtevima OER. Da bi se pokazala pokrivenost, razvijena je forma QMS matrice procesa, u korelaciji procesa sa zahtevima AS 91XX.

Prema tome, namera AS (EN) 9101 je razvijanje i poboljšanje procesa provere za vrednovanje procesno zasnovanog sistema upravljanja kvalitetom, koji je u skladu sa ISO 17021 i sastoji se od:

- Procesno zasnovanog prikupljanja informacija
- Procena ili analiza i planiranja provere
- Razvijanja metoda i tehnika provere zasnovanih na performansama procesa i procesnom pristupu
- Mogućnosti prikupljanja objektivnih dokaza usaglašenosti procesa i efektivnosti
Glavna namera izmena je:
- Kreiranje novog dokumenta koji pokriva AS (EN) 9100, AS (EN) 9110 i AS (EN) 9120
- Eliminisanje bodovanja i definisanja ključnih zahteva
- Korištenje podataka i povratne sprege od strane QMS-a razmatrane organizacije, kao ulaz u procesno orjentisanu proveru
- Uključivanje određivanja efikasnosti, kao dodatka usaglašenosti
- Stavljanje naglaska na merenje performansi
- Uvođenje zapisa objektivnih nalaza

4. KAKO ISPUNITI IZMENJENE ZAHTEVE?

Ono šta nije promenjeno u ponovo napisanom standardu AS 9101 je određivanje usaglašenosti QMS-a sa statutarnim i regulatornim zahtevima, zahtevima korisnika i standardnim zahtevima AS 91XX. Bilo kakva neusaglašenost otkrivena tokom provere mora biti dokumentovana u odgovarajućem zapisu o neusaglašenosti.

Zasnovano na informacijama prikupljenim tokom provere, proveravači moraju napisati zaključke o usaglašenosti i efektivnosti QMS-a date organizacije. Ovi zaključci moraju biti dokumentovani na standardnoj AS 91XX formi zapisa provere, koja se koristi za nivo jedan i nivo dva inicijalne sertifikacije, nadzorne provere, resertifikacione provere, specijalne provere korisnika, zahteve zainteresovanih strana, promene obima sertifikacije i transfera sertifikacije.

Dakle, šta ponovo napisan standard AS 9101 znači za organizaciju koja se sertifikuje prema novim AS 91XX zahtevima?

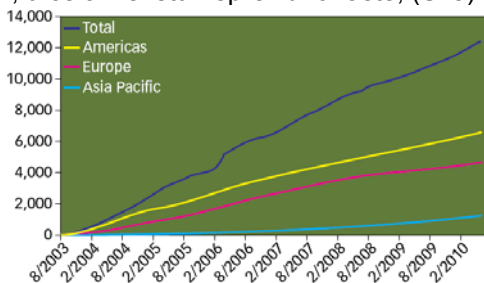
Osnovno, to znači da oni moraju:

- Demonstrirati usaglašenost sa standardom;
- Prikazati kartu procesa (identifikacija procesa, sekvence i interakcije);
- Objasniti merenja procesa, napr. ko preispituje podatke, da li su ciljevi definisani i postignuti, da li su merenja operativna i kako si ti podaci mogu koristiti;
- Pokazati aktivnosti koje se preduzimaju kada zahtevi o usaglašenosti i zahtevi za isporukom na vreme nisu postignuti;

Kratko rečeno, prednost ponovo napisanog AS 9101 uključuje naglašavanje procesnog pristupa unutar same organizacije, premeštanje resursa od kompletiranja upitnika do određivanja i dokumentovanja usaglašenosti i efektivnosti procesa i obezbeđivanje korisnih informacija tokom razmatranja performansi procesa i njihove istorije. Standard predstavlja značajnu prednost u proverama kvaliteta u vazduhoplovstvu.

Iako je provera efektivnosti uvek bila cilj standarda, kao i očekivanje kupca, u stvarnosti većina proveravača fokus stavlja na usaglašenost procesa sa proceduralnim zahtevima i prelaze preko rezultata procesa. Korisnici su se dugo žalili na sertifikovane proveravače, da oni ne stavljaju akcenat na elemente provere koji se odnose na pokazatelje performansi procesa, tj. na isporuku na vreme ili kvalitet proizvoda.

Zato izmenjeni standard tretira performanse procesa korišćenjem novog pristupa, a broj kompanija u oblasti vazduhoplovstva i odbrambene industrije, koje se sertifikuju na ovaj način, u celom svetu neprekidno raste, (Sl.3).



Sl. 3. Broj sertifikovanih korisnika

5. NOVI ZAHTEVI STANDARDA EN 9100:2009

Standardi AS (EN) 9100/9110/9120, koji su bazirani na ISO 9001, sa dodatnim zahtevima za AS&D industriju, nastoje da zadovolje potrebe ulagača i poboljšaju IAQG strategiju. Osnovni dodaci i izemene se odnose na:

7.1.2. Upravljanje rizikom – novi zahtevi za implementacijom procesa upravljanja rizikom na projekte, proizvode, odgovornost, kriterije, prihvatljivost;

7.1.1. Upravljanje projektima – novi zahtevi za planiranjem i upravljanjem realizacijom proizvoda, na strukturiran i kontrolisan način;

7.1.3. Upravljanje konfiguracijom – zahtev je pomeren iz tačke 4.3. u 7.1. i dodati su detalji za različite aktivnosti koje moraju biti pokriveno;

7.1.4. Upravljanje transferom (prebacivanjem) posla – zahtev pomeren iz tačke 7.5. (proizvodnja) u tačku 7.1., kako bi se naznačila potreba planiranja i kontrolisanja aktivnosti u procesu transfera;

Pojmovi: kritične tačke, posebni zahtevi i ključne karakteristike – ključne karakteristike ostaju zahtevane, ali koncept identifikacije specijalnih zahteva (bilo od strane korisnika ili organizacije), koji zahteva dodatnu kontrolu, (napr. upravljanje rizikom) se translata u kritične tačke, koje se mogu nastaviti do ključnih karakteristika, je nov;

Performanse kvaliteta i isporuka na vreme – dodat je zahtev za «usaglašenost proizvoda» i «isporuku na vreme», koji trebaju biti mereni i zahtev za preduzimanje aktivnosti ukoliko planirani rezultati nisu ostvareni. Namera je da sa obezbedi lančana veza između QMS-a i performansi organizacije.

5.1. Upravljanje rizikom, specijalni zahtevi, kritične tačke

Novi AS (EN) 9100 zahtev vezan za upravljanje rizicima generiše veći interes unutra i van zajednice korisnika AS&D.

Upravljanje rizikom je jedan od dodatnih koncepata koji su uvedeni u novu verziju AS (EN) 9100:2009. Koncept može biti primenjen unutar QMS-a, kroz preispitivanje od strane rukovodstva, kada se procenjuju zahtevi za resursima, kada se planiraju i provode interne provere.

Namera AS (EN) 9100:2009 je da uvede koncept upravljanje rizikom u poglavlje 7, planiranja realizacije proizvoda. Autori standarda su postavili ovaj dodatni zahtev u tačku 7.1.2, zato što je upravljanje rizikom, kao i planiranje, jedan iterativni proces koji se dešava kroz realizaciju proizvoda i životni ciklus proizvoda. Koncept upravljanja rizikom tokom realizacije proizvoda može biti kategorisan putem rizika koji su spojeni sa zahtevima standarda AS (EN) 9100 za realizacijom proizvoda i rizikom proizvoda.

Upravljanje rizikom nije potpuno nov zahtev u okviru AS (EN) 9100, zato što tačka 7.2.2.d) već zahteva vrednovanje rizika tokom preispitivanja zahteva vezanih za proizvod. Uključivanje tačke 7.1.2. u AS (EN) 9100:2009 je sledeći logičan korak u proširivanju razmišljanja o upravljanju rizikom, tokom cele realizacije proizvoda, u poglavlju 7.

Razmatranje rizika je direktno prozvano u sledećim tačkama AS (EN) 9100:2009:

7.1.1.- upravljanje projektom

7.1.2. - upravljanje rizikom

7.2.2. - preispitivanje zahteva vezanih za proizvod

7.4.1. - proces nabavke

Rizici proizvoda su primenjivi preko realizacije proizvoda, sa uvođenjem koncepta specijalnih zahteva i kritičnih tačaka. Specijalni zahtevi su oni koji su određeni od strane korisnika ili organizacije, a za koje postoji rizik da ne budu postignuti. Faktori koji se mogu uključiti su: kompleksnost proizvoda ili procesa, prethodno iskustvo ili zrelost procesa.

Primeri specijalnih zahteva uključuju zahteve za performansama, nametnutim od strane korisnika, ograničeni industrijskim mogućnostima ili zahtevi definisani od strane organizacije, ograničeni njihovim tehničkim ili procesnim mogućnostima. Procena ovih zahteva je povezana sa definicijom iz tačke 7.2. gde se definišu i preispituju zahtevi vezani za proizvod.

Specijalni zahtevi se presipituju i, ako je potrebno, prevode u kritične tačke, uključujući ključne karakteristike, tokom procesa konstruisanja i razvoja, definisanih u tački 7.3.

Kritične tačke su tačke koje imaju značajan efekat na realizaciju i upotrebu proizvoda. Ovo uključuje sigurnost, performanse, oblik, postavljanje, funkciju, produktivnost i radni vek. Kritične tačke zahtevaju specifične aktivnosti koje treba da osiguraju njihovo adekvatno upravljanje. Ovo nije nov koncept u AS&D industriji, gde postoje iskustva u ovoj oblasti, kao što su kritične tačke sa stanovišta sigurnosti, stanovišta loma i ključne karakteristike.

Ove kritične tačke se identifikuju i upravljaju kroz ugovaranje i proizvodne aktivnosti unutar firme, a zahtevi se dodaju na narudžbe, zahtevajući od isporučioaca da ugradi dodatno upravljanje (kontrolu), uključujući upravljanje varijacijama (kao što je definisano u AS (EN) 9103), kada je primenjivo.

Podisporučioци retko kreiraju specijalne zahteve ili kritične tačke. Oni obično dobijaju zahteve za kritičnim tačkama od korisnika, putem informacija za nabavku.

Identifikacija, nadzor, merenje i analiza specijalnih zahteva i kritičnih tačaka su uključeni u proces upravljanja rizikom.

AS (EN) 9100 ne obavezuje na propisan način kako upravljanje rizikom treba biti sprovedeno, mora biti uspostavljen samo siguran aspekt, implementiran i održavan na odgovarajući način, u skladu sa tačkom 7.1.2. standarda.

Formulacija upravljanja rizikom u AS (EN) 9100:2009 definiše korake, sekvence i interakcije organizacionih potreba koje trebaju biti sprovedene, kako bi se rizikom propisno rukovalo. Ovaj proces koji se odnosi na rizik može biti primenjen na različite načine, zavisno od pristupa poslu i integrisan u ključne tačke procesa realizacije proizvoda u datoj organizaciji.

6. ZAKLJUČAK

Krajnji cilj u razvoju QMS-a svake organizacije je dostizanje TQM-a, kao upravljanja u pristupu kontinualnog unapređenja procesa u organizaciji, koji se izvode na bazi definisane strategije, vizije i misije, okrenute potpunom zadovoljenju zahteva korisnika, sa ciljem postizanja svetske klase kvaliteta proizvoda.

Najveći problem u provođenju strateških odluka o praćenju savremenih tokova na polju QMS-a je promena svesti rukovodstva i svih zaposlenih o potrebi angažovanja raspoloživih resursa na realizaciji odluke. Jedino rešenje je edukacija i prihvatanje globalne potrebe za učenjem kroz čitav život.

Put na realizaciji projekta uvođenja zahteva standarda AS (EN) 9100 u QMS bilo koje vazduhoplovne kompanije ili kompanije iz oblasti odbrambene industrije, nije

niti lak, niti kratak, kao i proces uvođenja izmena koje neophodno unose inovirane i revidirane verzije standarda.

Kroz razmatranja data u ovom radu, nemera autora je bila da podvuče ključne tačke koji predstavljaju novine u revidiranim verzijama standarda AS (EN) 9100, te pomogne potencijalnim korisnicima u njihovoj primeni, proveravačima koji se bave vazduhoplovnim zahtevima, objašnjenjem tranzicionog perioda i namera izmena zahteva standarda.

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INTEGRATED SYSTEMS MANAGEMENT IN SMALL AND MEDIUM ENTERPRISES

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Abstract: Appearance of a number of management systems with various and sometimes divergent demands, demands for revise of optimal strategy on implementation of these standards in small and medium-sized enterprises (SMEs) and the attempt on their integration into integrated management system are suggested even more. Firstly question on choice and reasons for implementation of standards is raised. Management and employees expect benefits on the implementation and they pass and minimize the implementation barriers.

Basic concept on integrated management system (IMS) into SMEs and analyse on reasons and advantages at IMS implementation are presented in this paper.

Keywords: Quality, Environment, Safety, IMS, SMEs

1. INTRODUCTION

In previous period theory and practice of management have been rapidly changed, supplemented and sometimes excluded. The result is appearance of a great number of management concepts which acronyms cannot be recognized even by experts of this field (for example TPM, DDM, MBP, MBO, HRM). Development of movements on quality and environment in the 90's caused appearance of the management quality system (QMS - ISO 9000:2000), environmental management system (ISO 14000), management system for health and safety at work (ISO 18000), risk management system (ISO 17000) and other being under preparation.

As much as any standard attempts to explain that these standards are applicable equally to any organizations regardless their activities, size and structure, anybody, being run upon IMS, is cleared that there are no standard elements that may neither easily or effective be applied to activity and size of the organization. Such is also confirmed by numerous publications of ISO organizations and other international quality organizations for application as of QMS and SMEs as of standards in various

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activities to be helpful to these organizations to pass problems occurring with standards applied and to reach internal and external benefits.

This paper analyzes benefits (reasons and advantages) of IMS into SMEs.

2. SME – DEFINITION

Micro, small and medium-sized enterprises (SMEs) are socially and economically important, since they represent 99 % of all enterprises in the EU and provide around 65 million jobs and contribute to entrepreneurship and innovation. However, they face particular difficulties which the EU and national legislation try to redress by granting various advantages to SMEs. A legally secure and user-friendly definition is necessary in order to avoid distortions in the Single Market. The revision ensures that enterprises which are part of a larger grouping and could therefore benefit from a stronger economic backing than genuine SMEs, do not benefit from SME support schemes. The increase of the financial ceilings is designed to take into account subsequent price and productivity increases since 1996, however the headcount ceilings remain fixed (Table 1).

Table 1. Type of SMEs [4]

Enterprise category	Headcount	Turnover or	Balance sheet total
medium-sized	< 250	≤ € 50 million	≤ € 43 million
small	< 50	≤ € 10 million	≤ € 10 million
micro	< 10	≤ € 2 million	≤ € 2 million

3. INTEGRATED MANAGEMENT SYSTEM (IMS)

In the organization theory there is a basic rule:

1. Firstly the decomposition of various systems is done,
2. Integration key elements are single out and
3. Integration of decompounded systems is done.

What is common i.e. what are the key integration elements for the management systems – QMS, EMS, OHSAS, HACCP etc? Firstly, they are as follows:

- the same stakeholders, namely interest groups (employees, management, business partners, inhabitants, state, shareholders),
- the same processes in organization and environment,
- the same methods and techniques, theories and practice of management,
- similar concept of management in processes,
- similar resource management,
- identical concepts for measurement, analyses and improvement,
- the same responsibility of the leadership and
- the same vision, mission and business policy of organization.

Addition to common elements of IMS, there are also elements that are specific to any of partial management systems (sample – figure 1, for basic IMS).



Fig. 1. Basic IMS

The following question is propounded: which of the previous integration systems should be “the core” of integration? The response depends on the following: already implemented management system in the organization, activity field, i.e. type of documented business processes, dominant demand of stakeholders.

However, since the QMS according to ISO 9000 is documented in its application and the used process approach demonstrates a good base for integration, it is proposed that QMS becomes “the core of integration” in most cases. Therefore other solutions of “the core of integration”, due to specific business processes and demands of stakeholders, should be considered.

QMS has been accepted in most countries as their national quality system standard. There is no any “special” standard for SMEs, but many researches show that a large and growing number of small and medium-sized enterprises have already accepted the ISO 9000 standards.

There are many common features of management systems for quality, environment, and safety (Figure 2).

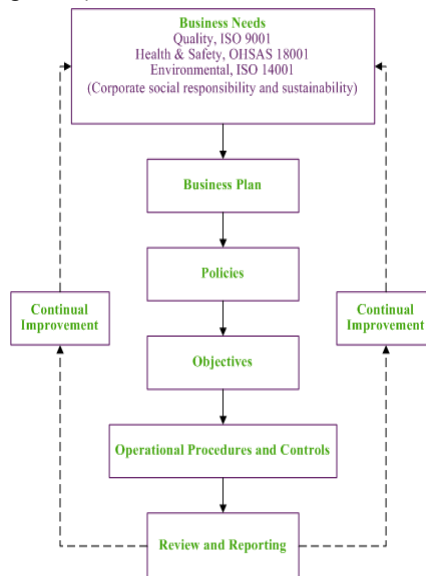


Fig. 2. Flow chart of integration process

In theory and practice there are some integration models. Mr. Seghezzi [7] indicates the models, being based on cross-processes, that include TQM models and process models (as in ISO 9000:2000), form a good integration base since the approaches, such as ISO 14001, ignore the scope and culture. Having followed this concept Mr. Wikinson and Mr. Dale developed the integrated organizational management system model for quality, environment, health and safety that include fields such as leadership and culture.

Euro Info Centre EIC/IT 378 and Research Centre for Quality and Environment of the University of Padova are to be the most frequently guide for implementation IMS in SMEs.

The main goals of the guide were (and at the present are): to stimulate SMEs to implement environmental management systems (EMS); to demonstrate the possibility to integrate EMS with other management systems (quality and safety); to improve the access of the companies to the IMS; to improve the knowledge of the companies on the sustainable development bases.

The intent of the IMS guide is to inform on the convenience and on the way to introduce an EMS when quality and/or safety management systems are already established in an enterprise.

This guide, far from being a substitute for the reference standards, is a support document for SMEs which, independently of their initial situation (ISO 9001 and/or ISO 14001 certification, EMAS registration, no certification, etc.) want to take advantage of the synergies and many points of contact between environment, quality and safety management systems.

The integrated management system guide has realised contents as shown [5]:

- 1. Quality systems,**
- 2. Environmental management systems,**
- 3. Management systems for health and safety at work,**
- 4. Model for an Integrated Management System** (Management responsibility, System resources, Product realisation, Measurement, analysis and improvement).

Beside this guide the BSI Management systems published **PAS 99**. Document is a Publicly Available Specification of common requirements for management systems that can be used as a framework for an integrated management system.

PAS 99 takes account of the six common requirements for management systems standards outlined in ISO Guide 72; guidance document and also follows the Plan, Do, Check, Act approach of all the major management systems requirements standards.

These **6** common requirements are:

- 1. Policy,**
- 2. Planning,**
- 3. Implementation & Operation,**
- 4. Performance Assessment,**
- 5. Improvement,**
- 6. Management Review.**

Figure 3 illustrates model IMS.

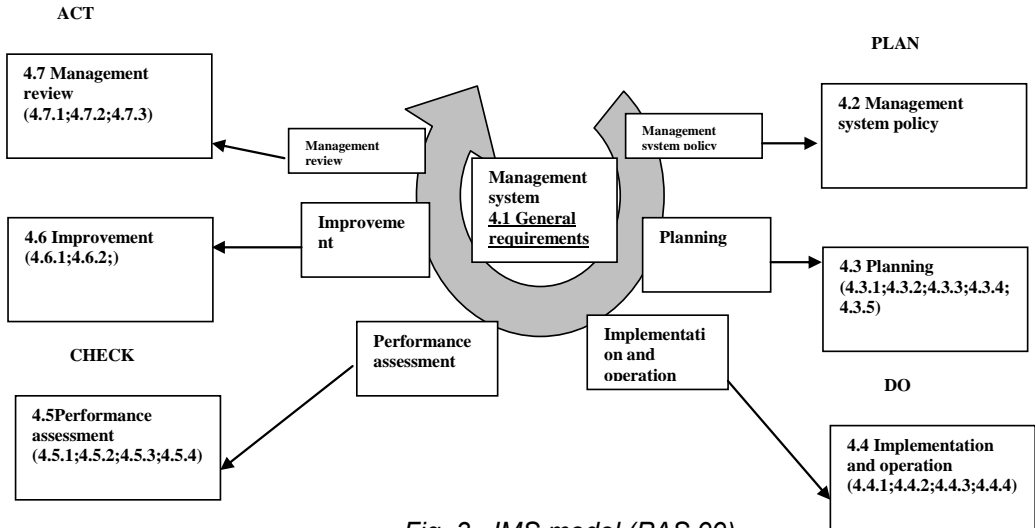


Fig. 3. IMS model (PAS 99)

4. REASONS TO ACCEPT IMS

Appearance of external pressure by any state shown through the pass of a number of laws and regulations and through extremely stern punishments for any errors in their implementation, then strengthen pressure of public requiring healthy and safe working environment, they all impel enterprises to revise their practice in implementation of management system. When added other reasons such as costs for service on consulting and evaluation, time needed to prepare certification and limited human resource it is obvious that some companies must find their own optimal way for parallel and cheap fulfillment of all external and internal requests.

The response is in implementation of integrated management systems, therefore the systems directed towards improvement of work processes in all fields being important for any enterprise.

The first step for establishment of integrated systems is to stipulate regular hierarchy of demands and to expect considered parties being needed for the system. To comply with the principle on risk minimization it should be started with a state as a considered party that may cause the highest damage to a company and than should include the others.

Thus the next hierarchy of demands is reached: Demands of laws and other regulations (law on environment protection, law on work protection, work legislations etc.), Demands of users, needs of enterprise, Demands and needs of social community, (surrounding where an enterprise operates), Demands of standard for management systems.

In addition, SMEs take part in one or more supply chains (SC - Supply Chain), where any buyer in SC has its own corresponding demands. These demands influence the SMEs operation i.e. the needs of the buyers of constant and high quality products and strong management that provides all these mentioned. To that effect SMEs are more and more required, as a condition for business cooperation, to implement the quality management system (ISO 9001:2000) or environmental management system

(ISO 14001). If the production program refers to the nutrition products, any organization should implement HACCP, and in case of work in risk production conditions, ISO 18001 (safety and protection at work) should be implemented. It is obvious that in SMEs the core of business activities should be “moved” from the production management onto management systems providing fulfillment of these and more complex demands of buyers. Large companies also play an important role in starting the SMEs up to accept innovations. This is the result of the fact that most of SMEs are typically included into business to business activities.

Other reasons may also start small and medium-sized enterprises up to integrate the standards. These starters have been already identified by many authors and it firstly refers to the important role of stakeholders.

Partial management systems are concentrated onto discrete fields being often in mutual contrast, thus some authority conflicts in organization may occurred their application.

Reasons for IMS implementation are also the expected benefits relating primarily to efficiency.

5. BENEFITS OF SMEs IN ACCEPTANCE OF IMS

SMEs may reach a number of benefits if accepts IMS. The benefits are divided into two categories: internal and external ones. The internal benefits are connected to internal function and processes of a company while external are connected to external company activities. More, internal benefits may be divided into three categories: organizational benefits, financial and benefits for employees. Similarly, external ones are grouped into commercial, communication and quality/environmental/safety benefits.

Improvement of internal efficiency and quality of the management is the first internal result that be reached by any small or medium-sized enterprise. That may be achieved for example, if three functional departments are fuzzed to one and by harmonizing organizational structure containing similar elements.

The next one is that integrated system permits equality in management methodology. The integrity of system results in reduce of unclear boundaries between individual systems and in expand of horizon above functional level any of individual system, sharing information across traditional organizational boundaries.

Many standards share the same elements; therefore their integration will enable a company to avoid duplication of system procedures and to eliminate overlap of efforts at identification of danger, development and maintenance of requested control and audit.

Finally, many authors notice reduce in volume of company documents and creation of usual forms that are more easily used by more operators as important material benefit.

Irrespective of above mention organizational benefits, the SMEs may also reach financial benefits. Cost savings that arise in reduction of the frequency of audit are already confirmed as in theory as in practice. However, audit may not be reduced to one audit only, since the program of internal financial audit will be necessarily enlarged to ensure efficiency of integrated procedures. Financial benefit will be reached by improvement of results on minimization of external certification costs over single certification audit and as a result of increase of data and management staff.

Acceptance of EMS by small and medium-sized enterprises increases motivation of employees, awareness and qualification. This argument may be applied to

IMS because it does not protect external surrounding only but it protects internal parameters over management systems for health and safety.

Thus, employees may enjoy better and more safety conditions that create better image of any company and improve relations among employees and management. Table 2 sums internal benefits that SME may reach through implementation of IMS.

Table 2. Internal benefits

INTERNAL BENEFITS
<p>Organizational Benefits</p> <ul style="list-style-type: none"> • Improvement of quality of management by down-sizing three functional departments to one and reducing fuzzy management boundaries between individual systems • Increase in operational efficiency by harmonizing organizational structures with similar elements and sharing information across traditional organizational boundaries • Avoidance of duplication between procedures of systems – Streamlining paperwork and communication
<p>Financial Benefits</p> <ul style="list-style-type: none"> • Cost savings by the reduction of the frequency of audits • Reduction in external certification costs over single certification audits • Increase in profit margins
<p>People Benefits</p> <ul style="list-style-type: none"> • Increase in employee motivation, awareness and qualifications • Creation of a better company image among employees

Considering external benefits, IMS may enable small and medium-sized enterprises to reach competitive advantage, to eliminate possibilities of competitive companies with their innovative strategies to exceed their activities. Furthermore, considering IMS, some authors verify that fulfillment of customer demands and perspective to attract new ones, offer some possibilities to company to increase market.

Besides above mention commercial benefits, SMEs may find positive outlet for company’s image. Synthesis of various proves for various management fields and their abilities to demonstrate legal compliance may enable the company to ensure “large picture” of their performances.

Finally, the field of obvious benefits may be identified in the conditions of quality, environment, health and safety performances. Implementation of IMS in small and medium-sized enterprises offers possibilities to reduce damages on machines, storages or product loss and hazardous waste generation as well as minimization of accidents and time loss. These potential positive effects may cause high values for SMEs, if we consider their disadvantages (for example: financial limits, shortage of human resources...) any damages, loss or accident, stoppage as catastrophe.

The fact is that in SMEs, only business parameters, being required by law and those being necessary for operational function, are filed. Objectively and transparently shown business parameters are rarely available to the leadership for decision making and business activities directing. Implementation of standards for

management system ensures collection of data through established evidence system as well as form the data through analyze needed for decision making.

The Table 3 presents external benefits.

Table 3. External Benefits, Categories and Examples

EXTERNAL BENEFITS
<p>Commercial Benefits</p> <ul style="list-style-type: none"> • Competitive advantage, • Improvement of market place • Gain new customers/satisfy existing ones
<p>Communication Benefits</p> <ul style="list-style-type: none"> • Improvement of company's image • Improvement of relations with stakeholders • Evidence of legal compliance
<p>Q/E/S Benefits</p> <ul style="list-style-type: none"> • Improvement in quality, environmental and health and safety • Reduction of hazardous waste generation • Reduction of equipment damage and product loss

It should be pointed out that properly established and developed IMS makes possible the business process rules and business activities are available to employees. That is multi useful due to often fluctuation of employees if, for example, one employee, who had important work duties, leaves the company and his colleagues have not had any insight in them. System of evidence and documented procedures and instructions enable any new employee to enter fast the work procedures.

The figure 4 shows benefits of IMS implementation into SMEs according to the East Anglia [6] research.

Implementation of standards and it's verification by the certification body ensure improvement on the markets especially on those activities where clients consider the certificated quality system as a condition for contract signing. Quality constant delivers are offered to clients.

The benefits of certifying to PAS 99 are:

- **Encourages risk management:** Provides third party reassurance that applicable laws and regulations are continually observed and that the organization's social, environmental and financial risks are being met,

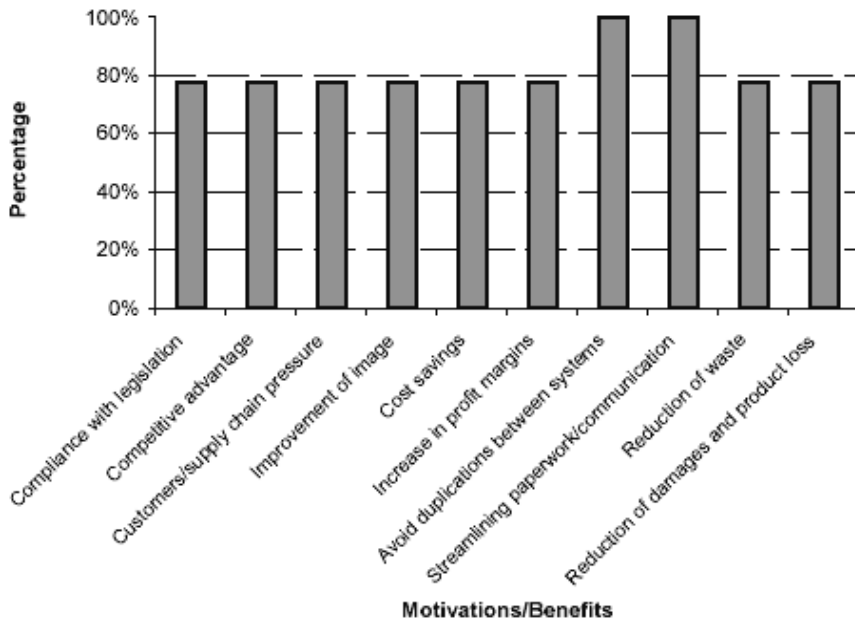


Fig. 4. Benefits of SME with IMS [6]

- **Gives a competitive edge:** By meeting contractual requirements and removing barriers to trade, independent assessment to Integrated Management provides purchasers with confidence in suppliers, products, services and goods.,
- **Attracts investment:** Demonstrates independent assurance of an organization's internal controls, efficiency and effectiveness helping to meet corporate governance requirements,
- **Improves & protects brand reputation:** The perception of your organization's brand is vital in today's markets. Consumers are demanding transparency in organizations while certification can help organizations meet those demands.,
- **Raises stakeholder perception and satisfaction:** Proves senior management's commitment to continually monitor and improve, creating a better performing organization.

6. CONCLUSION

From above mention it may be concluded as follows:

- IMS has become inevitable for SMEs,
- Management and internal efficiency are improved,
- By implementation of IMS the conditions for reduced costs are reached,
- External advantages are achieved (competition benefit, market position and relationship with customers as result of better quality, better performances in the view of environment, health and safety).

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PERSONALNI MENADŽMENT I MENADŽMENT LJUDSKIH RESURSA – RAZLIKE

Ljubica Duđak¹

Rezime: U radu je dat pogled na promene koje se dešavaju u savremenim organizacijama i njihovoj transformaciji u organizacije znanja. Ukazano je na neophodnost transformacije birokratske, personalne, posredničke funkcije između menadžmenta i zaposlenih i uspostavljanje menadžmenta ljudskih resursa, koji stavlja zaposlene u fokus poslovanja, zbog toga što su jedini inteligentni resurs i presudni činilac konkurentnosti organizacije. Prihvatanje koncepta strategijskog holističkog menadžmenta ljudskih resursa je ozbiljan zadatak za savremenu organizaciju, ali u isto vreme je i veliki izazov.

Ključne reči: organizacije znanja, personalni menadžment, menadžment ljudskih resursa

PERSONAL MANAGEMENT AND HUMAN RESOURCE MANAGEMENT – DIFFERENCES

Abstract : This paper discusses the changes that happen in modern organizations and their transformation in the organization of knowledge. It points to the necessity of transforming bureaucratic, personal, intermediary functions between management and employees and the establishment of human resource management, which puts the focus of the staff, because they are the only intelligent resource and a crucial factor in the competitiveness of the organization. Acceptance of the concept of holistic strategic management of human resources is a serious problem for the modern organization, but at the same time is a major challenge.

Key words: knowledge organization, personnel management, human resources management

1. UVOD

Kompanije koje su nastale u industrijskom dobu i koje smatraju da uspeh leži u razvoju bržih, jeftinijih i efikasnijih metoda proizvodnje, se nalaze pred imperativom promena svojih stavova prema tržištu i kupcima. Današnji fokus nije više na tradicionalnoj industrijskoj preokupaciji da se usavrše postojeći proizvodi, nego se do poslovnog uspeha stiže direktno preko inovacija. To znači da se bogatstvo ne stiže usavršavanjem poznatog, već nesavršenim otkrićem nepoznatog. Budućnost ne leži više u kompjuterima nego u novim konekcijama, odnosno, drugačije rečeno, odvija se drastičan zaokret od proizvoda ka uslugama [3].

Imperativ pred kojim se nalazi savremena organizacija se odnosi na preispitivanje znanja koje ima i njegovo obnavljanje, kako bi kontinuirano ostvarivala uspeh i razvijala se. Svaka organizacija će morati da nauči da dolazi do inovacija i da tome pristupi na sistematski način. Ako to ne bude činila, postojeće znanje će zastariti i

opteretiti procese, a organizacija će postati troma i neefikasna. Samim tim, organizacija će izgubiti sposobnost da privuče i zadrži stručne i obrazovane ljude, od čijeg znanja zavisi njen uspeh i opstanak. [3].

Jedini pouzdani izvor trajne konkurentske prednosti jeste znanje. U uslovima kada se neizvesnost nameće kao izvesna realnost, kada se tržišta dinamično pomeraju, tehnologije umnožavaju, broj konkurenata raste, a proizvodi i usluge skoro preko noći zastarevaju, uspešne su one organizacije koje stalno dolaze do novih znanja, šire ih po celoj svojoj strukturi i brzo pretvaraju u poslovne inovacije koje pospešuju i dinamiziraju razvoj i povećavaju efikasnost poslovanja [5].

Stopa učenja mora biti veća od stope promena – stav je koji se mora poštovati u uslovima težnji za ostvarenje ravnopravne saradnje na tržištima sveta uz uslov trenutne i stalne, u toku rada, primene ostvarenih znanja. Sve ukazuje na ubrzano preusmeravanje napora od već razvijenih K – konvencionalnih industrijskih zahvata u ostvarenju kvaliteta, efektivnosti, "optimizacije" i drugih ka I – inteligentnim postupcima razvoja i korišćenja znanja, iskustva, sticanja veština, rasta odgovornosti, ponašanja, razvoja veza na dobavljače i potrošače, izgradnje efektivnog sistema motivacije i spremnosti za izazove promena i druge slične neopipljive zahvate [9].

Pred organizacijama se nalazi izazov da prepoznaju potencijal koji imaju usvojim zaposlenima, da u svom poslovanju stave akcenat na ljudske resurse i da im omoguće da svoje znanje stave u funkciju ostvarivanja svojih ciljeva, ali i organizacionih ciljeva. To će biti moguće samo ako tradicionalni personalni menadžment, kao birokratska, administrativna funkcija bude zamenjen menadžmentom ljudskih resursa koji je strategijski, obuhvata sve zaposlene i proaktivno deluje u organizaciji i okruženju.

2. SAVREMENE ORGANIZACIJE - ORGANIZACIJE ZNANJA

Karakteristika savremenog poslovanja je da osnovni ekonomski resurs nisu više sirovine, kapital ili fizički rad (koji prestaju da budu jedini i presudan izvor bogatstva), nego je to znanje. To svakako utiče na vrstu, obim i dinamiku promena u okruženju preduzeća koje mogu ugroziti njegov opstanak. Slobodno se može zaključiti da organizacije koje na vreme ne uoče nastanak društva znanja u svom okruženju i ne transformišu se u organizacije znanja, odnosno ne shvate i prihvate promene koje se dešavaju na globalnom nivou, postepeno, ali sasvim sigurno idu u pravcu samolikvidacije.

Tradicionalni faktori proizvodnje, zemlja, rad i kapital, nisu nestali, ali su izgubili na značaju. Raspolagati njima bez specijalizovanog znanja ne predstavlja nikakvu retkost. Ali specijalizovano znanje nije dovoljno samo po sebi i ima značaj samo kada je povezano sa radom. Zbog toga kažemo da je društvo znanja vezano za same organizacije. Svrha i funkcija svake organizacije i savremenog poslovanja je integrisanje specijalističkih znanja u zajedničkim poslovima. Znanje i intelektualni kapital kojim raspolaže savremena organizacija su glavni razvojni faktori i najefikasniji mogući odgovor na poslovnu stvarnost. Usled toga se odvija prelazak sa ekonomije koju su pokretale opipljive stvari, kao što su fizički resursi i proizvodi, na ekonomiju koju pokreću neopipljive – ideje, koncepti, apstrakcije.

U savremenim uslovima, organizacije se transformišu u organizacije znanja koje procesiraju ogromne količine informacija, odvojeno od tokova roba i opipljivih resursa. Organizacije znanja su organizacije koje u svom bilansu stanja imaju malu količinu sredstava u odnosu na dodatu vrednost koju stvaraju, jer u procesu stvaranja dodate vrednosti koriste manje opipljiva sredstva. Ovaj proces vodi ka stvaranju virtuelnih organizacija koje koriste mreže, odnosno, već spomenute konekcije, kako bi stvarale dodatu vrednost.

Organizacija znanja primenjuje potpuno drugačije strategije, jer prihvata stav da je stvarna konkurentna prednost za organizaciju njena sposobnost da uči brže od konkurencije, da stiče znanje i stalno ga uvećava. "Organizacija koja uči" je organizacija sa čvrsto izgrađenom filozofijom usmerenom na sagledavanje, reakciju i odgovore na promene, kompleksnost i neizvesnost. P. Sengi (1991.) pod pojmom "organizacija koja uči" podrazumeva grupu ljudi koja kontinuirano povećava svoju sposobnost da kreira ono što želi [7]. Dakle, brzina kojom organizacija uči postaje jedini trajni izvor njene konkurentne prednosti.

S obzirom da su promene u okruženju brze i nepredvidive i da je konkurencija na globalnom nivou sve oštrija, samo "učeća organizacija", kompetentna, kreativna, inovativna i fleksibilna, može računati na dugoročni opstanak na tržištu i konkurentnost. Inovativnost i kreativnost postaju osnova tržišne konkurentnosti u savremenom poslovanju i uz znanje, predstavljaju novi izvor ekonomskog bogatstva, što savremenu organizaciju stavlja pred imperativ kontinualnog inoviranja i restrukturiranja svojih poslovnih modela.

U društvu znanja, organizacije znanja posluju u ekonomiji znanja koja se fundamentalno razlikuje od ekonomije u poljoprivrednoj i industrijskoj eri na osnovu sedam karakteristika [1]:

1. Znanje zamenjuje radnu snagu i kapital kao fundamentalne resurse u proizvodnji, a neopipljivi resursi, kao što su, na primer, robne marke, stvaraju značajan deo dodate vrednosti. Postoje procene da su privatne američke kompanije u 2002. godini uložile najmanje milijardu dolara u neopipljive resurse. Brojna istraživanja pokazuju da neopipljivi resursi u sve većoj meri utiču na buduću profitabilnost, kao i na tržišnu vrednost kompanije, koju sada zajedno grade finansijski i intelektualni kapital.
2. Udeo znanja u proizvodima i uslugama se rapidno povećava. Elektronika u današnjim automobilima je mnogo vrednija od ugrađenog čelika. U ekonomiji znanja od znanja u sve većoj meri zavise i poslovni procesi, a ne samo proizvodi. Inovacija procesa postaje važna koliko i inovacija proizvoda (*IKEA, Dell Computers*).
3. Ekonomija znanja je ekonomija u kojoj su usluge važne koliko i proizvodi. Značajan je rast industrije usluga. Postoje podaci da je procentualno učešće usluga veće od učešća proizvoda u ukupnom prihodu mnogih zemalja. To ukazuje na činjenicu da ne zavise samo proizvodi od količine znanja ugrađenog u njih, već i da samo znanje, plasirano kao usluga, postaje važan proizvod.
4. U ekonomiji znanja važe drugačiji ekonomski zakoni. Razlozi zbog kojih se ekonomija znanja razlikuje od ekonomije finansijskih i fizičkih resursa su, između ostalog, sledeći:
 - neopipljiva sredstva nisu rivalska, ona se istovremeno mogu upotrebljavati,
 - za neopipljiva sredstva su karakteristični veliki fiksni troškovi i minimalni marginalni troškovi (na primer, razvoj softvera zahteva ponekad vrlo velike investicije, ali njegova distribucija i prodaja košta mnogo manje),
 - neopipljiva sredstva su vrednija ako su umrežena, odnosno ostvaruju veću korist (na primer, upotrebljivost i vrednost računarskog operativnog sistema se povećava sa povećanjem broja korisnika).
5. U ekonomiji znanja menja se koncept vlasništva nad resursima. S obzirom da znanje u najvećoj meri počiva u glavama zaposlenih, organizacije više nisu vlasnici svog najvrednijeg resursa – znanja.
6. Menjaju se i karakteristike zaposlenih. Sve je manje klasičnih industrijskih radnika koji koriste fizičku snagu i manuelne veštine, a povećava se broj

zaposlenih sa specijalizovanim znanjem koji stvaraju najveći deo dodate vrednosti u organizacijama.

7. Kao rezultat svega navedenog, menjaju se i organizacije. U odnosu na fizičke i finansijske resurse, neopipljivi resursi zahtevaju i zaslužuju drugačiju poslovnu filozofiju i koncepciju menadžmenta. U fokusu menadžmenta sada je čovek, zaposleni koji poseduje posebna znanja, i sloboda koju mu to znanje omogućava. Samim tim na značaju dobija menadžment ljudskih resursa kao pokretač svih procesa i promena u organizaciji, jer je znanje produktivno samo ako je usmereno na stvaranje dodate vrednosti za organizaciju i društvo u celini. Mnogo je teže za menadžment savremene organizacije da usmerava zaposlene, uglavnom profesionalce i stručnjake, jer više ne funkcionišu zastareli kontrolni mehanizmi, propisi, pravila i procedure. Neophodno je zaposlenima, kao kreatorima budućeg uspeha organizacije, obezbediti slobodu stvaranja.

Istovremeno, više ili manje usklađeno, deluju različiti trendovi i njihovo objedinjeno delovanje određuje društvenu i poslovnu klimu, kako na globalnom, internacionalnom nivou, tako i na nacionalnim i lokalnim nivoima. Anticipiranje tih trendova je preduslov opstanka i razvoja i omogućava organizaciji jasnije smernice za izgrađivanje vizije i strategija koje će realizovane savremenim menadžerskim instrumentima. U privredama razvijenih zemalja uočeni su trendovi koji su imali značajan uticaj na transformaciju industrijskog društva u društvo znanja, u kome se rast i razvoj zasnivaju na znanju, koje se može transformisati u materijalnu ili nematerijalnu vrednost [6]:

1. Privredni rast razvijenih zemalja se sve više temelji na uslužnim delatnostima, a sve manje na materijalnoj proizvodnji. Suština savremenog poslovanja je da se poslovne strategije više ne usredsređuju na kontrolu troškova nego na stvaranje nove vrednosti. Može se reći da se proces stvaranja vrednosti kreće iz sfere materijalnog u sferu nematerijalnog.
2. Prelazak iz industrijsko doba u doba znanja obeležava i zahtev za povećanjem kvalifikacija i stručnosti radnika, odnosno nastanak "radnika znanja" ili "umnih radnika" (*knowledge worker*). To se pre svega odnosi na kompanije u tehnološki zahtevnim delatnostima, a ne na niskokvalifikovani i malo plaćeni rad, na primer, u maloprodaji i restoranima brze hrane. Povećanje kvalifikacijske zahtevnosti rada nije značajno samo za intelektualne delatnosti, već i za proizvodnju koja sve više zavisi od intelektualnog inputa.
3. U sve većoj meri, poslovanje se temelji na znanju i zahtevnim tehnologijama. Među uspešnima opstaju samo inovativne organizacije, sposobne da se prilagode naučnim i tehnološkim trendovima. Od 500 najuspešnijih kompanija po rang listi američkog ekonomskog časopisa "Fortune" iz 1955. godine, danas posluje svega 30%. Ostale nisu uspele da se prilagode i prežive dramatične promene u okruženju.
4. Procentualno smanjenje učešća industrijskih radnika u ukupnom radnom stanovništvu je još jedan značajan trend. U SAD industrijski radnici čine oko 15% ukupne radne snage, a u Velikoj Britaniji oko 18%. Istovremeno, iz godine u godinu se povećava razlika između plata visoko i srednje kvalifikovanih radnika i niskokvalifikovanih radnika.
5. Neverovatno je veliki obim tehnološkog razvoja, pre svega obim razvoja informacionih tehnologija, posebno personalnih računara i računarskih mreža (Internet, Intranet, Ekstranet). Godine 1975. je bilo svega 50.000 računara, a danas ih je oko 140 miliona. Računarska tehnologija je doprinela povećanju produktivnosti i omogućila globalizaciju finansijskih tržišta. Savremene

komunikacione mreže omogućile su nove organizacione oblike – manje, horizontalne i virtuelne organizacije.

3. RAZLIKA IZMEĐU PERSONALNOG MENADŽMENTA I MENADŽMENTA LJUDSKIH RESURSA

Organizacija je stalno izložena i konkurenciji po pitanju kvalifikacija i ljudi sa znanjem. U mnogim organizacijama se danas govori da su ljudi njihova najvažnija aktiva. Međutim, u praksi je malo onih koje stvarno tako misle, odnosno, ponašaju se u skladu sa tim stavom. U većini organizacija još uvek preovladavaju shvatanja iz devetnaestog veka da su one potrebnije ljudima nego što su njima potrebni ljudi, odnosno, da zaposleni treba da se prilagođavaju organizaciji. U stvari, organizacija je ta koja treba da privuče ljude, da ih zadrži, nagrađuje, motiviše i učini ih zadovoljnim poslom kojim se bave.

Menadžeri, profesionalci i tehničari su shvatili da je znanje njihov kapital i da su oni vlasnici jednog sredstva za proizvodnju. Jedna od posledica ovih novih odnosa je stvaranje nove tenzije u modernom društvu, a vezana je za dužinu trajanja lojalnosti. Organizacija mora svojim postupcima da održava lojalnost pokazujući da zaposleni mogu svoje znanje da stave u funkciju ostvarivanja individualnih i organizacionih ciljeva. Ne tako davno su upotrebljavani izrazi „radnik“ i kadrovi, a sada se govori o ljudskim resursima. Ova promena nas podseća da se više govori o pojedincima, i posebno, o stručnim i obrazovanim radnicima, koji su odlučili da daju svoj doprinos organizaciji svojim znanjem. U tom kontekstu dolazi do afirmacije menadžmenta ljudskih resursa, koji razrešava protivurečnosti između organizacije i zaposlenih [5].

3.1 Kriza tradicionalnog personalnog menadžmenta

Personalni menadžment prati sudbinu globalnog hijerarhijskog menadžmenta, koji je dominantan u tradicionalnim organizacijama. Zahtevi da se zaposleni, kao najdominantniji izvor konkurentske prednosti, zbog svojih sposobnosti, veština, znanja, ideja i kreativnosti, tretiraju kao saradnici a ne kao potčinjeni znatno su doprineli krizi tradicionalnog personalnog menadžmenta (TPM). Hijerarhijska, centralizovana struktura organizacije u kojoj su menadžeri tirani, ostali zaposleni bez prava glasa, učešća i odgovornosti u donošenju odluka i gde je komunikacija jednosmerna, ne može da odgovori zahtevima savremenog poslovanja i da omogući funkcionisanje i uspeh na svetskom tržištu. Brojni su razlozi za to, a neki od njih su:

- Sporost i rigidnost sistema odlučivanja isključuju mogućnost proaktivnog delovanja u okruženju koje se menja sve većom brzinom - reaktivan odgovor na promene neminovno donosi neuspeh.
- Nemotivisani zaposleni su mnogo manje produktivni od onih koji poslu pristupaju sa motivacijom – pad produktivnosti se tokom vremena sve više izražava.
- Zaposleni u podaničkim ulogama teško da mogu da stvore nova znanja, a u atmosferi skepticizma još manje da ga međusobno razmenjuju.
- Formalni odnosi i posebno jednosmerna komunikacija, gde se dobro zna ko je „gore“ a ko „dole“, koji u potpunosti isključuju mogućnost aktivnog učešća zaposlenih u donošenju odluka, isto tako onemogućavaju razvijanje osećaja pripadnosti organizaciji i stvaranje uslova za timski rad.
- Preterano i komplikovano administriranje usporava poslovne procese.

Svi napori teorije i prakse tradicionalnog personalnog menadžmenta nisu urodili plodom, niti su dali zadovoljavajuće rezultate. Personalni menadžment ostvaruje posredničku funkciju između radnika, odnosno tržišta radne snage i menadžmenta

tradicionalne organizacije. Pri tome, menadžeri imaju svu moć i vlast, dok radnicima ostaje samo da izvršavaju naređenja. TPM je činovnička struktura, koja obavlja rutinske poslove, prema odgovarajućim procedurama, bez aktivnog učešća i uticaja na donošenje strateških odluka.

Nedostatak personalnog menadžmenta nije proceduralne prirode, jer on objašnjava personalne procedure, koje ima svaka savremena organizacija. Suštinske primedbe na personalni menadžment se odnose na svako odsustvo strateškog pristupa, kao i na hijerarhijsku strukturu kojoj pripada i birokratsku filozofiju na kojoj se zasniva. Stavljajući ljude u neravnopravan položaj, ovaj koncept razvija pasivnost kod većine zaposlenih, ne dozvoljavajući im da iskažu svoje kreativne i inovativne sposobnosti.

3.2 Afirmacija menadžmenta ljudskih resursa

Dramatične promene u poslovnom okruženju, u kontekstu globalizacije, razgrađuju tradicionalne organizacije zasnovane na hijerarhijskim odnosima. Turbulentno okruženje zahteva ambivalentno spretnu organizaciju, koja je istovremeno efikasna, inovativna i fleksibilna [5]. S druge strane, savremeni menadžment iznalazi adekvatne odgovore na tržišne izazove u uslovima globalizacije i turbulencija u poslovnom okruženju. Zahvaljujući menadžmentu, organizacija uspostavlja fleksibilne i harmonične poslovne odnose u ritmu promena, koristeći raspoložive resurse, sa težnjom da ostvari najpovoljniju tržišnu poziciju i poslovne rezultate.

Kontekst u kome posluju savremene organizacije je društvo znanja koje je visoko konkurentno i koje uspostavlja zahteve za kontinuelnim sticanjem znanja i angažovanjem kompetentnih ljudskih resursa. Savremene organizacije su profesionalni entiteti, u kojima ljudski resursi multiplikuju svoju ulogu, kontinuelno formiraju timove i učestvuju u novim i različitim organizacionim grupama koje rade na različitim projektima i rešavaju različite probleme.

Promene su dovele i do toga da tradicionalni hijerarhijski menadžment postaje prevaziđen u današnjim uslovima i ustupa prostor savremenom menadžmentu na holističkim osnovama, a *menadžment ljudskih resursa postaje fokusno područje globalnog menadžmenta*.

Izraz menadžment ljudskih resursa, još uvek, često predstavlja samo laskaviji naziv za tradicionalni personalni menadžment ili kadrovski menadžment. Sa druge strane *podrazumeva mnogo više od osavremenjivanja samog naziva i sugerise drugačiju filozofiju i koncepciju, koja je za savremenu organizaciju efektivnija i efikasnija od tradicionalnog personalnog menadžmenta i koja se ne odnosi samo na izvršavanje administrativnih aktivnosti vezanih za ljude u jednoj organizaciji*.

Istraživanja prakse potvrđuju stavove da su ljudski resursi efikasan izvor konkurentne prednosti, nasuprot tradicionalnom pristupu, koji počiva na analitičkim sredstvima i determinizmu. *Prihvatanje stava da su ljudi ti koji stvaraju različitost, u sličnim uslovima, kada su u pitanju ostali faktori, predstavlja dobru vest za menadžment ljudskih resursa i njegovu legitimnost u poslovnim procesima*.

Danas organizacija ne očekuje da se zaposleni njoj prilagođavaju već traži način kako da privuče i zadrži talentovane ljude. Ljudi postaju najznačajniji resursi savremene organizacije, odnosno poseduju najvredniji resurs u društvu znanja, a to je znanje samo. To jasno govori da je TPM prevaziđen koncept, a da je MLJR i holistički pristup ono što je do sada nedostajalo da bi zaposleni mogli da iskažu sve svoje stvaralačke potencijale.

MLJR je strateški orijentisan i integralni je deo globalnog strateškog menadžmenta, te deluje katalički na sve procese u organizaciji. Tako postavljen u organizaciji, MLJR omogućava da se sagleda i iskoristi sva kompleksnost ljudske prirode i da se, na do sada, neuobičajen način, razmišlja o poslovanju i uticaju koji na

to poslovanje imaju zaposleni. *Filozofija i koncepcija menadžmenta ljudskih resursa se zasniva na holističkom pristupu, koji tako obezbeđuje sinergetske efekte.* Dakle, više od prostog zbira efekata koje bi ostvarile pojedinačno, svaka za sebe, pojedine celine u organizaciji.

Ukoliko kompleksan pravac konkurentске strategije organizacije u potpunosti zavisi od pojedinačnih sposobnosti i neposrednog učešća zaposlenih, onda će funkcija MLJR imati proaktivnu ulogu u oceni i razvoju ljudskih potencijala, kako bi strategija bila u funkciji ostvarenja definisanih ciljeva. U tom slučaju, operativni menadžeri imaju značajnu ulogu u planiranju i implementaciji strategijskog MLJR.

Menadžment ljudskih resursa u odnosu na ostale poslovne funkcije se razlikuje, pre svega, po tome što je u domenu njegovog delovanja čovek, kao jedini inteligentni, misleći resurs u organizaciji. MLJR treba da obezbedi sklad između interesa zaposlenih i interesa organizacije. Doktrina ljudskih resursa pristupa ljudima kao resursu svih resursa, premešta ih iz kategorije troškova u kategoriju osnovnih bogatstava i obezbeđuje njihovo potpuno angažovanje u inovativnoj, tržišno orijentisanoj organizaciji.

Organizacija može da ostvari konkurentsku prednost nad drugim organizacijama samo ako stvori vrednosti koje su retke i koje su teške konkurentima da ih imitiraju. Za razliku od kapitalnih investicija, patenata ili tehnologije, odgovarajući menadžment ljudskih resursa predstavlja nevidljivu aktivu, koja stvara vrednost kada je ugrađena u organizaciju kao poslovni sistem, poboljšavajući organizacione performanse i performanse zaposlenih.

Delujući kao savest čovečanstva i kao racionalna poslovna filozofija, Menadžment ljudskih resursa pomera civilizacijske granice na globalnoj osnovi. Formirajući holističke sisteme, sa katalitičkim dejstvom u njihovim strukturama, Menadžment ljudskih resursa ima značajan uticaj na sinergetske efekte savremenih organizacija [5]. Polazeći od principa ravnopravnosti i jednakih šansi, MLJR podržava dvosmerno komuniciranje, postavljanje pravih ljudi na odgovarajuća mesta, razvoj individualnih i organizacionih performansi i nagrađivanje prema uložnim naporima i ostvarenim efektima. Na toj osnovi, MLJR podstiče dinamiziranje razvoja i kontinuelno povećanje efikasnosti u poslovanju.

Praksa pokazuje da u uspešnim organizacijama u kojima MLJR počiva na strategijskom pristupu, operativni menadžeri, koji snose glavnu odgovornost za poslovne rezultate, istovremeno učestvuju u kreiranju strategije ljudskih resursa, dok menadžeri ljudskih resursa, kao glavni nosioci funkcije MLJR, aktivno učestvuju u formiranju globalne poslovne strategije, preuzimajući odgovornost za ukupne poslovne rezultate i ciljeve [5]. Ova svojevrsna koalicija, ukoliko dobro funkcioniše, dovodi do fundamentalnih promena, kako u poslovnoj kulturi, tako i u organizacionoj strukturi i menadžment procesima. Na toj osnovi, organizacije ostvaruju značajno poboljšanje svoje tržišne pozicije i ukupnih poslovnih rezultata.

Menadžeri za ljudske resurse imaju značajnu odgovornost u organizaciji, ne samo za delovanje funkcije MLJR, nego i za globalni uspeh organizacije. Da bi ostvario svoju ulogu na pravi način, menadžment za ljudske resurse, mora da ima efikasnu saradnju sa svim ostalim funkcijama u preduzeću, odnosno, menadžmentom marketinga, istraživanja i razvoja, proizvodnje, finansija i kvaliteta. Različite poslovne funkcije i organizacione jedinice se prožimaju u svim aspektima svog delovanja i tako doprinose uspehu organizacije na globalnom nivou. Ukoliko to nije slučaj, organizacija i njeni zaposleni se neizbežno suočavaju sa brojnim problemima.

Menadžment ljudskih resursa ima svoju filozofiju i instrumentarijum za strategijsko i operativno delovanje. MLJR koristi procedure i politike, ali stavlja akcenat na akciju. Menadžment ljudskih resursa se bavi rešavanjem problema zaposlenih radi ostvarenja organizacijskih ciljeva i pomaže zaposlenima da se razvijaju i da sa

zadovoljstvom rade. To znači da tretira svakog zaposlenog kao pojedinca kad god je to moguće, obezbeđuje programe i mogućnosti koje zadovoljavaju njihove individualne potrebe. MLJR pomaže organizaciji da ostvari ciljeve u budućnosti, obezbeđujući kompetentne i motivisane ljude. Tako ljudski resursi treba da budu inkorporirani u dugoročne, strategijske planove organizacije.

Akciona usmerenost je suštinska karakteristika MLJR, pre svega u smislu stvaranja optimalnih uslova za uspešno ostvarenje akcija organizacije, obezbeđujući visoko motivisane zaposlene koji raspolažu potrebnim performansama. U procesu izvođenja poslovnih akcija važnu ulogu ima timski rad koji podstiče zaposlene da ostvaruju bolje rezultate. Savremena praksa pokazuje da postoji čvrsta korelacija između menadžmenta ljudskih resursa i uspešnosti u izvođenju poslovnih akcija u organizaciji, jer upravo MLJR deluje na ostale poslovne jedinice i funkcije kao katalizator koji, u krajnjem rezultatu, doprinosi ostvarenju sinergetskih efekata na nivou poslovnog sistema. U procesu izvođenja akcija, menadžment ljudskih resursa deluje preko svojih instrumenata, odnosno, funkcija koje se aktiviraju pojedinačno i integralno i usmerene su u različitim pravcima:

- **Eksterno i interno dvosmerno komuniciranje** - deluje kao nervni sistem u organizaciji i obezbeđuje protok informacija u poslovnim procesima,
- **Ravnopravnost i jednake šanse** - pomera civilizacijske granice u procesu formiranja holističkih struktura, obezbeđujući ljudima pravo na različitost i omogućavajući im da iskoriste svoje potencijale,
- **Selekcija** - raspoređuje prave ljude na prava mesta i u pravo vreme,
- **Procena performansi** - obezbeđuje uslove da ljudi sa odgovarajućim znanjem i sposobnostima ostvaruju maksimalne efekte,
- **Sistem nagrađivanja** - motiviše članove organizacije i obezbeđuje pravično nagrađivanje za uložene napore i ostvarene rezultate,
- **Razvoj i obuka zaposlenih** - povećava nivo znanja i menja način razmišljanja članova organizacije i
- **Razvoj karijere** - motiviše zaposlene na aktivno angažovanje u kontinuitetu.

Zahvaljujući mogućnosti optimalne kombinacije navedenih funkcija, menadžment ljudskih resursa raspolaže visokim potencijalom za efikasno delovanje u poslovnim procesima. Na toj osnovi, MLJR svoju filozofiju transformiše u praksu, a poslovni efekti pokazuju koliko se u tome uspelo. Polazeći od principa ravnopravnosti i jednakih šansi, MLJR podržava dvosmerno komuniciranje, postavljanje pravih ljudi na odgovarajuća mesta, razvoj individualnih i organizacionih performansi i nagrađivanje prema uložanim naporima i ostvarenim efektima. Na toj osnovi, MLJR podstiče dinamiziranje razvoja i kontinuelno povećanje efikasnosti u poslovanju. U procesu operacionalizacije, instrumenti menadžmenta ljudskih resursa deluju kao ciklus funkcija (slika 1.) [5]. Konceptijska osnova instrumenata MLJR proizlazi iz filozofije i koncepcije MLJR, koja, opet, proizlazi iz konteksta globalnog menadžmenta. Kompleksna struktura instrumenata MLJR omogućava strategijsko i operativno delovanje u procesu ostvarenja individualnih i organizacionih ciljeva.



Sl.1 Ciklus funkcija menadžmenta ljudskih resursa

Kao racionalni okvir za operacionalizaciju, model na slici 1. reprezentuje interaktivnost između funkcija MLJR u odnosu na performanse, kao fokusni instrument. Isto tako se uočava i integrisanost vizije, misije, ciljeva i strategije MLJR, u kontekstu vizije, misije, ciljeva i strategija globalnog menadžmenta organizacije.

Ukoliko je u procesu strateškog menadžmenta uspostavljena odgovarajuća strateška ravnoteža, na holističkim osnovama, MLJR može da predstavlja moćno sredstvo u rukama veštih menadžera, odnosno da presudno deluje na ostvarivanje i zadržavanje konkurentske prednosti. Zbog toga je veoma značajno da se pravilno uočavaju korelacione veze, kako internih instrumenata, tako i faktora okruženja.

4. ZAKLJUČAK

Promene koje se dešavaju u svetu imaju dalekosežne implikacije i zahtevaju promenu paradigmi na kojima počivaju društva i organizacije, odnosno promenu načina razmišljanja, promenu političkih odnosa, promenu načina komuniciranja na svim nivoima, promenu svesti i odnosa prema radu i zaposlenima. Menadžment ljudskih resursa je jedini sposoban da, delujući kao katalizator u savremenoj organizaciji, takvu odgovornost prihvati.

Menadžment ljudskih resursa je celovita i kompleksna nauka, ali njegovi principi će ostati u domenu teorije sve dok ne dođe do promene svesti, odnosno promene načina razmišljanja i promene paradigmi na kojima počiva organizacija, što je imperativ sadašnjeg vremena, a pogotovo vremena koje dolazi. Neophodan je drugačiji odnos prema poslovanju, prema okruženju i prema organizacijama i ljudima koji su njihov sastavni deo, bez obzira da li govorimo o zaposlenima, potrošačima ili građanima. Bez dubinskog preispitivanja i redefinisavanja relacija unutar sebe same i relacija u odnosu na spoljašnje okruženje, organizacija neće biti u stanju da u budućnosti pobeđuje u utakmici znanja, neće imati zaposlene koji su probuđeni, samoostvareni i pobuđeni da stvaraju, ali neće biti ni preduslova da bilo koja država, odnosno društvo koje postaje društvo organizacija, ima integritet i da se uspešno uklopi u svetske tokove.

S druge strane, afirmacijom Menadžmenta ljudskih resursa na holističkim principima, organizacija može najefikasnije da utiče na promenu svesti u organizaciji, promenu koja, u odnosu na tradicionalne organizacije, dovodi do revolucionarno drugačijeg odnosa prema zaposlenima, koji postaju partneri i saradnici organizacije u procesu ostvarivanja individualnih i organizacionih ciljeva.

Koncept strategijskog menadžmenta na holističkim osnovama koji organizaciju posmatra kao celinu koja ima sposobnost postizanja sinergetskih efekata, daleko većih od pojedinačnih efekata koje mogu da ostvare delovi organizacije, a u sklopu globalnog menadžmenta, koncept MLJR sa svojim instrumentima, kao funkcija koja brine o jedinom inteligentnom resursu u organizaciji, što ga u ekonomiji znanja čini ključnim izvorom konkurentne prednosti, je dovoljno širok i sveobuhvatan (univerzalan), racionalan, zasnovan na ekonomskoj logici, a opet ostavlja prostor za ljudsku kreativnost i inovativnost.

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ULOGA I PRIMENA INFORMACIONO-KOMUNIKACIONE TEHNOLOGIJE U VISOKOŠKOLSKOM OBRAZOVANJU

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Rezime: Revolucionaran razvoj interneta i informacione tehnologije uticao je na pojavu novih obrazovnih metoda učenja, koje su otvorile nove mogućnosti da se korisnici samostalno obrazuju i nadograđuju već usvojena znanja. Obrazovne institucije došle su u izazov da osiguraju kvalitetno obrazovanje prema zahtevima tržišta koje diktira dinamiku promena u svim aspektima života. Mnoge škole, visokoobrazovne ustanove došle su do zaključka da moraju odgovoriti zahtevima te su postakle razvoj novih načina obrazovanja, a jedan od njih je i obrazovanje na daljinu. Najviše programa za učenje na daljinu javilo se u području obrazovanja odraslih, koji žele da steknu relativno stručno obrazovanje, nego za osnovno obrazovanje dece ili adolescenata. U radu akcenat je stavljen na primeni obrazovne platforme otvorenog koda, koje u mnogome može doprineti integraciji obrazovnih institucija u Srbiji i šire, s obzirom da je Moodle platforma korišćena kao rešenje širom sveta.

Ključne reči: obrazovanje na daljinu, visokobrazovne institucije, Moodle platforma, kvalitet

THE ROLE AND USE OF INFORMATION-COMMUNICATION TECHNOLOGY IN HIGHER EDUCATION

Abstract: Revolutionary development of Internet and information technology called for emergence of new educational methods of learning, thus opening new opportunities for the users to self-educate and upgrade already acquired knowledge. educational institutions are facing the challenge to ensure high quality education in accordance with the demands of the market which dictates the dynamics of change in every aspect of life. Many schools, and higher education institutions have come to conclusion that the demands have to be met, so they encouraged development of new ways of education, one of which is distance learning. Majority of distance learning programs emerged in the area of education of adults, who want to acquire relatively professional education, as opposed to the areas of primary children or adolescent education. In practice the

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emphasis is on open source platforms, which can greatly contribute to the integration of education institutions in Serbia and beyond its borders, having in mind that Moodle platform has been in use for these purposes throughout the world.

Keywords: distance learning, higher education institutions, Moodle platform, quality

1. UVOD

U današnje vreme, kada imamo mnogo životnih obaveza i raznih aktivnosti, učestala je pojava nedostatka slobodnog vremena. Pomoću učenja na daljinu, velikom broju ljudi pružena je mogućnost učenja u slobodno vreme. Ovaj vid obrazovanja posebno odgovara "bivšim" studentima, ljudima koji žele nadograditi svoje znanje, a zbog raznih svakodnevnih obaveza i poslova nemaju mogućnost odlaska na studije. Veliki broj svetski priznatih visokoškolskih ustanova u svom programu studija kao obavezan izbor savremenog načina obrazovanja primenjuju ovu kategoriju učenja kroz ozbiljno organizovane programe koje karakteriše veliki broj studenata (podaci za 2003. godinu prema Američkoj asocijaciji za učenje na daljinu, ukazuju na oko 3.000.000 studenata koji primenjuju neku od formi obrazovanja na daljinu)[1].

Učenje na daljinu se upotrebljava već duže vreme i na različite načine, ali se u poslednjih pet godina kompjuterska tehnologija značajno usavršila tako da je obrazovni softver od jednostavnih DOS aplikacija usavršen do trodimenzionalne virtuelne realnosti kojom se podiže unutrašnja motivacija studenata i postaju veoma interesantni. Razvoj obrazovanja na daljinu datira od polovine prošlog veka kada su korišćene radio emisije i dopisna škola kako bi obrazovanje bilo dostupno i onim studentima koji nisu mogli da se transportuju do škola ili nisu mogli svakodnevno da prisustvuju nastavi. U Francuskoj je, na primer, još 1939.godine, stvoren Nacionalni centar za nastavu na daljinu (CNED) kako bi se odgovorilo potrebama mladih izbeglica koje su napustile zemlju na početku Drugog svetskog rata. CNED je od tada radio pre svega za potrebe siromašnog naroda ili onih koji su imali poteškoća sa učenjem [2].

Programi studiranja na daljinu su doneli zaposlenima, kao i onima koji iz bilo kog razloga nisu u mogućnosti da studiraju na klasičan način, ne samo mogućnost da studiraju van klasičnih učionica, već još važnije, omogućili su studentima da im se i formalno priznaju znanja i iskustva već stečena tokom studiranja. Ovaj način edukacije pokazao se fleksibilnim jer studenti nastavnim sadržajima mogu pristupati s raznih mesta i lokacija, sami određuju vreme i trajanje učenja, brzinu savladavanja nastavnih jedinica. Jedini uslov je pristup internetu.

Prednost učenja na daljinu je i izvrsna podrška studentima od strane nastavnika, zatim mogućnost komunikacije putem elektronske pošte, korišćenje foruma i slično. Studenti imaju mogućnost međusobne komunikacije i razmene raznih informacija. Sve to dovodi do podizanja kvaliteta učenja. Znači, korišćenjem informacionih tehnologija predviđeno je individualno sticanje znanja, stalna povratna informacija i praćenje napredovanja učenika što nastavniku pomaže da realnije vrednuje njihovo znanje i da ih upućuje na druge medije kako bi uspešnije ovladali novim znanjima. Učenje kod kuće znatno je jeftinije nego svakodnevna putovanja i odlasci u obrazovne ustanove.

Čest problem kod studenata bio je sužena ponuda obrazovnih ustanova koje mogu pohađati. Najčešće se odlazilo na studije koji su se nalazili u rodnom gradu. Ovim oblikom učenja te prepreke više nema, udaljenost nije problem, svima su

dostupni kvalitetni programi, a njihov broj raste iz dana u dan. Još jedna od prednosti posebno je izražena u manje razvijenim i siromašnim zemljama. Studenti tih zemalja mogu se uključivati u savremene nastavne programe i na taj način podići jaz obrazovanja u svojim zemljama. Učenje kod kuće znatno je jeftinije nego svakodnevna putovanja i odlasci u obrazovne ustanove.

Evropska komisija u svojim dokumentima (e-learning Action Plan 2004-2006) snažno podržava razvoj učenje na daljinu odnosno e-obrazovanja u svim državama članicama EU. U Evropskoj komisiji razrađen je jasan plan da se do kraja 2005. godine na univerzitetima u svim zemljama članicama ponudi studentima distance learning i e-obrazovanje.

2. NAČIN IZVOĐENJA NASTAVE NA DALJINU

Obrazovanje preko Interneta, kao vid školovanja van uobičajenih institucija, u kome profesori i studenti razdvojeni fizički i vremenski, javlja se kao osnov za promene u tradicionalnom modelu univerziteta i za kreiranje nove obrazovne paradigme – virtuelnog univerziteta [3]. Studentima su dostupni svi sadržaji vezani za osnovnu literaturu iz svakog predmeta u tekstualnom obliku, predavanja profesora u pisanoj formi i u Power Point-u, video-klipovi sa predavanja profesora, zadaci za vežbu, primeri realizovanih projekata, ispitna pitanja, uputstva za pripremu ispita. Svaki predmet bi trebalo da ima diskusioni forum preko kojeg bi studenti mogli da pročitaju odgovore na najčešće postavljena pitanja, da postavljaju nova pitanja i dobijaju odgovore, da šalju seminarske i diplomske radove i dobijaju povratne informacije i uputstva kako da izvrše korekcije i što kvalitetnije završe svoje obaveze.

Ovaj vid edukacije podrazumeva čestu upotrebu i videokonferencija preko kojih bi studenti srodnih fakulteta mogli da prate nastavu u isto vreme sa različitih fakulteta, međusobno komuniciraju i razmenjuju znanja, što bi obogatilo njihova iskustva, podiglo motivaciju i stvorilo preduslove za interaktivnu nastavu na različitim fakultetima. Videokonferencijska veza je dvosmerna, pa studenti iz svih učionica imaju mogućnost postavljanja pitanja profesoru koji predaje. Broj dolazaka gostujućih profesora se, na taj način se smanjuju, troškovi se redukuju, a vreme racionalnije koristi. Slična praksa postoji na univerzitetima razvijenih država i realizuje se tako da saradnik organizuje studente koji preko bim projektora i interneta prate predavanja, a kada žele da postavljaju pitanja aktivira se kamera i mikrofon koji su smešteni u učionicu čime se ostvaruje stalna interakcija. U bogatijim zemljama zapadne i severne Evrope postoje i primeri obrazovnih programa u kojima svaki polaznik u svom domu ili radnom stolu prati predavanje putem tzv. stonih videokonferencija. Pretpostavka je da polaznik na svom računaru ima priključenu kameru, zvučnike i mikrofon, kao i instaliran neki od programa za stonih videokonferencije. Moguće je istovremeno učestvovanje više polaznika. Video konferencijska tehnologija, u sprezi sa Internetom, omogućuje povezivanje kompanija, državnih ustanova, akademskih institucija i privatnih domova. Obrazovni softver pruža studentima mogućnost periodične provere znanja kroz testove koje šalju elektronskim putem profesorima na pregled. Na taj način profesor prati i analizira napredovanje studenata i kvalitetnije finalizira ispite.

Posebno je značajno osmisliti organizaciju nastave koja bi se uskladila sa zahtevima Bolonjske deklaracije i nacrtom Zakona o univerzitetu po kojem se broj ispitnih rokova smanjuje, što znači da mora da se poveća angažovanost nastavnika i studenata i da se češće vrše provere znanja (merenje, praćenje i vrednovanje različitih aktivnosti) studenata. Informaciona tehnologija sa tzv. inteligentnim softverom može da

bude od velike pomoći nastavniku da prati, ne samo, ishode nego i proces kojim student ostvaruje ishode. Svaki korak u procesu rešavanja zadatka bi se vrednovao, ukazivalo bi se na eventualne greške i student bi dobijao uputstva za pravilno rešavanje zadataka. Posebno je značajno naglasiti da informaciona tehnologija ne isključuje niti umanjuje značaj nastavnika u obrazovnom procesu, nego mu daje sofisticiraniju ulogu kojom se smanjuje vreme za izlaganje nastavnih sadržaja koje studenti mogu samostalno da pročitaju, a ostaje više vremena za razvoj kreativnih potencijala, kritičkog mišljenja i razvoj razumevanja principa rešavanja zadataka

3. OBRAZOVANJE NA DALJINU U SRBIJI

Svest o obrazovanju na daljinu u Srbiji još nije dovoljno jaka, iako na pojedinim fakultetima izvodi se online nastava, te se pristupa i izradi online nastavnih materijala. Nastavu se odvija primenom koncepta Blended learning, koji predstavlja kombinaciju tradicionalnog učenja i učenja na daljinu. Smatra se da je ovaj vid nastave, tj. mešovita (distribuirana, hibridna) nastava predstavlja adekvatno balansiranu primenu rada u učionici sa radom uz pomoć medija/tehnologije. Na taj način se omogućava da se u isto vreme iskoriste prednosti oba načina.

Strateški cilj Srbije je povećanje broja visokoobrazovnih ljudi uz što bolji kvalitet visokog obrazovanja, a za to je potrebno postaviti standarde kvaliteta obrazovanja i proveravati njihovu primenu, ulagati u obrazovanje, uspostaviti vezu sa tržištem rada. Neophodno je utvrditi koji studijski programi nisu dobri, koji profesori ne rade kvalitetno, da li su dostupni studentima, kakva je literatuta koju koriste. Danas, učenje treba da bude dostupno svakom građaninu, nezavisno od godina, nivoa obrazovanja, društvenog statusa i prilagođeno individualnim potrebama.

Srbija ne poseduje veliko iskustvo sa pokretanjem online studija i virtuelnih fakulteta. Sprovedena je studija tokom 2009.godine, koja je za cilj imala merenje uloge online učenja i koliko je ovaj proces prihvaćen kod studenata i preduzetnika u Srbiji. Intervjuisano je 54 učesnika (34 žene i 20 muškaraca) starosti od 18 do 30 godina, i postavljena su im sledeća pitanja:

- Šta mislite o učenju na daljinu?
- Šta mislite o virtuelnim profesorima?
- Kakva je interakcija između studenata, i između studenata i profesora?
- Da li nove tehnologije izoluju studenta od profesora?
- Da li dajete prednost obrazovanju na daljinu ili tradicionalnom obrazovanju?
- Kakvi su rezultati učenja na daljinu u odnosu na učenje licem u lice?

Na osnovu empirijskih istraživanja došlo se do sledećih podataka da:

- Da veliki procenat učesnika (njih 63%) nije upoznato sa programom obrazovanja na daljinu
- 30% učesnika je izjavilo da postoji mnoštvo razloga za upisivanje online kurseva.
- 50% učesnika ne želi da diskutuje sa drugim studentima ili profesorima koje ne mogu da vide.

- Većina učesnika (95% njih) smatra da je poznavanje rada na računaru najbitnije za online učenje.

Nacionalni savet za visoko obrazovanje je formirao Komisiju za akreditaciju i proveru kvaliteta primene Bolonjske deklaracije, kao radnu jedinicu koja će se baviti akreditacijom, proverom kvaliteta i procenom studijskih programa. U akreditacionom materijalu, Standard 12 je posvećen učenju na daljinu. Po ovom standardu svaka ustanova visokog obrazovanja može organizovati učenje na daljinu za bilo koju obrazovnu oblast, pri čemu mora posedovati adekvatne resurse. Kvalitet stečenog znanja i trajanje studija moraju biti isti kao u slučaju tradicionalnog oblika obrazovanja i stečena diploma mora biti ista u oba vida studiranja. Studijski program mora imati moderan koncept i biti pogodan za učenje na daljinu, sa odgovarajućim vremenom koje je studentima potrebno za konsultacije. Obrazovne ustanove moraju dati uputstva koja će polaznicima pomoći da razviju strategiju učenja i samostalnog testiranja stečenog znanja. Ispiti se moraju sprovoditi u prostorijama obrazovne ustanove.

Obrazovne ustanove moraju imati kvalifikovane i osposobljene profesore i asistente za studijski program organizovan u obliku učenja na daljinu. Jedan profesor može biti zadužen za tri predmeta tokom jednog semestra. Profesor i asistent ne može imati konsultacije sa više od 80 studenata tokom jednog semestra. Obrazovna ustanova mora imati najmanje 70% profesora sa punim fondom časova (najmanji broj profesora se izračunava prema broju studenata i broju časova).

4. OBRAZOVNA PLATFORMA MOODLE LMS

Moodle (Modular Object Oriented Developmental Learning Environment) je jedan od najpopularnijih i najviše korišćenih sistema otvorenog koda (engl. Open source) za upravljanje online učenjem (engl. Learning Management System-LMS)[5]. Trenutno se koristi u više od 200 zemalja širom sveta i do sada je lokalizovan na čak 78 jezika. Od skora je dostupna i verzija prilagođena na srpskom jeziku (ćirilčna i latinična). Osnivač i kreator Moodle je australijanac Martin Dougiamas, koji je predavač i naučnik što predstavlja veoma dobru kombinaciju za razvoj ovakvog tipa softvera.

Moodle je mrežna aplikacija koja se instalira na serveru, a pristupa joj se s bilo kojeg umreženog računara putem web čitača (engl. web-browser). Poseban naglasak kod svih besplatnih rešenja (rešenja otvorenog koda), je stavljen na dokumentaciji i podršku u eksploataciji. S obzirom da kreatori ovakvih aplikacija nisu odgovorni za eventualne štete nastale upotrebom njihovih proizvoda često za takva rešenja ne postoji dobra dokumentacija, a ni podrška od strane tvorca rešenja. Tvorci Moodle platforme su shvatili da takav pristup ne može dovesti do veće upotrebe njihovog proizvoda i iz tog razloga su posebnu pažnju posvetili dokumentaciji i uopšte podršci za instalaciju, razvoj, ali i krajnju upotrebu. Online zajednica na zvaničnom sajtu moodle.org broji preko 900 hiljada registrovanih korisnika. Korisnicima je pored dokumentacije i liste najčešće postavljanih pitanja (FAQ) na raspolaganju i forum gde mogu pronaći odgovore na svoja pitanja, ali takođe mogu otvarati nove teme i pitanja. Posebna stavka na moodle.org je i lista dodatnih modula i plugin-ova koji se mogu ugraditi u svaki sajt zasnovan na moodle platformi.

Moodle i njemu slični sistemi omogućavaju da student u bilo koje vreme i sa bilo kog mesta pristupi nekim sadržajima kursa, obaveštenjima, polaganju ispita. Studiranje na daljinu, kao jedan od sve popularnijih metoda studiranja, omogućava manje stresa jer studenti nemaju pritisak da moraju biti na određenom mestu, u

određeno vreme, a tako lakše i efikasnije organizuju svoje vreme. Razmena iskustva je veoma bitan koncept u procesu učenja. Omogućava studentima da aktivno učestvuju u kreiranju sadržaja kurseva, kao i mogućnost ostavljanja iskustava i komentara vezanih za neki predmet, događaj. Korisnici se mogu podeliti na administratore, predavače sa raznim rangiranim ovlašćenjima i polaznike.

Ne postoji ograničenje u broju servera koji jedna ustanova može da ima i nije redak slučaj da organizacije imaju više od jednog Moodle servera. Postoje sajtovi koji imaju prijavljeno više od 40 hiljada i 19 hiljada kurseva, jedan od većih sajtova je i Open University iz Velike Britanije koji ima 200 hiljada korisnika u svom sistemu za obrazovanje na daljinu.

5. PLAN IMPLEMENTACIJE MOODLE NA VISOKOJ POSLOVNOJ ŠKOLI STRUKOVNIH STUDIJA U NOVOM SADU

Po mnogim anketama koje su objavljene na Internetu, Moodle predstavlja jednu od najprihvaćenijih platformi u svom segmentu. Jednostavna instalacija i eksploatacija ovaj proizvod čine veoma prihvatljivim rešenjem i za studente i profesore, ali i za ljude čiji je posao održavanje aplikacija. Srbija na ovoj platformi ima 112 registrovanih sajtova [6]. Visoka poslovna škola bi mogla, primenom programa studiranja na daljinu, pružiti šansu zaposlenima, kao i onima koji nisu u mogućnosti da studiraju na tradicionalan način, koji su ograničeni vremenom, udaljenošću ili fizičkom hendikepiranošću.

Sistem za studiranje na daljinu fakulteti i visoke škole mogu realizovati primenom softverskog rešenja Moodle LMS. Uspeh obrazovanja na daljinu zavisice od primene sistema za upravljanje učenjem, alata za kreiranje i distribuciju sadržaja i integracije sa postojećim informacionim sistemima u obrazovnoj ustanovi. Implementacije Moodle obuhvataće sedam faza[6]:

- *Prva faza: Utvrđivanje potreba i ciljeva.* Određivanje potreba i ciljeva koji se mogu ispuniti upotrebom Moodle-a;
- *Druga faza: Lansiranje softvera.* Donošenje odluka vezanih za instalaciju Moodle softvera, backup, održavanje, nadogradnju i prilagođavanja izgleda;
- *Treća faza: Konfigurisanje Moodle-a.* Kofigurisanje izgleda sajta, organizacione strukture, ustanovljavanje politike sajta, kreiranje kurseva i korisničkih naloga;
- *Četvrta faza: Profesionalni razvoj i podrška.* Donošenje odluka koje se tiču profesionalnog razvoja osoblja i trenutno potrebnog nivoa podrške.
- *Peta faza: Ponovna procena.* Ponovna procena potreba i ciljeva, u cilju praćenja ostvarenog napretka;
- *Šesta faza: Prilagođavanje.* Ustanovljavanje potrebnih izmena na osnovnoj instalaciji Moodle-a
- *Sedma faza: Nastavak profesionalnog razvoja.* Određivanje neophodne obuke osoblja, radi unapređivanja upotrebe i usvajanja najbolje prakse.

Prva faza: Potrebe i ciljevi

Tokom ove faze, Visoka poslovna škola treba odrediti potrebe i ciljeve, koji se mogu ispuniti upotrebom Moodle softvera. Škola ide u korak sa vremenom i učinila je ogromne napore kako bi svoju tehničku opremljenost dovela na nivo koji se očekuje od jedne savremene obrazovne institucije. Raspolaze sa najmodernijom tehničkom opremom, za potrebe nastave su kupljene interaktivne Smart tabla, koja omogućava profesorima i asistentima da snime svoja predavanja, koja su kasnije dostupna studentima. Nastavni kadar ima i svoje sajtove, gde postavljaju sva važna obaveštenja i materijale za nastavu. Cilj idejnog projekta jeste uvođenje koncepta Blended learning, koji bi studentima omogućio da uče u slobodno vreme, dostupnost osnovne literature iz svakog predmeta, video klipove sa predavanja profesora, diskusione forume. Student bi imao obavezu jedino da polaže ispite u Školi. Obrazovanje na daljinu u kombinaciji sa tradicionalnom nastavom bi predstavljalo značajnu inovaciju, koja bi znatno doprinela poboljšanju kvaliteta nastave. Tokom ove faze, nastavni kadar se upoznaje i stiče iskustvo u korišćenju Moodle softvera.

Druga faza: Lansiranje softvera

Tokom ove faze, donosićete odluke koje se tiču lansiranja Moodle softvera. Sada je najbolje vreme za planiranje backup-a, održavanja, nadogradnje i brendinga kroz prilagođavanje tema (izgleda interfejsa). Danas Škola poseduje adekvatnu internet konekciju i dovoljan protok za pristup željenog broja korisnika Moodle-u. Infrastrukturu za realizaciju sistema obrazovanja na daljinu Visoke poslovne škole činiće jedan računar – server sa dovoljnim kapacitetom da ispuni zahteve implementacije Moodle paketa. Računar sa svojim performansama mora da zadovoljava sve zahteve koje mu nameće učenje na daljinu i raspolaze: dovoljno snažnim procesorom, velikom količinom memorije i memorijskog prostora.

Treća faza: konfiguracija Moodle-a

Ova faza vezana je za administrativnu obuku, konfiguraciju Moodle-a, postavljanje naloga i kurseva i pokretanja strategija za upravljanje kursevima i korisnicima. Škola će obezbediti obuku za određenog Moodle administratora, koji će uspešno da administrira sistem za upravljanje učenjem, pokrivanjem svih aspekata konfiguracije Moodle-a, uključujući izgleda sajta, organizacionu strukturu, politiku sajta, kreiranje kurseva i upravljanje korisničkim nalogima.

Moodle korisnički nalozi (student, nastavnik i administrator) se mogu kreirati ručno ili se ovaj proces može automatizovati. Automatizacija kreiranja naloga se postiže povezivanjem Moodle-a sa informacionim sistemom škole, pritom se kreira jedinstveni identifikacioni broj za svakog korisnika. Ovo omogućava da sve aktivnosti unutar sistema budu zabeležene i praćene, i da korisnici imaju pristup funkcijama i resursima koji odgovaraju njihovim ulogama u procesu obuke.

Četvrta faza: Profesionalni razvoj i podrška

U ovoj fazi Škola donesi odluke koje se tiču profesionalnog razvoja i trenutno potrebnog nivoa podrške. Razmatraće pitanja poput:

- Kojim članovima osoblja je neophodan profesionalni razvoj?
- Ko će im pružiti taj profesionalni razvoj?

- Kakav materijal za obuku će biti potreban?
- Da li će biti neophodna tekuća podrška?

Škola treba da obezbedi za potrebe Moodle obuke računare za učesnike, zadovoljavajući pristup internetu i projekcioni uređaj. Tokom ove faze, nastavni kadar će se upoznati sa osnovama Moodle interfejsa, učiče kako da instaliraju i pokrenu Moodle. Svi standardni resursi, aktivnosti i blokovi će tokom obuke biti predstavljeni, kao i njihova primena. Takođe će biti predstavljeni efikasni projekti kurseva i predložene strategije obuke.

Nastavni kadar koji poseduje napredno tehnološko znanje će biti zadužen za obuku ostalog nastavnog osoblja u Školi. Biće predstavljene sve komponente uvodnog kursa, kao i napredne teme, poput metakurseva, grupa, ugradnje Web 2.0 aplikacija, održavanje kurseva i sistema.

Materijali namenjeni nastavnom kadru prilikom uvođenja i korišćenja Moodle softverskog rešenja su:

- Digitalni vodič za nastavnike - Osmišljen za nastavnike koji su početnici u Moodle-u, ovo uputstvo daje uvod u alatke koje su dostupne u okviru Moodle-a. U njemu su korak po korak date instrukcije za upotrebu ovih alatki.
- Alat za često postavljana pitanja (FAQ) - Ovaj alat daje brze odgovore na često postavljana pitanje i prilagođen je potrebama nastavnog kadra. Pitanja se mogu pretraživati po ključnoj reči ili pregledati po kategoriji.

Peta faza: Ponovna procena

U ovoj fazi Škola će izvršiti procenu postignutog napretka u smeru ostvarenja ciljeva i zadovoljenja potreba. Anketiranje i ocenjivanje nastavnog kadra može doneti značajan uvid u napredak implementacije Moodle i merenje uspešnosti u obučavanju. Ukoliko je nastavni kadar savladao osnove spremni su da koriste neke od naprednih funkcija Moodle-a:

- Modul za lekcije – demonstrira kako kreirati interaktivne, samostalne razgranate lekcije;
- Edukativne ugradive komponente – koje uče kako da ugradimo Web 2.0 resurse u Moodle i gde da pronađemo takve resurse;
- Održavanje – demonstrira procese backup-a, oporavka sistema, uvoza komponentata i vraćanja sistema u početno stanje;
- Spektar moguće primene – demonstrira kako se Moodle može iskoristiti do punog potencijala.

Šesta faza: Prilagođavanje sistema

Tokom ove faze, Škola će utvrditi potrebu za prilagođavanjem osnovne Moodle instalacije. Širok dijapazon eksterno razvijenih modula i integracija mogu proširiti osnovnu moodle instalaciju.

Sedma faza: Kontinuirani profesionalni razvoj

Kao rezultat završene procene Moodle implementacije, Škola će doneti odluku da li je potrebna dodatna obuka za profesore. Može se sprovesti obuku i za napredni nastavni kadar za dodatke i integracije dodatke Moodle sistemu.

6. ZAKLJUČAK

Razvoj obrazovanja, odnosno učenja na daljinu, u svetu je dostigao značajan nivo sa velikim brojem korisnika. Obrazovne institucije došle su u izazov da osiguraju kvalitetno obrazovanje prema zahtevima tržišta koje diktira dinamiku promena u svim aspektima života. Mnoge škole, visokoobrazovne ustanove došle su do zaključka da moraju odgovoriti zahtevima te su postakle razvoj novih načina obrazovanja, a jedan od njih je i obrazovanje na daljinu.

Mnogi univerziteti u svetu nude razne programe obrazovanja na daljinu. Primenjivanje ovakvog oblika obrazovanja u našoj zemlji nije u toj meri zastupljeno, a neki od tih razloga su: nedovoljno informatičkog obrazovanja, nedostatak adekvatnog softvera, nedostatak opreme, nedostupnost adekvatne literature, nepoverenje nastavnika prema novim oblicima izlaganja gradiva.

Učenje na daljinu je izazov i sredstvo za poboljšanje i unapređenje obrazovnih procesa, kao i jedan od temelja za nove i bolje načine upravljanja znanjem. Intenzivno uvođenje informacionih tehnologija u obrazovne procese postao je prioritet modernih visokoobrazovnih institucija širom sveta. Tako se poslednjih godina u Srbiji uveliko radi na implementaciji Bolonjske deklaracije. Bolonjska deklaracija daje jasne normative i standard koje svaka obrazovna institucija mora ispuniti da bi se uspešno akreditovala i uhvatila korak sa evropskim i svetskim obrazovnim institucijama.

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ORGANIZACIONI MODELI I RAZVOJ GENERIČKIH TEHNOLOGIJA ZA PROIZVODNU INDUSTRIJU

Vlado Medaković¹, Bogdan Marić² Slaviša Moljević³ Srđan Vasković⁴

Rezime: Inovacije i generičke tehnologije za razvoj proizvodnog sektora imaju važnu ulogu. Uslovi kao i podrška razvoju generičkih tehnologija nisu na dovoljnom nivou. Razvoj generičkih tehnologija još uvijek ne može da zadovolji nacionalnu privredu i potrebe razvoja prerađivačke industrije. Generičke tehnologije imaju veliki značaj i uticaj na prerađivačku industriju i preduzeća koji mogu dati ogromnu ekonomsku korist za državu. U radu su prikazani organizacioni modeli za razvoj generičkih tehnologija u proizvodnoj industriji kao i njihove međusobne veze.

Ključne riječi: Generičke tehnologije, organizacija, proizvodne industrije

ORGANIZATIONAL MODELS AND DEVELOPMENT GENERIC TECHNOLOGIES FOR THE MANUFACTURING INDUSTRY

Abstract: The innovation and the development of generic technologies for the manufacturing sector have an important role. Conditions and support the development of generic technologies are not affordable level. The development of generic technologies still can not meet the needs of the national economy and the development of the manufacturing industry. Generic technologies are of great importance and impact on the manufacturing industry and the companies that can provide a huge economic benefit for the country. This paper presents models of organizations for the development of generic technologies in the manufacturing industry as well as their interrelations.

Keywords: Generic technologies, organizations, manufacturing industries

1. UVOD

U skladu s klasifikacijom firme „Artur D.Little Ltd.“ tehnologije se mogu podijeliti na tri velike kategorije. Prva kategorija, bazne tehnologije su tehnologije koje su u najvećoj mjeri prisutne u osnovi određene djelatnosti, čiji konkurentski uticaj više nije odlučujući, jer su široko rasprostranjene i u njima konkurenti imaju ekvivalentne mogućnosti. Druga, ključne tehnologije su one u kojima je konkurentski uticaj najjači, koje čine bazu konkurencije i čijim ovladavanjem se stiče sasvim specifična kompetentnost, nužna za uspjeh u određenom domenu proizvodnje. Treća, generičke

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(dolazeće ili nastajuće) tehnologije su tehnologije koje se tek stvaraju, nastaju, prolaze kroz etapu ispitivanja u pilot postrojenjima i prve primjene u nekim domenima. One samo djelimično učestvuju u proizvodnim procesima u određenim granama industrije. Poslije provjere u praksi i zadovoljavanja uslova kao što su efikasnost, efektivnost i ekološki standardi, neke od generičkih tehnologija mogu postati ključne u određenoj grani industrije. Generičke tehnologije ili njihove komponente u hibridnim tehnologijama nazivaju se tehnologijama budućnosti ili tehnologijama III milenijuma, odnosno tehnologijama XXI vijeka.

Savremenu svjetsku privredu karakterišu nagle promjene koje su vođene, prije svega, tehnološkim progresom velikih industrijskih zemalja. Među progresivnim tehnologijama, prije svih, prednjači informaciona koja je približila udaljena tržišta i resurse, ujedinila ukuse i potrebe. Tehnologija je oduvijek bila važan faktor ekonomskog blagostanja. Proizvodnja je temelj ekonomskog razvoja i konkurentnosti svake države. Prerađivačka industrija je snaga razvoja visoke i nove tehnologije (Kotnou, 2000.). Generičke tehnologije imaju veliki uticaj na prerađivačku industriji i preduzeća. Da bi se postigao uspjeh u pogledu inovacija i generičkih tehnologija za proizvodnju moramo imati odgovarajuću organizaciju (Longcan, 2005.). Dobra organizacija ne može ostvariti sama uspjeh u razvoju generičkih tehnologija za proizvodnju, kao i promociju inovacija, ali može da ostvari normalnu difuziju tehnoloških dostignuća. Zbog različitih tipova generičkih tehnologija za proizvodnju, moramo kombinovati karakteristike proizvodnje i primjenjivati odgovarajuće modele organizacije za razvoj generičkih tehnologija.

2. RAZVOJ GENERIČKIH TEHNOLOGIJA

Subjekti razvoja generičkih tehnologija za proizvodnju su različiti i uključuju preduzeća, vlade država, univerzitete, istraživačko – razvojne institute i posredničke organizacije. Preduzeće je direktni korisnik generičkih tehnologija, koji je predmet tehnološke inovacije. Vlada vodi politiku tehnološkog razvoja, koja je ključ nacionalnih tehničkih politika. Univerzitet je važan i koristan sa aspekta pružanja znanja i obrazovanja talenata. Naučno istraživačke institucije su ključne u direktnom istraživanju i razvoju generičkih tehnologija za proizvodnju. U tabeli 1. prikazana je komparativna studija razvoja generičkih tehnologija.

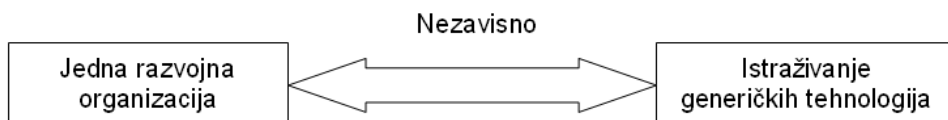
Tabela 1. Komparativna studija razvoja generičkih tehnologija za proizvodnu industriju

Subjekti	Funkcija	Izvor	Status
Preduzeća	<i>Integrisanje eksternih i internih informacija i resursa</i>	<i>Informacije sa tržišta odnosno kupaca</i>	<i>Osnovni subjekt</i>
Univerziteti	<i>Simulacija rada preduzeća, mogućnosti generičkih tehnologija</i>	<i>Talenti</i>	<i>Bazni subjekt</i>
Naučno istraživačke institucije	<i>Iznalaženje tehničkih rješenja</i>	<i>Tehnologije</i>	<i>Bazni subjekt</i>
Vlada	<i>Podrška državnih institucija i publicitet</i>	<i>Politika i Fondovi za razvoj</i>	<i>Organizovanje i vođenje</i>

Klasifikacija organizacija po svom specifičnom razvoju, odnosno nivoima pri razvoju generičkih tehnologija, mogu se podijeliti na jednu razvojnu organizaciju, zatim vladine organizacije i vođenje organizacije i organizacije na tehničkoj saradnji.

Jedna razvojna organizacija uključuje instituciju koja se bavi i istraživanjem i razvojem generičkih tehnologija. To mogu biti univerziteti i istraživački instituti.

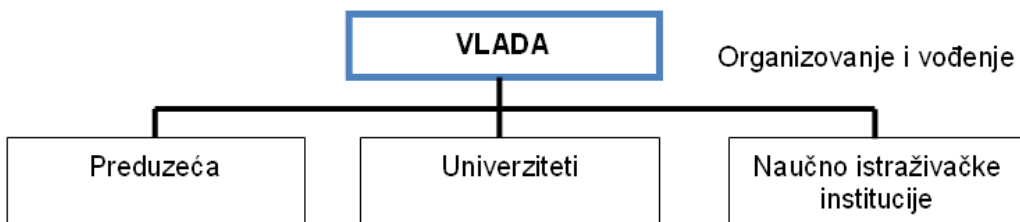
Na Sl. 1. prikazana je jedna razvojna organizacija.



Sl. 1. Jedna razvojna organizacija

Drugi oblik organizovanja jeste taj da vlada države daje snažnu podršku nacionalnim istraživačkim institucijama kao vodećim faktorima i da vodi organizaciju kroz planiranje i donošenje strategija za razvoj. Preuzima na sebe da ujedini razne institucije pri provođenju planova i projekata.

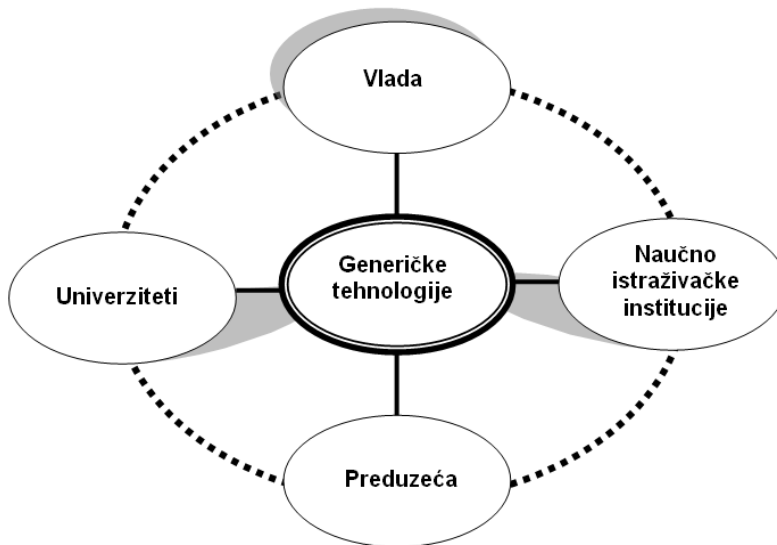
Na Sl. 2. prikazan je model Vladine organizacije i vođenje organizacija.



Sl. 2. Vladine organizacije i vođenje organizacija

Tehnička saradnja organizacija uključuje projektnu saradnju, baziranu na tehnološkoj saradnji, saradnji u pogledu istraživanja i razvoja. Za generičke tehnologije svojstvena je i odlučujuća saradnja sve više i šire u pogledu istraživanja i razvoja.

Tehnička saradnja organizacija je prikazan na slici 3.

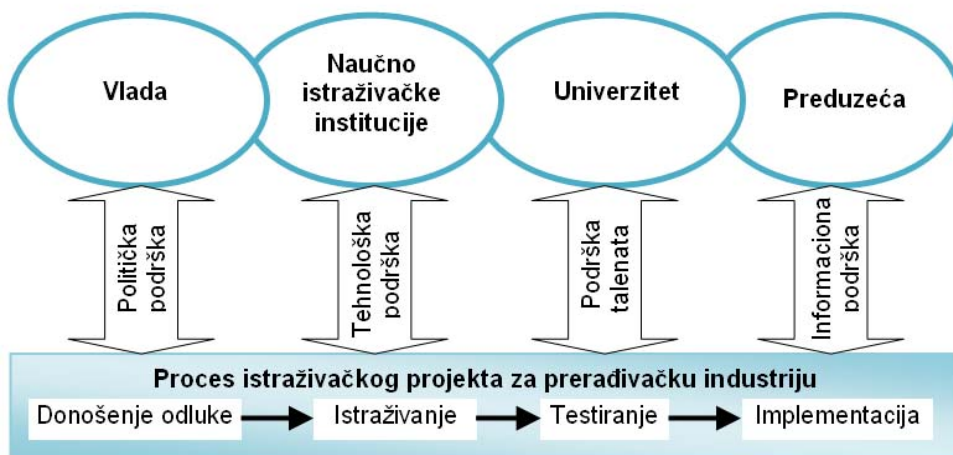


Sl. 3. Tehnička saradnja Organizacija

Inovativna organizacija za razvoj generičkih tehnologije za industrijsku proizvodnju može se podijeliti na projektnu organizaciju, tehnološki savez, istraživačke baze i nacionalne istraživačke institucije za razvoj generičkih tehnologija.

Projektna organizacija odnosi se na privremenu saradnju u koju su uključene sve relevantne strane kako bi izradili naučno – istraživački projekat u određeno vrijeme i za određeni cilj. Njegove prednosti su u pogledu da su organizovani sa jasnim ciljem za razvoj generičkih tehnologija te rokom da ispune zahtjeve složenog istraživačkog procesa u prerađivačkoj industriji.

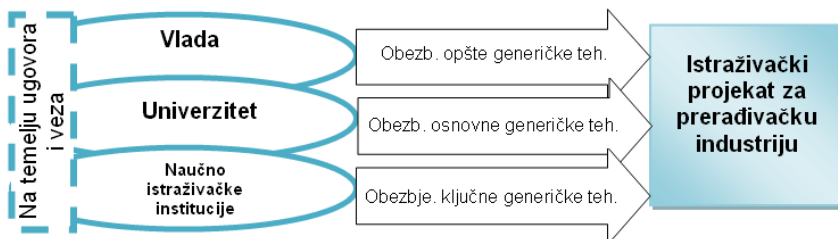
Projektna organizacija je prikazan na slici 4.



Sl. 4. Projektna organizacija

Tehnološki savez je saradnja različitih organizacija i to vlada, preduzeća, univerziteta i naučno – istraživačkih institucija na temelju ugovora. Različita tijela s istim ciljem uključena su u aktivnosti istraživanja i razvoja generičkih tehnologija kako bi se zadovoljile potrebe proizvodne industrije.

Tehnološki savez je prikazan na slici 5.

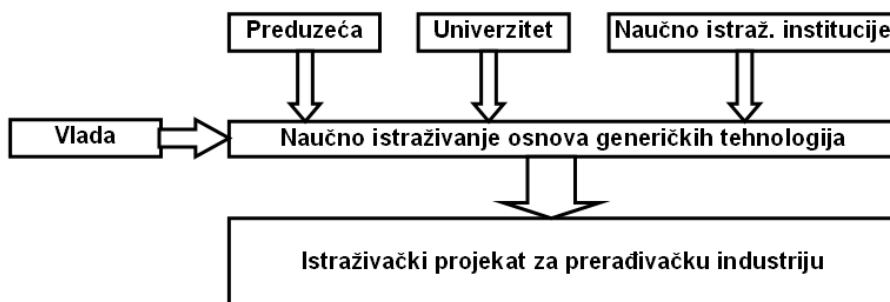


Sl. 5. Tehnološki savez

Naučno – istraživačka baza generičkih tehnologija je baza istraživanja i razvoja, koja se oslanja na vrede država sa aspekta kapitala, zatim preduzeća, univerzitete ili naučnog istraživačke institute, fokusirajući se na zadatak odnosno istraživanje generičkih tehnologija.

Naučno – istraživačka baza je dugoročni organizacioni model za istraživanje i razvoj generičkih tehnologija, koji nemaju za cilj neku posebnu tehnologiju ili industriju, no međutim, ima opštu upotrebljivost i širi uticaj. Pogodna je za vremenski duža istraživanja kompleksnih procesa u proizvodnji.

Na slici 6. prikazana je naučno – istraživačka baza generičkih tehnologija.



Sl. 6. Naučno – istraživačka baza generičkih tehnologija

Nacionalna institucija za istraživanje generičkih tehnologija je organizacija čiji fond gotovo ili potpuno iz vlade, uglavnom se bave razvojem generičkih tehnologija u oblasti mjerenja i standarda koji pružaju osnovnu podršku u procesu poboljšanja industrijskih tehnologija.

3. ZAKLJUČAK

Organizacioni modeli za razvoj generičkih tehnologija trebaju biti utemeljeni na više nivoa, odnosno podstaknuti sa više nivoa i različitih subjekata. Treba podsticati i promovisati razvoj generičkih tehnologija za proizvodnju na temelju tržišne mobilizacije resursa i inovacija. Mi treba da odaberemo odgovarajući model organizacije za različite vrste generičkih tehnologija, te razmotriti vrste i osnovna obilježja industrijske generičke tehnologije, faktore unutrašnjeg, društvenog i ekonomskog okruženja itd. Ne postoji dovoljno razvijena svijest kod menadžera i preduzetnika o potrebi uvođenja i ulaganja u ove vrste tehnologija. Osim toga, čini se da mala i srednja preduzeća, odnosno preduzetnici ne shvataju da ulaganje ne znači trošak, nego investicija koja će im omogućiti smanjenje troškova i bolju konkurentnost.

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Session VII ***MAINTENANCE AND TECHNICAL*** ***DIAGNOSIS***



THE METHODOLOGY ASPECTS FOR MONITORING THE MACHINE ELEMENTS, COMPONENTS AND SYSTEMS

Andreja Ilić¹, Lozica Ivanović², Danica Josifović³, Vukić Lazić⁴

Abstract: *The aspects of present methodology for monitoring the machine elements, components and systems in relation to modern demands in mechanical engineering are presented in this paper. Monitoring of elements, components and systems is complex task that include set of procedures with define order with usage of specific testing and measuring equipment. For detection and analysis of cracks and leaks due to porosity and cracks, hydraulic and pneumatic methods are presented in the paper. Vibro-acoustic method is presented as methodology for testing of mashing, assembling and functioning of rotating elements, so as eccentricity and rigidity of joints. The surface conditions analysis such as impact damages, pits, flexions, deflections, damages of the surface properties are done visually, while the testing of the internal surfaces are done by endoscopic methods. The surface damages, cracks and flaws at ferromagnetic materials are tested by magnetic methods. Penetrant and luminescent methods are used for detection and analysis of the deep surface cracks. For detection and analysis of internal cracks and cavities the radiography, ultrasound testing and acoustic emission testing are used.*

Stress and strain state in present mechanical constructions becomes far more complex with simultaneous reduction in its weight, dimensions altogether with using of new lightweight materials, higher energy efficiency demands and environmental concerns. The risks of failures at mechanical constructions rise with simultaneous improving its safety and reliability. In those conditions, the importance of methodology for monitoring the machine elements, components and systems come in the focus of the present machine diagnostics.

Keywords: *monitoring, machine elements, safety, reliability, machine diagnostics*

1. INTRODUCTION

The object of mechanical construction testing in exploitative conditions is to provide relevant information about quality of constructions, technical conditions of

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those constructions and its elements, functional reliability and proper functionality, so as to provide data about exploitative conditions of constructions in order to define and verify data about load and environment conditions. The characteristic of technical systems, in general, are identified on the basis of the output value (output vector) for precise defined input (vector of control).

During exploitation, the technical systems are under the influence of large number of different factors that affect to their technical condition and functionality. The influence of those exploitative factors on system technical condition is basically through continual alterations of certain characteristics and parameters starting from nominal to critical values. These alterations of characteristics and parameters of the technical systems in time are consequences of unwanted but inevitable physical-chemical processes that act within those systems. Monitoring of technical systems enclose the set of precisely defined activities in aim to provide qualitative and quantitative analysis of the system characteristics. From the methodology aspects, the most important are the nondestructive testing methods that do not require disassemble of the technical systems elements and those testing methods are considered in this paper.

2. EXPERIMENTAL PROCEDURE FOR MONITORING OF TECHNICAL SYSTEMS

Experimental procedure for monitoring of technical systems enclose the set of the precisely define methods that are used in industry, so as for scientific researches for determination of their functional conditions and characteristics and usually do not have invasive approaches. Even if methods of mechanical constructions testing are strictly define in standards related to this topic, the methodologies for experimental procedures for monitoring of technical systems are still based on recommendations of the producers and on experience of their users. The experimental procedures for monitoring of technical systems have to provide reliable, efficient and prompt detection of dangerous conditions, so as to identify causes. In order to consider the methodology aspects of technical systems monitoring, the basic experimental procedures are briefly presented in this paper with focus on comparative characteristics of every procedure.

3. NONDESTRUCTIVE METHODES FOR EXPERIMENTAL TESTING OF MACHINE SYSTEMS

Visual control

The accuracy and reliability of visual control method is small and limited and depend on large number of factors that cannot be put under the influence.



Fig. 1 Endoscopes: a) flexible, b) rigid and c) endoscopes with camera

Due to wide range of applications, minimal costs, small time need, this method still have significant usage for monitoring of technical systems. For the visual control of inaccessible areas without of disassembly, the endoscopes are used. The endoscopes can be flexible, rigid or can be equipped with camera (Fig. 1).

The special care during monitoring by those methods has to be focused on the zones of high temperature and mechanical loads, so as on zones with high levels of stress concentrations. The damages on specific elements of machine systems such as gears and connecting rod of piston identified by visual control are presented at Fig. 2 and Fig. 3.

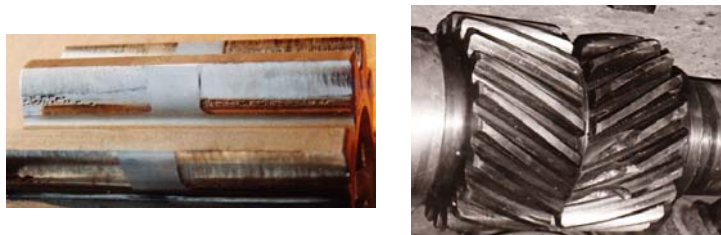


Fig. 2 Gear damages identified by visual control



Fig. 3 Damages on connecting rod of piston

Hydraulic and pneumatic methods

Hydraulic method for experimental testing of technical systems is used for detection of cracks and damages in machine elements such as housings, suction and exhaust pipes and so on. Liquid under the controlled pressure is bringing inside of the element that is subjected to testing. The confirmation of functionality of tested element is done by measuring of pressure during defined period of time. In case when pressure maintain within allowable limits, the tested characteristics of the element satisfied required conditions.

Pneumatic method is used for detection of cracks and failures at the elements of mechanical constructions such as heating elements and boilers. The openings at tested elements are sealed at the begging of the monitoring procedure, after that the element is put in liquid. The presence of the air bubbles in liquid is identification of cracks at tested elements of mechanical constructions. If dimensions of element do not allowed it to be put in the liquid, soap solution is applied on the surface of the tested element and at the zones of defects and cracks the bubbles of soap solution are formed.

Penetrant testing

The penetrant testing method at mechanical constructions is quantitative technique for detection of surface defects on elements of those constructions (Fig. 4). Penetrant is applied to the surface of examined object. The liquid is pulled into surface defects by capillary action. This method is used to trace cracks, porosity, and other defects that break the surface of a material and have enough volume to trap and hold the penetrant liquid. The developer pull penetrant to the surface, react with it and by that, form the clear visualization of the defect.



Fig. 4 Penetrant nondestructive testing method

Main advantages of penetrant nondestructive testing can be recognized as large surface or large volumes of parts can be tested fast and with low cost, parts with complex geometry are easily tested, indications are produced directly on surface of the part providing a visualisation of the discontinuity. Main disadvantages can be recognized as this method detects only surface defects and this method is sensitive to surface preparation because contaminants of surface can mask defects, requires a relatively smooth and nonporous surface, cleaning after procedure is necessary to remove chemicals, requires multiple operations under controlled conditions with chemical handling precautions.

Very similar approach is used for florescent testing method, with difference in the way that identification of defect is visible under the special type of light. This method provides the estimation of defect dimensions on the bases of wideness of the fluorescent zones. The efficiency of this method depends on type of applied solution for testing, the thickness of its layer, its penetrating ability and, also, on type and power of light source (Fig. 5).

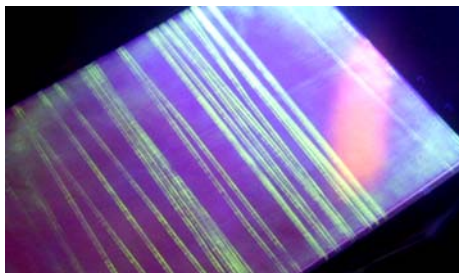


Fig. 5. Identification of surface defects by fluorescent methods

Magnetic particle testing

At zones of unhomogeneity of the tested element the alterations of magnetic permeability are present, which result in alterations of magnetic particle orientations and by that, the identifications of defects are formed (Fig. 6).



Fig. 6 *Magnetic particle nondestructive testing method*

Advantages of this nondestructive testing technique can be recognized as large surface of complex geometry parts can be examined fast with detecting surface and subsurface defects, surface preparation is less critical than it is in penetrant testing. The identifications of defects are formed on the surface of the tested element directly and by that, a special type of defect map is obtained. Disadvantages of magnetic particle testing can be recognized as only ferromagnetic materials can be examined, proper alignment of magnetic field and defect is critical, large homogeneous magnetic fields are needed for large parts, requires relatively smooth surface while paint or other nonmagnetic coverings badly affect sensitivity and also cleaning after testing procedure is necessary.

Strain gauge method – tensometric methods

The strain gauge method is based on the phenomena of alterations of electrical resistance in correlation to deformations of the tested element of mechanical construction with strain gauges placed on (Fig. 7). The main disadvantage of this monitoring method is in the fact that measuring is limited to small zones at the surface of the element with strain gauges placed on without possibility of 3D analysis. The main advantages of this method are in its simplicity, affordability, low costs and suitability for continual monitoring on remote locations.

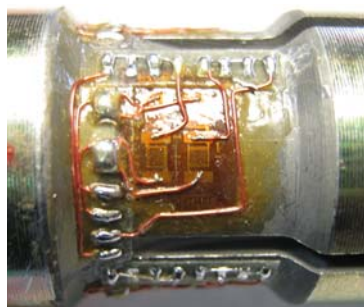


Fig. 7 *System of strain gauges to continual monitoring*

Photoelastic Testing

Photoelasticity is method of analyzing stresses which is based on the characteristic of photoelastic materials to become optically anisotropic in loaded conditions. Optical anisotropy of these materials can be measured with polarized light in a polariscope and depend on the values and the distributions of the stresses in them (Fig. 8). This method provide getting of relevant results by analysis at the models of the considered elements made of photoelastic sensitive materials with same shapes and stresses levels or directly on real constructions by the use of photoelastic layers or coatings.

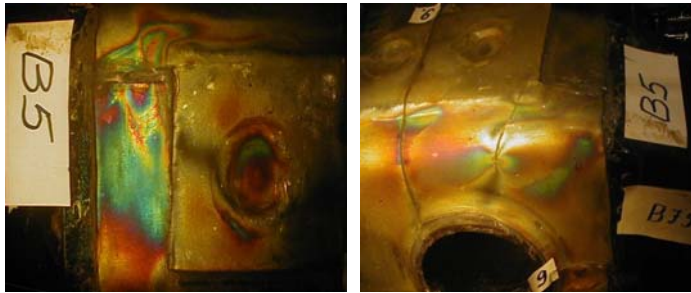


Fig. 8. Identification of defects by photoelastic method

Radioscopy

X-rays slightly loose in intensity during passing through metallic materials at the zones of unhomogeneity and discontinuity, such as defects and cracks, while losses are bigger when there are no unhomogenities on their way. The presented phenomenon is base for the technical system monitoring by radioscopy method. The radioscopy method that uses gamma rays, which are characterized by higher penetrating than X-rays, is more sensitive and defects with dimensions higher than 5% of thickness of examined elements can be identified. The usage of radioscopy method required adequate protection of the environment from the radiation and that is major disadvantage of this method.

Ultrasonic Testing

Ultrasonic nondestructive testing method uses high frequency sound wave beams introduced into materials for the detection of subsurface discontinuities in examined object.

High frequency sound pass through material with constant decrease of energy within examined element and they are reflected by its surfaces and discontinuities. The reflected beams are registered, measured and analyzed in order to identify the present and location of defects (Fig. 9). Ultrasonic testing is suitable for automation of the technical system monitoring. The alterations of thickness and characteristics of the materials can also be measured. Advantages of this method are very significant such as depth of penetration for discontinuities detection or measurement is superior to other methods, only single sided access is required, provides distance information, minimum part preparation is required, method can be used for providing much more information and data than just defect detection of defects.



Fig. 9. *Ultrasonic testing: a) Ultrasonic testing device; b) Testing probe*

Ultrasonic nondestructive testing method disadvantages are: surface must be accessible to probe, skill and training required is more general than other technique, surface finish and roughness can interfere with inspection, thin parts may be difficult to inspect, linear defects oriented parallel to the sound beam can be undetected, reference standards are often needed.

Vibro–acoustic method and acoustic emission method

Generation of sound and vibrations followed the operation of mechanical systems and present relevant parameters about their operation conditions. Acoustic oscillations and vibrations usually act simultaneously. These complex types of oscillations provide sufficient quantity of information and data about technical conditions of the monitored systems in exploitation. As acoustic oscillations can be detected by hearing sense and vibration can be detected by touch, those methods are one of the oldest methods of investigations that are still used in present. The evolutions of these methods are related to automatic spectral analysis of acoustic and other vibrations.

Acoustic emission method is nondestructive experimental method that is based on the phenomenon that discontinuities at rigid loaded body emitted short impulses of acoustic energy. Those acoustic emissions are identifications of defects at tested elements such as cracks. Acoustic emission method is different to other monitoring methods because the signal that is measured during testing are formed within tested element and not generated by external source. This method identified the formation and growth of the defect while other methods identified the presence of defects. Acoustic emission is related to movement of dislocations that followed the plastic deformations of the material, so as formation and growth of cracks at loaded element.

4. CONCLUSION

Complexity of modern mechanical constructions cannot be archived with simultaneous development of monitoring methods. The methods of technical systems monitoring are related to analysis of processes that conditioned the alterations of their characteristics in exploitation. Monitoring methods of technical systems are related with prevent maintains of those systems. The obtained data are basis for verifications of mathematical models or the examined mechanical constructions. Modern mechanical systems are very different in functions and in nature of its elements, so the mathematical models of those systems are very complex. The developments of computers open possibilities for numeric simulations of mechanical systems in real exploitation, stress-strain analysis by considerations of the mathematical models. The

wide range of numerical methods are developed, so as software packs that are based on application of those numeric methods as finite elements method, finite difference method and so on. Those numeric considerations can be very useful for identification and selection of optimal experimental monitoring method. As uniform microstructure and homogenous continuum are assumption at numeric methods, the relevant information and data, that are base for monitoring of mechanical systems in exploitation, can be provide only by experimental testing.

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THE INFLUENCE OF THE DSLR CAMERA SHUTTER COUNT ON THE ACCURACY OF THE PHOTOGRAMMETRIC MEASUREMENTS

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Abstract: *Photogrammetric methods are modern methods of measurement predominantly used in quality control, measurement of deformation and reverse engineering. Thanks to a series of favourable properties their share is growing in modern measuring chains. The accuracy of method is confirmed in each measurement by the so-called selfcalibration, a process in which the system determine its internal characteristics and their impact on the accuracy of measurements. Over time, the characteristics of the equipment components, primarily high-resolution DSLR camera, is changing. In this paper the effect of the shutter count (total number of recorded images) on the accuracy of photogrammetric measurements is examined by comparing measurements performed by cameras with a small and a large shutter count. The presented results show that the measurement error is significant, thus the shutter count affect the quality of the measurement result.*

Keywords: *photogrammetry, triangulation, quality control, accuracy and precision of measurement*

1. INTRODUCTION

Optical measuring technology have become a standard tool within almost all industries [1]. Conventional measuring machines' tasks, traditionally performed by tactile CMMs, now are carried out with the optical CMM systems [2]. This contactless method is suitable, because the measuring instruments are robust and mobile. Using the optical measuring system significantly reduces the time required to develop and manufacture products, while increasing quality.

Foundation of optical measuring technology is photogrammetry [3]. Photogrammetry is tool for determining the geometric properties of objects from photographic images as the main metrology medium using methods from many disciplines, including optics and projective geometry. This method is suitable for objects of various sizes and complexity [4]. The measuring sensor used in this method is high resolution CCD camera [5]. One standard method of photogrammetry clasification is based on camera location during photography: aerial and close-range

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photogrammetry. In close-range photogrammetry the camera is close to the measuring object. In Mechanical and Civil Engineering photogrammetry offers an accurate and cost-effective solution in a number of different application areas including: Quality Control, Reverse Engineering, Rapid Prototyping, Rapid Milling, Digital Mock-Up, etc.

With simple configuration measuring objects for the entire measurement just a few photos is taken. However, for large and complex geometric objects measuring project requires recording dozens or even hundreds of measuring images. This number is significantly higher in the case of deformation measurements. Then, for any observed configuration a separate measuring project is created. In such cases, the total number of images recorded by measuring equipment is growing rapidly, much faster than in the classical case of shooting professional photos. This fact raises the question of whether such a trend in the recording images affects the accuracy of the measurement method?

A single-lens reflex (SLR) camera typically uses a mirror and prism system. Digital single-lens reflex cameras (also named digital SLR or DSLR) are digital cameras combining the parts of a single-lens reflex camera (SLR) and a digital camera back, replacing the photographic film. DSLR cameras incorporate a shutter mechanism capable of moving extremely fast to help capture split second detail. However, as with everything mechanical, it may need to be serviced or replaced someday. Shutter count, shutter actuations, or the number of pictures taken on the camera shutter is one of the indicators of the camera's state. In this paper, the influence of this parameter on the measurement accuracy and precision is investigated using industrial solution TRITOP.

2. BASICS OF PHOTOGRAMMETRY

The fundamental principle used by photogrammetry is triangulation. The basic idea of photogrammetry is to look at markers applied on object's surface (reference points) from different directions by taking photographs from at least two different locations with the largest possible angle to each other. It is possible to calculate the camera location using this reference point relation by means of images. Then, so-called lines of sight can be developed from each camera to points on the object, as depicted in Figure 1. The reference points visible in an image have a fixed relation to each other.

Main hardware and software components of conventional photogrammetric measuring system are: (a) High-resolution digital camera with interchangeable lenses of fixed focal length, (b) Storage medium, (c) Flashlight, in order to optimally light the measuring object, (d) Coded reference point families; each point has its own ID in order to generate an image set that can be automatically evaluated in software and to allow for calculating the camera positions, (e) Uncoded reference points, to get 3D coordinates of the measuringrelevant parts of the object to be measured, (f) Certified scale bars for scaling the measuring results; they have ultra-precisely measured reference points for determining their length, and (h) Application software for analyzing and evaluating the image sets and measuring results [6].

The main task of software is to precisely find ellipses (a perspective view of reference points) in all images of the image set and their 3D orientation. The, software interprets the images and generates 3D measuring data. The measuring data can be used in CAD comparison and inspection or made available to subsequent systems like, for example, ATOS.

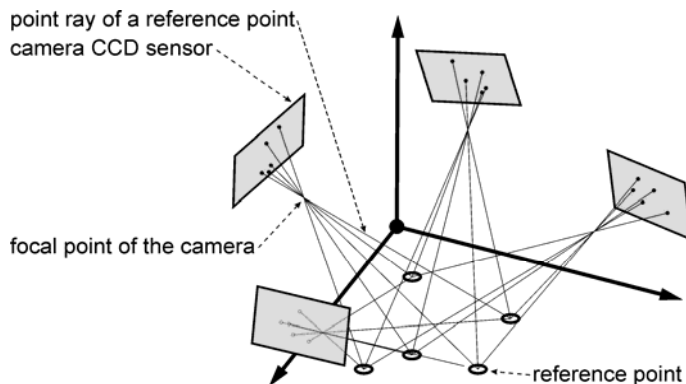


Figure 1 Principle of photogrammetry

3. SETTINGS OF TRITOP PHOTOGRAMMETRIC CAMERA NIKON D200

Different camera systems are supported. The cameras are based on professional digital reflex camera housings in connection with a manual fixed focus lens and a ring flash. Each TRITOP camera system is factory-verified and certified in order to guarantee the measuring accuracy. The use of the photogrammetric camera considerably differs from normal photography because other criteria apply for photogrammetry. Therefore, most of the automatic functions need to be disabled. Photogrammetric systems from GOM are factory-preadjusted. Therefore, user generally do not need to make any configuration settings for the camera and software. The information given in Table 1 only ensures that the correct settings are adjusted on both cameras [7]. Settings of parameters non related to camera is shown in Table 2.

It should be noted that TRITOP image group is always recorded with fixed camera settings. The camera and lens settings should not be changed while recording an image group. The focus is set by means of the distance between camera and measuring object and never by using the focusing ring of the lens.

Table 1 *Factory-preadjusted settings of TRITOP photogrammetric camera*

Camera Settings	
<i>Image Quality:</i>	JPEG Fine
<i>Image Size:</i>	L (3872 x 2592)
<i>JPEG Compression:</i>	Optimal Quality
<i>ISO Sensitivity:</i>	200
<i>Image Sharpening:</i>	Optimize Image > Custom > Image Sharpening > None
<i>Tone Compensation:</i>	Normal
<i>Non-CPU Lens Data:</i>	Focal Length 24 mm, Maximum Aperture 2.8
<i>Auto Image Rotation:</i>	Off
<i>Exposure mode:</i>	M (manually)
<i>Shutter speed:</i>	250 (1/250 s)
<i>Aperture setting:</i>	11
<i>White balance:</i>	S (single frame)
<i>White balance:</i>	A (Automatic)
<i>Focus mode:</i>	M (manually)
<i>Focus area:</i>	Center

Table 2 Other system specific settings

Flash Light Settings	
<i>Recommended flash light power for distances up to 2 meters is ¼. Use of build-in wideflash adapter is mandatory.</i>	
TRITOP Software Settings	
<i>Project Settings</i>	
<i>Minimum ellipse radius:</i>	<i>2.0 pixels</i>
<i>Ellipse quality:</i>	<i>0.3 pixels</i>
<i>Camera Settings</i>	
<i>Image width:</i>	<i>3872 pixels</i>
<i>Image height:</i>	<i>2592 pixels</i>
<i>Principle point offset:</i>	<i>0 each</i>
<i>Pixel size:</i>	<i>6.1 µm</i>
<i>Binarisation offset:</i>	<i>5</i>

4. EXPERIMENT AND RESULTS

There is no way to accurately determine the DSLR camera shutter count. While there are third party software applications designed to read a cameras shutter count, this number is not always accurate because the shutter release times may be reset by firmware updates, or reset in the service department. Since an exact number of releases before failure cannot be exactly calculated, a formula is used to estimate when it may occur, called Mean Time Between Failures (MTBF). Based on testing and past performance, along with service information, an estimated average number of shutter releases that can be expected before probable shutter failure is formulated. Estimated number of shutter actuations for most of NIKON DSLR models are tested to 150,000 cycles [8].

Instead, there are several options to monitor DSLR camera's shutter use. Most of available solutions use photography as a medium for the transmission of information about shutter count. This information is contained in the EXIF data [8]. Because EXIF data is erased by external applications, photo (NEF or RAW files, or untouched JPG's) must be taken with the camera without any external processing. Shutter count is determined by uploading image to a website that processes and displays the information [9].

Reference measurement is performed with a camera with small shutter count (Fig 2a). This measurement is considered as accurate because the camera is in excellent condition, and the overall accuracy of the measurement system is guaranteed by the manufacturer. Ten measurements were performed by camera with a large shutter count. The fixed focus lens used in measuring with the two cameras is shown in Figure 2b while Figure 2c shows configuration of the measuring device ready for measurement. According to EXIF data from images based on the first measurement shutter count of the reference camera is 13228, while for the investigated camera is 164911.

The accuracy check of the measuring device was performed on a simple set-up (Fig. 3). Comparison was done by measuring the distance between the randomly placed reference points. Ideally, the scale bars fit 1:1 to the measuring object. The measured distances correspond to 10%, 25%, 50%, 75%, and 100% of scale bars length. For measuring this simple project eight images is need, four calibrating images

made from the top and four images recorded laterally at an angle of approx. 45°. An image group consists of overlapping images recorded in succession combining the right and the left side as well as the front and the rear side of the model in order to avoid accumulated errors.

Results of accuracy test are shown in table 3.

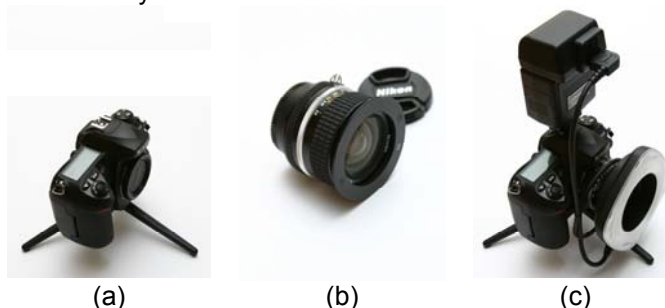


Figure 2 Photogrammetric camera: (a) NIKON D200 body, (b) fixed focus lens, and (c) camera prepared for measurements



Figure 3 Measuring Set Up

Table 3 Accuracy experiment for TRITOP photogrammetric camera NIKON D200

Number of Measurement	Percent of scale bars length				
	~10%	~25%	~50%	~75%	~100%
	Measured reference length				
	98,902	249,510	495,784	747,473	981,264
1	98,900	249,507	494,881	747,479	981,248
2	98,907	249,519	495,787	747,462	981,263
3	98,908	249,521	495,787	747,747	981,270
4	98,920	249,525	495,792	747,478	981,278
5	98,914	249,525	495,797	747,476	981,272
6	98,893	249,512	495,779	747,469	981,264
7	98,927	249,522	495,795	747,478	981,273
8	98,915	249,524	495,786	747,467	981,252
9	98,904	249,503	495,775	747,471	981,258
10	98,917	249,509	495,781	747,469	981,253
Standard deviation	0,010	0,008	0,286	0,087	0,010
Min-Max Value	0,034	0,022	0,916	0,285	0,030
Mean value	98,911	249,517	495,696	747,500	981,263
Precision	0,102	0,033	0,578	0,117	0,010
Accuracy	0,025	0,015	0,903	0,274	0,016

5. CONCLUSION

Compared with tactile measuring systems, typical optical measuring system provides significant benefits, especially for complex geometry. This is the most cost-effective and affordable way to do accurate 3D measurement. It does not require any complex, heavy and maintenance-intensive hardware. Also, the measuring machine comes to the object.

Photogrammetric measurement accuracy can fluctuate significantly, because it depends on several interrelated factors. The most important factors are: quality and resolution of the camera used to measure, size of measured object, the number of recorded images in the project, the geometric arrangement of images in relation to the object, and in relation to each other images. Photogrammetry is more accurate in the x and y direction than in the z direction.

Based on the measurements we conclude that the accuracy and precision of the measuring device decreases over time. Keeping track of shutter count is important in making sure camera is serviced at the proper intervals and the shutter and mirror are replaced at the appropriate times in order to ensure that the device does not introduce measurement error.

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NOVE TEHNOLOGIJE U FUNKCIJI NADZORA RADA MAŠINSKIH SISTEMA

Željko Batinić¹, Zoran Radović², Petar Nikšić³, Ranko Antunović⁴

Rezime: Pojavom sve složenijih i zahtjevnijih tehničkih sistema od presudnog značaja postaje potreba razvoja i primjene odgovarajućih dijagnostičkih sistema koje treba da obezbijede visoku raspoloživost i pouzdanost u radu tih sistema. Razvoj mikroprocesorske tehnologije i na njoj zasnovane digitalne obrade signala omogućava praćenje i prikazivanje svih relevantnih podataka, u odgovarajućem obliku (formatu), koji govore o stvarnom stanju (zdravlju) mašinskih sistema. Tako razvijen nadzorni sistem omogućava da upravljamo mašinskim sistemima i procesom u cjelini.

U ovom radu su prikazani potrebni dijagnostički parametri i trenutno razvijeni nadzorno-dijagnostički vodećih svjetskih kompanija. Dat je i primjer razvijenog nadzornog sistema hidroagregata.

Ključne riječi: parametri nadzora, metode nadzora, nadzorno-dijagnostički sistemi

NEW TECHNOLOGIES AS A FUNCTION OF CONTROL OF MECHANICAL SYSTEMS

Abstract: The advent of ever more complex and demanding technical systems becomes crucial need for the development and application of appropriate diagnostic systems to ensure high availability and reliability of these systems. The development of microprocessor technology and based on her digital signal processing allows you to track and display all relevant data in the appropriate format (format), speaking about the actual state (health) of mechanical systems. Once developed, the system allows the monitoring control mechanical systems and the process as a whole, resulting in increasing the safety of machinery and plant in general, reduce the costs of maintaining and increasing profitability. In this paper, the necessary diagnostic parameters have been developed and are currently monitoring-diagnostic world's leading companies. An example of a developed diagram of the monitoring system.

Key words: rotating machines, monitoring, diagnostics

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1. UVOD

Napredak računarske i mjerne tehnike, te stalno smanjenje cijena razvoja kompjuterskog hardwera, omogućuje danas značajan iskorak u zaštiti mašinskih sistema, uz finansijski vrlo prihvatljiva ulaganja. Za dostizanje tog cilja opremaju se, već više od 30 godina, svi veći agregati, tako da se mogu pravovremeno otkriti greške u pogonu, prateći promjene stanja mašine, zatim postaviti zavisnosti sa pogonskim režimima, dijagnosticirati uzroke kvara i pohraniti, po događajima, bitne podatke o stanju. Takvi uređaji za nadzor stanja potvrdili su se u velikom broju širom svijeta i ostaju, neizostavna oprema, takođe i u budućnosti, kako za nova tako i za rekonstruisana stara postrojenja. Da bi smo imali na raspolaganju potrebne podatke, mora postojati sistem za sakupljanje svih relevantnih podataka. Taj sistem mora omogućiti prikazivanje podataka u relevantnom obliku (formatu) iz kojih se donosi odluka o stanju mašine i preduzimaju odgovarajuće akcije u održavanju. Uz postojanje sistema za sakupljanje (i analizu) relevantnih podataka mora postojati i organizacijski sistem upravljanja mašinama koji jasno definiše ko dobija na uvid koje podatke i ko na temelju njih donosi odgovarajuće odluke. Neposrednim praćenjem i analizom stanja dobija se kvalitetan uvid u stanje mašine te se sprovode akcije održavanja kad je stvarno potrebno, tj. sprovode se na osnovu stanja mašine. Na taj način upravljamo mašinama i procesom u cjelini što rezultira povećanju raspoloživosti i iskoristivosti mašina i pogona, smanjuju troškovi i povećanju profitabilnosti, što je uslov za tržišno poslovanje.

2. PARAMETRI I TEHNIKE MONITORINGA

Parametri monitoring sistema su posredne individualne veličine povezane sa strukturnim parametrima (vibracije, temperatura, zazor u ležaju, pritisak ulja i dr.) i nosioci su tačnih informacija o tehničkom stanju sistema. Parametri koji nose najviše informacija o stanju tehničkog sistema svakako su parametri vibracija, pored njih takođe su biti i parametri pomjeranja, temperature, buke, strujni parametri, parametri ulja za podmazivanje i dr.

Veliki broj tehnika je raspoloživ kod monitoringa rotacionih sistema, a koji će biti izabran zavisi od dubine potrebnog dijagnosticiranja, uz ekonomski opravdana ulaganja [8]. Navedimo neke od najčešće korištenih tehnika kod monitoringa ove vrste:

- **vibroakustička analiza**
 - **vibrodijagnostička analiza:** analiza ukupnog nivoa vibracija, spektralna analiza, fazna analiza, vektorska real-time analiza, analiza orbite, DC analiza, trendiranje parametara, metoda udarnog impulsa (SPM metoda), energetska analiza, Zoom FFT analiza, CPB analiza, kepstralna analiza, SED detekcija, HFD detekcija, LFD detekcija, SEE tehnologija
 - analiza buke
- **analiza radnih parametara:** energetska analiza, termovizijska analiza, analiza premještanja i širenja određenih sklopova u sistemu, analiza tehnoloških parametara (protok, pritisak, nivo tečnosti, tehnološki parametri vode i dr.)
- **analiza produkata habanja i sagorijevanja:** analiza ulja i maziva (atomska spektroskopija, infracrvena spektrofotometrija, membranska filtracija, gasna hromatografija, i dr.), analiza gasova
- **monitoring korozije:** vizuelne metode (opička mikroskopija, metalografija, itd), gravimetrijske metode (pH-metrija, metoda AAS, volumetrija, itd.), elektrohemijske metode

3. MJERNO-DIJAGNOSTIČKA OPREMA

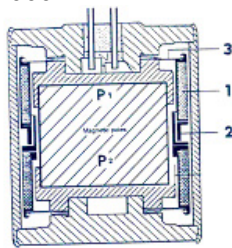
U posljednje vrijeme, većina savremenih prenosnih mjernih uređaja se radi u digitalnoj (kompjuterskoj) izvedbi a veza sa sensorima je ostvarena pomoću A/D konvektora.

Osnovu jednog nadzorno- mjernog lanca čine:

- davači (senzori) vibracija
- mjerno-analiitička jedinica
- dijagnostički sistem za monitoring i analizu

3.1. Senzori vibracija

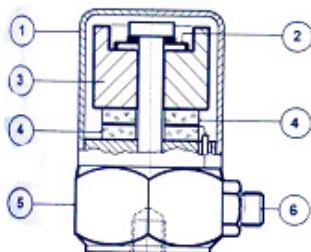
- **Seizmički senzori** vibracija, mjere vibracijsku brzinu, sa frekventim opsegom od 10 Hz do 2000 Hz.



- 1- Pokretni namotaj (kalem)
- 2- Membranska opruga
- 3- Permanentni magnet

Sl.1. Konstrukcija seizmičkog davača vibracija (elektro-dinamički pretvarač vibracija)

- **Piezo-električni akcelerometri**, mjere ubrzanje vibracija, sa mjernim frekventnim domenom do 40 kHz. Upotrebljavaju se kod mjerenja i analize visokofrekventnih vibracija.



- 1- Kućište
- 2- Opruga
- 3- Seizmička masa
- 4- Piezo-električni disk
- 5- Baza
- 6- Izlazni kontakt

Sl. 2. Šematski prikaz piezo-električnog senzora

- **Induktivni senzori**, mjere vibracijsko pomjeranje, sa mjernim frekventnim rangom do 2 kHz. To su bezkontaktni senzori vibracijskog pomjeranja koji rade na principu vrtložnih struja, a mogu biti u odvojenoj izvedbi kao mjerni lanac koji se sastoji iz vibracijskog pretvarača sa vrtložnim strujama, produžnog kabla i oscilatora i u integralnoj izvedbi, tzv. VIBRONECS-pretvarač, kod koga je vibracijski pretvarač i oscilator u zajedničkom kućištu.



Sl. 3. Primjeri izvedbe beskontaktnih senzora vibracija

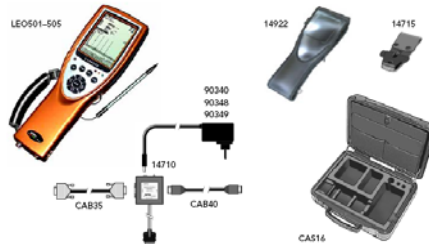
3.2. Mjerno-analička jedinica

Signal iz senzora se treba pojačavati i kondicionirati tako da se na instrumentu mogu očitati ili zapisati karakteristične vrijednosti vibracija tj. nivoi vibracija, frekvencijske komponente, fazni uglovi i sl. Treba napomenuti da većina savremenih mjernih instrumenata ima mogućnost povezivanja sa računarom ili su sami u digitalnoj (kompjuterskoj) izvedbi. Kod toga računar omogućuje detaljnije analize signala u zavisnosti od programa sa kojim se raspolaže.

Prikažimo neke od trenutno razvijenih analizatora vibracija vodećih kompanija u svijetu, sa akcentom na njihov programski sadržaj.

Leonova- platforma

Leonova je SPM-ov industrijski prenosni višekanalni analizator koji radi pod operativnim sistemom Windows CE [6]. Tehničke karakteristike sistema su: procesor 206 MHz Intel, memorija 64 MB RAM i 32 MB Flash, komunikacija RS232 i UBS, dinamički rang 16 bitni A/D konvektor, baterijsko punjenje 8 sata neprekidnog korištenja, težina 600 g.



Sl.4. Prikaz Leonova platforme

Metode vibrodijagnostike koje su ugrađene u ovaj analizator su: **mjerenje ukupnog nivoa vibracija** (brzine, ubrzanja ili pomjeranja), inkorporiran je standard ISO 10816. **spektralna analiza** sa opcijom zoom. Karakteristike spektra: 6400 linija spektra i mjernim opsegom 0,5 Hz - 20 kHz. Prozorske funkcije: Rectangle, Hanning, Hamming, Flat Top, **analiza envelope**, **vektorska analiza**, **SPM-ova analiza** (mjerenje bBm/dBc, LR/HR, SPM spektar)

Ima ugrađene dopunske funkcije: balansiranje u jednoj i dvije ravnisoftver za lasersko centriranje vratila.

Microlog CMVA 60

Microlog CMVA 60 je SKF-ov industrijski prenosni Data Colector/Analizator [4]. Tehničke karakteristike procesora su: mikroprocesor Intel, 32 bit i brzine 25 MHz, memorija 6 Mb RAM i 4 Mb fleš memorije, baterijsko punjenje: 7,2 V 3,8 AH



Sl. 5. Prikaz Microloga CMVA 60

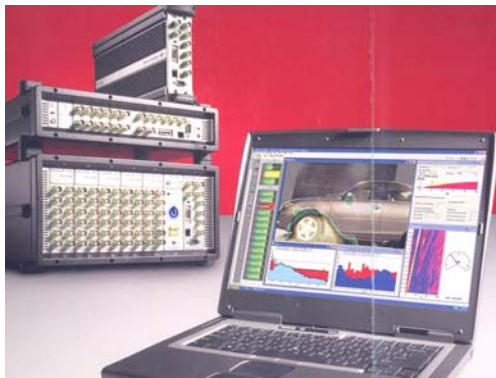
Karakteristike konektora: vibracioni kanali za senzore brzine, ubrzanja i pomjeranja, ulaz za SEE Senzor, ulaz za AC/DC senzor, univerzalni taho input, ulaz za senzore temperature i pritiska, modemska komunikacija sa štampačom i dijagnostičkim sistemom.

Metode vibrodijagnostike koje su ugrađene u analizator: **Mjerenje ukupnog nivoa vibracija** (brzine, ubrzanja ili pomjeranja), **Spektralna analiza** sa opcijom zoom. Karakteristike spektra: 6400 linija spektra i mjernim opsegom 0,5 Hz - 20 kHz. Prozorske funkcije: Rectangle, Hanning, Hamming, Flat Top, **Analiza envelope**, **Vektorska analiza**, **Analiza redova**, **HFD detekcija**, **LFD detekcija**, **SEE analiza**, **DC analiza**.

Ima razvijen aplikacioni program za balansiranje u jednoj i dvije korekcijske ravni.

PULSE Analyzers & Solutions

PULSE analizator je Bruel & Kjaer-ov modularni višekanalni prenosni sistem za analizu vibracija i buke [3]. Minimalna kompjuterska konfiguracija koja podržava ovaj sistem je Pentium II, 300 MHz procesor, 256 MB RAM, operativni sistem Windows.



Sl.6. Prikaz PULSE analizatora

Metode vibrodijagnostike koje su ugrađene u analizatoru: **vremenska slika signala**, **mjerenje ukupnog nivoa vibracija** (brzine, ubrzanja ili pomjeranja), inkorporiran je standard ISO 10816, **spektralna analiza** sa opcijom zoom. Karakteristike spektra: 400 linija spektra i mjernim opsegom 0,5 Hz - 40 kHz. Prozorske funkcije: Rectangle, Hanning, Hamming, Flat Top, **analiza envelope**, **kepstalna analiza**, **CPB analiza**, **vektorska analiza**, **analiza redova**, **DC analiza**, **orbitalna analiza**, **analiza buke**, **modalna analiza**.

Ima ugrađenu dopunsku funkciju balansiranje u jednoj i dvije ravni.

3.3. Nadzorni instrumenti

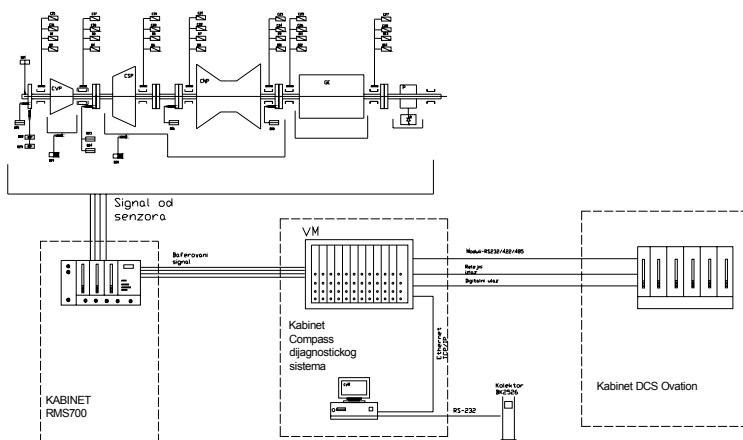
Stalni nadzor vibracija može biti jednostavno koncipiran ukoliko se prati nivo vibracija (obično nivo vibracijske brzine) sa ugrađenim dodatnim relejima koji mogu signalizirati prekoračenje nekog unaprijed podešenog nivo vibracija. Kompleksniji nadzor vibracija osim praćenja vibracija na ležajevima i vratilu, prati i fazne uglove vibracija u odnosu na vratilo a ima i dodatne mogućnosti praćenja procesnih parametara mašine. Nadzorna instrumentacija raspolaže mogućnošću analize i kondicioniranja signala, te komunikacije sa računarom i ekspertnim sistemima, koji osim funkcije zaštite vrše dijagnostičke analize iz kojih se otkriva uzrok vibriranja i daju mjere za otklanjanje istog. To vrijedi kako za kontinuiran rad u stacionarnim uslovima tako i za mjerenje i analizu vibracija tokom pokretanja/zaustavljanja mašine.

Ovdje ćemo prikazati neke od razvijenih nadzornih instrumentacija vodećih svjetskih kompanija.

COMPASS dijagnostički sistem

COMPASS (COMputerised Predictive Analysis and Safety) je Bruel & Kjaer CDS (kompjutersko dijagnostički sistem) namijenjen za nadgledanje mehaničkog stanja rotacionih mašina i predviđanje potencijalnih grešaka u mašini- PFM (Potential Failure Mode monitoring) [7]. Satoji se od VM monitora i CVM kompjuterskog sistema. Funkcija **VM** monitora je da izvrši strategiju motioringa i implementaciju u on-line COMPASS bazu podataka. Distributivno digitalno procesiranje signala obezbjeđuje analizu signala u realnom vremenu. **CVM** je Intel-ov mikroprocesorski sistem baziran na SCO UNIX platvormi. Namijenjen je za Compass aplikativne pakete i Compas-ovu bazu podataka. Za prikupljanje vibracionih i procesnih podataka u off line COMPASS-ovu bazu služi Data Kolektor 2526/2526E.

U okviru COMPASS dijagnostičkog sistema razvijen je i eksperstski sistem ADVISOR koji pored standarde baze znanja omogućava unošenje i korisničke baze znanja, sve to doprinosi razvoju automatizovane dijagnostike.



Sl. 7. Šematski prikaz instalisanog COMPASS dijagnostičkog sistema u TE Gacko

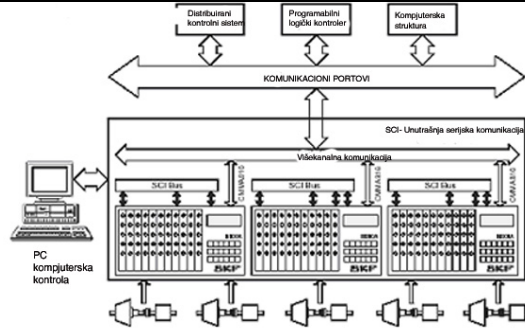
Softverski moduli omogućavaju širok set formata vibrodijagnostike za potrebe dijagnostike: Histogram mašine (živo mjerenje ukupnog nivo vibracija, paralelno sa svih senzora), Prikaz trenda ukupnog nivoa vibracija, Orbitalni prikaz, Bodeov i Polarni prikaz pojedinih harmonika, Spektralni trend prikaz, Kaskadni spektralni prikaz, Trend X-Y pozicije vratila, Trend vektorskog prikaza pojedinih vibracijakih komponenti, Kaskadni spektralni prikaz, Trend envelop spektara, Trend kepstrum spektra.

M800A dijagnostički sistem

M800A je SKF-ov CDS (kompjutersko dijagnostički sistem) za monitoring i zaštitu mašina [4].

Ovaj sistem pruža mogućnost:

- kontinualnog on-line monitoringa i zaštite poštujući direktive API 670
- brze integracije i procesne kontrole sistema sa ASCII i 584 modulima
- digitalnog prikaza alarma, mjernih vrijednost po kanalima i GAP napona

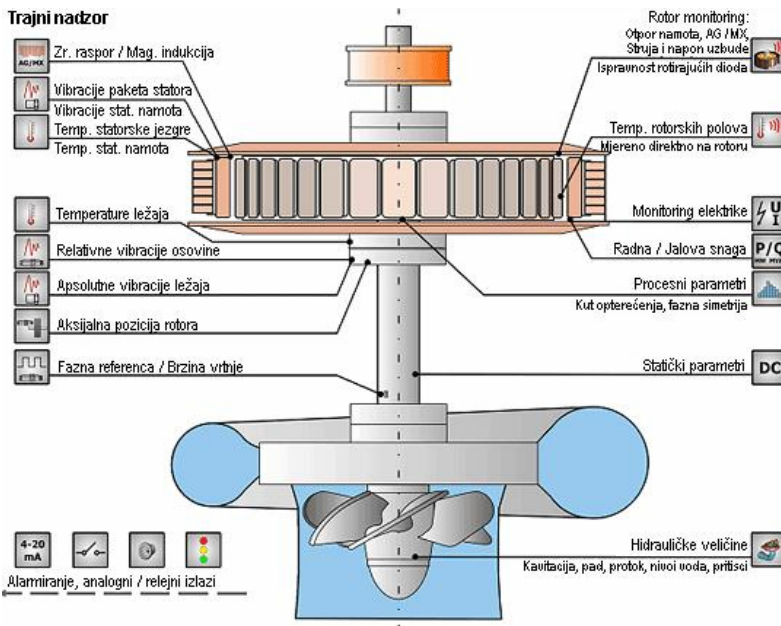


Sl. 8. Prikaz jedne arhitekture M800A sistema

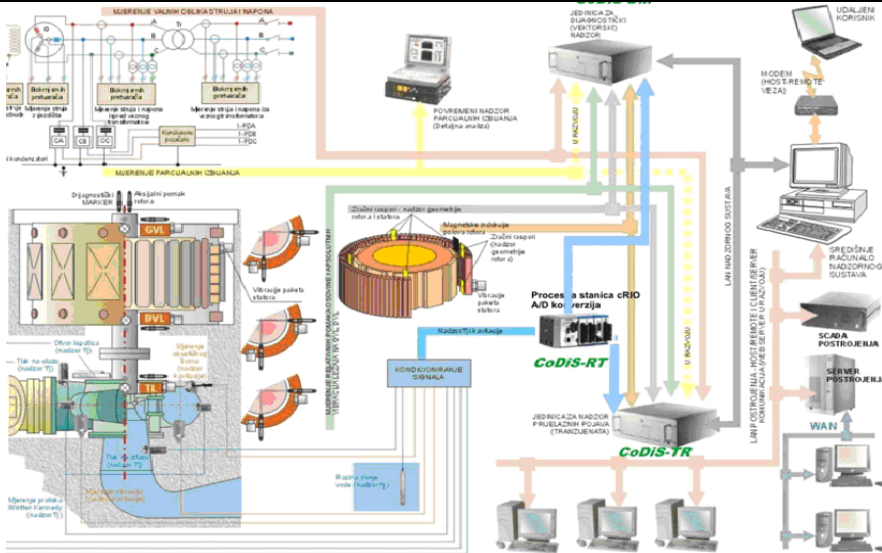
Softverski moduli omogućavaju širok set formata vibrodijagnostike za potrebe dijagnostike: Histogram mašine (živo mjerenje ukupnog nivoa vibracija, paralelno sa svih senzora), Prikaz trenda ukupnog nivoa vibracija, Orbitalni prikaz, Bodeov i Polarni prikaz pojedinih harmonika, Spektralni trend prikaz, Kaskadni spektralni prikaz, Trend X-Y pozicije vratila, Trend vektorskog prikaza pojedinih vibracijakih komponenti, Kaskadni spektralni prikaz, Trend envelop spektra.

4. NADZORNO-DIJAGNOSTIČKI SISTEM HIDROAGREGATA

Prema praksi poznatih svetskih proizvođača hidrogeneratora prate se sledeće veličine i parametri nadzora: temperature delova i sklopova generatora i rashladnih fluida, vibracije mehaničkih delova i relativna pomeranja (orbite), forma statora, rotora i zazor generatora, parcijalna pražnjenja u namotaju, radni podaci generatora, prisustvo vode u ulju, brzina obrtanja, magnetni fluks, protok - pritisak vode za hlađenje, nivoi ulja u ležajevima, kontrola malih obrtaja, stanje magnetnog jezgra statora, sadržaj gasova i vlage u rashladnom vazduhu, stepen iskorišćenja generatora, temperature namotaja rotora, kvalitet rashladne vode (destilata), merenje buke u buretu generatora, kavitacija i pritisci kroz turbinu.



Sl.9. Mjerni parametri monitoringa hidroagregata



Sl.10. Implementacija nadzorno dijagnostičkog sistema hidroagregata

5. ZAKLJUČAK

U posljednje vrijeme, razvojem mikroprocesorske tehnologije i na njoj zasnovanog digitalnog procesiranja signala, omogućen je značajan iskorak u zaštiti mašina, uz finansijski vrlo prihvatljiva ulaganja. Neposrednim praćenjem i analizom stanja dobija se kvalitetan uvid u stanje mašine te se sprovode akcije održavanja kad je stvarno potrebno, tj. sprovode se na osnovu stanja mašine. Na taj način upravljamo mašinama i procesom u cjelini što rezultira povećanju sigurnosti i iskoristivosti mašina i pogona.

Dalji pravci istraživanja i razvoja na ovom polju mogli bi biti:

- razvoj novih struktura senzorskog sistema kao i novih analizatora vibracija sa novim tehnikama monitoringa, a koje su prilagođene tržištu
- razvoj automatizovanih sistema dijagnostike
- povezivanje privrednih subjekata i aktivnosti na ostvarivanju telemonitoringa značajnih industrijskih postrojenja

Sve ovo nameće potrebu formiranja i opremanje centra za tehničku dijagnostiku sa odgovarajućim probnim stolovima i senzorskim sistemima.

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PRIMJENA TEHNIČKE DIJAGNOSTIKE U ODRŽAVANJU GEOTEHNIČKIH MAŠINA

Mihajlo Vujičić¹, Radoslav Tomović²

Rezime: U radu su prikazane specifičnosti primjene tehničke dijagnostike u održavanju geotehničkih mašina tipa MUSTANG 4-N3. Opisane su osnovne konstrukcione karakteristike ovih mašina, kao i karakteristike primjenjenih metoda tehničke dijagnostike. Na kraju rada su prikazani dobijeni rezultati i zaključci doneseni nakon analize.

Ključne riječi: metode tehničke dijagnostike

APPLICATION OF TECHNICAL DIAGNOSTIC IN MAINTENANCE OF GEOTECHNICAL MACHINES

Abstract: The paper describes the specifics of application of technical diagnostics in maintaining geotechnical machines type MUSTANG 4-N3. The basic constructional characteristics of this machine are described, as well as the characteristics of the methods which used in technical diagnostics. Finally, the paper presents the results and conclusions of the analysis after.

Keywords: methods of technical diagnostics

1. UVOD

Pojam "tehnička dijagnostika" podrazumijeva niz aktivnosti kojima se uz primjenu mjernih instrumenata vrši praćenje i ocjena stanja pojedinih elemenata i sistema u cjelini, ali i predviđaju događaji koji će najvjerojatnije uslijediti. Ocjena stanja dijagnosticiranog sistema se vrši upoređivanjem utvrđenih vrijednosti posmatranog parametra sa prethodno definisanim graničnim vrijednostima, nakon čega se donosi odluka da li sistem ispunjava projektovanu funkciju cilja ili je potrebno izvoditi odgovarajuće aktivnosti održavanja. U tom smislu, izbor dijagnostičkih parametara vrši se na osnovu istorije podataka o radu sistema, vodeći računa o tome da svi parametri ne utiču jednako na stanje sistema.

Provjera stanja (dijagnosticiranje) se često može sprovesti bez većih rasklapanja tehničkih sistema uz pomoć odgovarajućih uređaja ili instrumenata. Ukoliko je to nemoguće pristupa se rasklapanju mašine i opreme i detaljnom premjeravanju i ispitivanju vitalnih sastavnih elemenata. Mogućnost pravovremenog i tačnog uočavanja

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nastalog otkaza, odnosno uočavanja stanja koje traži sprovođenje postupaka održavanja ima veliki značaj sa aspekta brzine i kvaliteta održavanja mašina i opreme. Zaključak koji se postavi u procesu dijagnostike predstavlja dijagnozu, odnosno stanje posmatranog tehničkog sistema ili elementa.

U ovome radu je prikazan detaljan opis postupka dijagnoze stanja Rotacione jedinice RH 50 na hidrauličnoj bušilici tipa MUSTANG 4-N3, proizvođača Atlas Copco Craelius AB Sweden. Pored opisa problema, u radu su detaljno opisane osnovne karakteristike bušilice kao i osnovne karakteristike primijenjenih metoda tehničke dijagnostike.

2. OPIS PROBLEMA

Bušenje geotehničkom mašinom tipa MUSTANG 4-N3, na poziciji PDG 4, prema projektu HE Dabar, je bilo otežano na 47 m dubine, prilikom bušenja sa HQ priborom za jezgrovanje. Pregledom mašine je ustanovljeno da radne karakteristike mašine odgovaraju preporučenim, ali je problem u tzv. "gubljenju rotacije" na izlaznom vratilu iz rotacione jedinice RH 50. Metodom udarnih impulsa izvršena je provjera stanja ležajeva na izlaznom vratilu.

Na izlaznom vratilu se nalaze tri ležaja i to jedan u gornjoj, a dva u donjoj zoni rotacione jedinice. Izmjerene vrijednosti udarnih impulsa su bile jako visoke, što ukazuje da postoji jako visok stepen rizika za otkaz navedenih ležajeva. To je izazivalo veliku nedoumicu, obzirom da se radi o novoj mašini, koja je radila svega 670 m.č. i koja je remontovana na 24 m.č., kada su zamijenjeni svi kotrljajni ležajevi rotacione jedinice. Nakon izvršene demontaže u donjoj zoni rotacione jedinice pronađene su izvjesne nečistoće - metalni opiljci, koji su uzrokovali blokadu donjih ležajeva rotacione jedinice. Analizom je utvrđeno da su opiljci poticali od prethodno zamijenjenog ležaja na 24 m.č. Opiljci u prethodnom remontu nisu bili uklonjeni, jer su se najvjerovatnije zadržali u donjem dijelu rotacione jedinice, koji je znatno niži od otvora za ispuštanje ulja.

3. OSNOVNE KARAKTERISTIKE HIDRAULIČNE BUŠILICE TIPA MUSTANG 4-N3

Mustang 4-N3 (Sl. 1) je hidraulična bušilica za višenamjenska bušenja, kako za površinska tako i za podzemna, u svim vrstama stijena, uz mogućnost bušenja sa standardnim konvecionalnim priborom, kao i sa wire-line priborom (rotaciono bušenje sa opremom za jezgrovanje). Bušilica ima mogućnost bušenja sa vanjskim čekićem ili sa DTH čekićem. Mustang 4-N3 je predviđen za bušenje rupa prečnika 75-150 mm, sa dubinom bušotine do 150 m. Bušilica je u potpunosti pokretna i upravljiva. Bušenjem se upravlja pomoću upravljačke konzole sa mogućnošću praćenja osnovnih parametara bušenja. Hidraulično pozicioniranje grane i lafeta omogućava bušenje u većini pravaca. Hidraulični sistem pokreće dizel motor snage 86.5 kW . Motor se nalazi na postolju sa gumenim točkovima i odvojen je od radnog dijela koji se nalazi na gusjenicama. Preko seta hidrauličnih crijeva dužine 20 m radni pritisak se prenosi od pogonskog agregata do radnog dijela mašine. Radni dio se sastoji od lafete sa rotacionom jedinicom i radnim stolom za odvijanje alata.

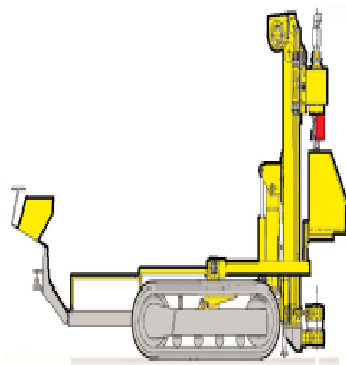
Mustang 4-N3 je opremljen rotacionom jedinicom RH50, koja se lako može modifikovati za bušenje mlaznim injektiranjem. Garnitura za bušenje ima radnu dužinu

lafeta od 1800 mm, tako da je teoretski, najveća moguća dužina cijevi za bušenje 1,8 m. U praksi se najčešće koriste cijevi od 1500 mm.

Ostala oprema kao što su snažno glavno vitlo, radni sto za držanje i odvijanje pribora omogućavaju bušilici da buši duboko uz lako i brzo rukovanje. Pumpa za vodu, pjenu i isplaku kao i sistem za dovođenje i regulaciju komprimovanog vazduha, takođe je sastavni dio ove bušilice, čijom se upotrebom u zavisnosti od postupka bušenja značajno olakšava sam postupak i smanjuju prateći troškovi.



a) Dizel motor sa hidrauličnim pumpama



b) Lafeta sa rotacionom jedinicom i radnim stolom za odvijanje alata i gusjenički podvoz

Sl. 1 Sastavni dijelovi geotehničke mašine tipa MUSTANG 4-N3

Tabela 1 osnovne karakteristike geotehničke mašine tipa MUSTANG 4-N3

BUŠENJE SA RAZLIČITIM PRIBOROM	
Geotehničko istražno bušenje sa jezgrovanjem i profilom bušenja	
Geobor S	Ø 146 mm
PQ wire-line	Ø 122 mm
HQ wire line	Ø 96,1 mm
NQ wire line	Ø 75,6 mm
Bušenje istražno-eksploatacionih bunara	
Udarnom metodom DTH – pneumatski čekić	4 " (101,6 mm)
TEHNIČKE KARAKTERISTIKE	
Snaga pogonskog motora Deutz D 914 L06 2V	86,5 [KW]
Masa bušilice	7400 [kg]
Rotaciona glava RH 50, 85 l/min na 260 bar, 2 brzine	161 – 700 [o/min]
Vodena crpka Trido 80 M	80 l/min, 40 [bar]

4. METOD UDARNIH IMPULSA (SPM)

Za dijagnozu stanja ležajeva koji su predmet analize u ovom radu je primijenjena tehnika mjerenja i analize udarnih impulsa – SPM metoda.

Mjerenje je obavljeno pomoću uređaja za ispitivanje stanja mašina tipa T30, proizvođača SPM Instrument iz Švedske. T30 je multifunkcionalan analizer, vrhunskih performansi. Podržava mjerenje i analizu vibracija, mjerenje i analizu udarnih impulsa (SPM metod - za dijagnostiku kotrljajnih ležajeva), mjerenje broja obrtaja i mjerenje temperature. T30 radi kao zaseban mjerni uređaj, ali i kao „Data Loger“ i povezan sa računarom uz odgovarajući softver predstavlja veoma moćan dijagnostički alat. Na Sl. 2 prikazan je sistem za dijagnozu stanja mašina T30, koji se sastoji od sledećih dijelova:

- mjerni instrument koji služi za prikazivanje, prikupljanje i obradu rezultata mjerenja;
- mjerne sonde za mjerenje udarnih impulsa TRA-22 i TRA-30;
- senzora za mjerenje vibracijske brzine TRV 22;
- senzora za mjerenje broja obrtaja TAD-18;
- sonde za mjerenje temperature TEN-10.



Sl.2 Mjerni uređaj T30

Metoda udarnog impulsa - SPM (*Shock Pulse Method*) je patentirana 1970. godine od Švedske firme SPM i od tada se snažno razvila, tako da danas slovi kao najčešće korišćena i najpouzdanija tehnika za detekciju stanja kotrljajnih ležajeva. Metoda se zasniva na analizi i mjerenju udarnih impulsa koji se stvaraju u toku rada ležaja.

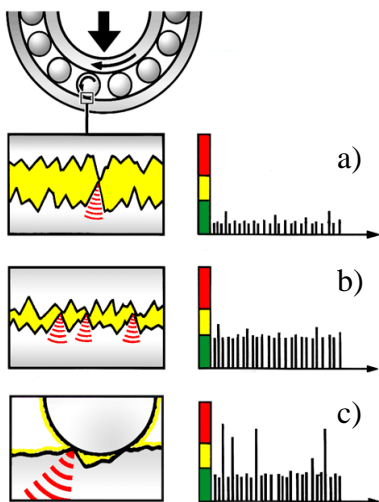
Metoda daje stvarne informacije o mehaničkom stanju radnih površina i stanja podmazanosti kotrljajnih ležajeva. Pogrešna montaža i loša podmazanost, osnovni uzroci otkaza mnogih ležajeva, takođe mogu biti detektovani ovom metodom.

SPM metoda ležaj posmatra kao "generator udarnih impulsa", a ne kao "generator vibracija". Udarni impulsi su kratkotrajni tranzientni talasi veoma niske energije, znatno niže od one koja izaziva vibracije kod mašina, ali sa frekvencijama višestruko većim od frekvencija vibracija. Nastaju u trenutku sudara dva čvrsta tijela

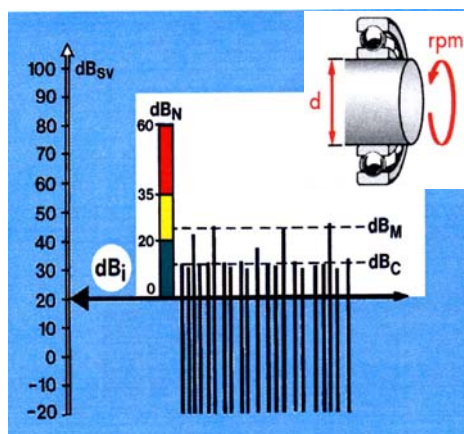
(Sl.3), kada se stvara udarni talas koji se poput eksplozije prenosi kroz materijal u svim smjerovima. Nivo udarnog impulsa u funkciji je od brzine sudara i površine na kojoj se sudar događa.

Udarni impulsi se u toku rada javljaju kod svih kotrljajnih ležajeva, kako kod dotrajalih, tako i kod novih. Kod novih ležajeva udarni impulsi se javljaju kao posledica hrapavosti kontaktnih površina elemenata ležaja. Kada je uljni film u ležaju dovoljno deo, nivo udarnih impulsa je nizak, bez karakterističnih vrhova (Sl.3.a). Jačina udara se povećava sa smanjenjem debljine uljnog filma, ali još uvijek ne postoje karakteristični vrhovi (Sl.3.b). Oštećenje radnih površina elemenata ležaja prouzrokuju pojedinačne udarne impulse većeg inteziteta i drugačijeg oblika u odnosu na dijagram udarnih impulsa kod neoštećenog ležaja (Sl.3.c). Ovakvi impulsi se najčešće javljaju nasumice i u veoma kratkim intervalima.

Za ocjenu stanja ležaja analizom udarnih impulsa koristi se takozvana *dBm/dBc tehnika*. Na slici (Sl.3) prikazan je pojednostavljen grafički prikaz veličina koje se koriste za ocjenu stanja ležaja pomoću dBm/dBc tehnike. Svaka vertikalna na dijagramu predstavlja jedan impuls. Gusti niz podjednakih niskih impulsa označava tepih vrijednost. Pojedinačne duže linije predstavljaju udarne impulse većih vrijednosti. Intezitet udarnih impulsa se mjeri u **dBsv** (*decibel shock value*). Maksimalna prosječna vrijednost udarnog impulsa **dBm** služi za ocjenu pogonskog stanja ležaja. Tepih vrijednosti (eng. Carpet) **dBc** pomaže pri utvrđivanju uzroka takvog pogonskog stanja ležaja. Razvojem oštećenja ležaja rastu i dBc i dBm vrijednosti, kao i razlika između ovih veličina. dBm je mjerna vrijednost za najače impulse koji se pojavljuju u toku jednog intervala mjerenja i direktno određuje stanje ležaja na skali za ocjenu stanja. Tepih vrijednosti udarnih impulsa daje važne podatke o podmazanosti ležaja, hrapavosti radnih površina, kvalitetu montaže, načinu opterećenja ležaja i sl.



Sl. 3 Kako nastaju udarni impulsi

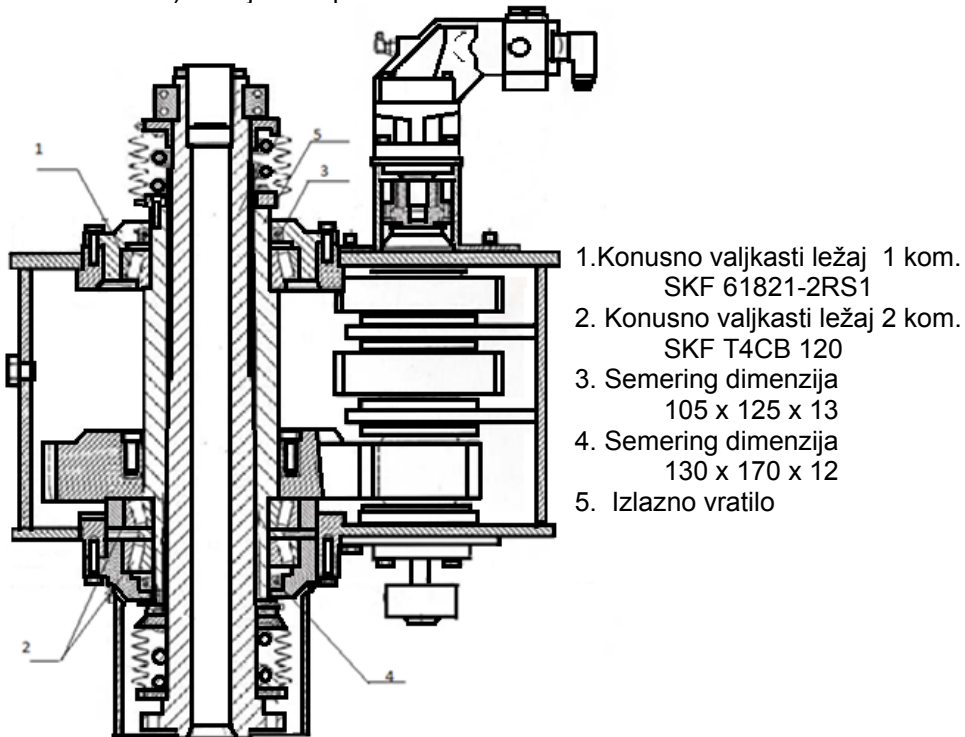


Sl. 4 Dijagram za ocjenu stanja ležaja pomoću dBm/dBc tehnike

5. PRIMJENA TEHNIČKE DIJAGNOSTIKE NA PRIMJERU ROTACIONE JEDINICE RH 50 UGRAĐENE NA GEOTEHNIČKU MAŠINU TIPA MUSTANG 4-N3

Pored pravilnog izbora mjernih tehnika i pouzdane mjerne opreme sprovođenje tačne i efikasne dijagnostike podrazumijeva i odgovarajuću sistemsku proceduru u skladu sa međunarodno priznatim i u svijetu prihvaćenim standardima.

U prvom redu potrebno je izvršiti pravilan izbor mjernih mjesta, u skladu sa karakteristikama pojedinih sklopova i podsklopova sistema i postavljenim ciljem dijagnoze. Opšte je poznato pravilo da za mjerna mjesta treba birati uležištenja, jer se na tim mjestima najbolje odlikava većina nepravilnosti u radu mašina. Tako smo prilikom dijagnosticiranja RJ RH 50 na izlaznom vratilu br. 5 (Sl. 4) kao mjerna mjesta birali uležištenja konusno valjkastih ležajeva br. 3 i br. 4 (Sl.4) i prema uputstvu za upotrebu proizvođača uređaja za dijagnozu stanja - T30, koje su navedene u prethodnom poglavlju rada. S obzirom na snagu motora (86,5 kW), kao i karakteristike temelja, mašina je rangirana u II klasu, što je u skladu sa preporukama koje propisuje standard ISO 10816. Za analizu stanja su izmjerene i vrijednosti RMS u radijalnom (čeonom i bočnom) i aksijalnom pravcu.

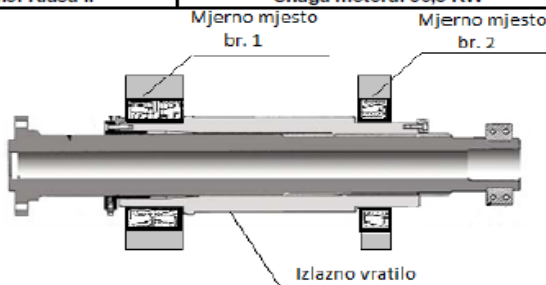


Sl. 4 Šematski prikaz rotacione jedinice RH 50

6. ANALIZA DOBIJENIH REZULTATA

U Tabeli 2. prikazan je položaj mjernih mjesta, izmjerene vrijednosti RMS za rad RJ RH 50 u neopterećenom i opterećenom slučaju i odgovarajući zaključci dobijeni na osnovu sprovedenih aktivnosti tehničke dijagnostike.

Tabela 2 izvještaj sa rezultatima mjerenja o tehničkoj dijagnostici stanja RJ RH 50

Mašinski fakultet u Podgorici TEHNIČKA DIJAGNOSTIKA			Broj: TD 01-09/12	
IZVJEŠTAJ O izvršenoj tehničkoj dijagnostici stanja RJ RH 50 u ZIGMA A.D. NIKŠIĆ			Strana: 8/10	
Prostrojenje / Uređaj: MUSTANG 4-N3 / RJ RH 50 -			Datum: 28.09.2012	
Klasa mašine: Klasa II			Snaga motora: 86,5 KW	
			Ocjena stanja prema preporukama ISO 10816	
				
STANJE MAŠINE: neopterećeno				
Mjerno mjesto : 1	Oznaka ležaja: T4CB 120 Nazivni prečnik: 100		Proizvođač: SKF Broj obrtaja: 170	
Mjerna tehnika	Rezultati	Stanje ležaja	dBi: 15	
SPM	dBm dBc	47 34	Visok rizik otkaza	
RMS	Čeono Bočno Aksijalno	3,1 4,0 4,7	Loše Loše Loše	
Napomena: Relativno visoka očitavanja vibracija govore o oštećenu površina ležajeva ili prisustvu nečistoća u ulju.				
Mjerno mjesto : 2	Oznaka ležaja: 61821-2RS1 Nazivni prečnik: 105		Proizvođač: SKF Broj obrtaja: 170	
Mjerna tehnika	Rezultati	Stanje ležaja	dBi: 15	
SPM	dBm dBc	60 10	Visok rizik otkaza	
RMS	Čeono Bočno Aksijalno	4,4 4,4 10,2	Loše Loše Neprihvatljiv	
Napomena: Relativno visoka očitavanja vibracija govore o oštećenu površina ležajeva ili prisustvu nečistoća u ulju.				
STANJE MAŠINE: opterećeno				
Mjerno mjesto : 1	Oznaka ležaja: T4CB 120 Nazivni prečnik: 100		Proizvođač: SKF Broj obrtaja: 132	
Mjerna tehnika	Rezultati	Stanje ležaja	dBi: 15	
SPM	dBm dBc	58 38	Visok rizik otkaza	
RMS	Čeono Bočno Aksijalno	2,8 3,4 3,7	Loše Loše Loše	
Napomena: Relativno visoka očitavanja vibracija govore o oštećenu površina ležajeva ili prisustvu nečistoća u ulju.				
Mjerno mjesto : 2	Oznaka ležaja: 61821-2RS1 Nazivni prečnik: 105		Proizvođač: SKF Broj obrtaja: 132	
Mjerna tehnika	Rezultati	Stanje ležaja	dBi: 15	
SPM	dBm dBc	73 52	Visok rizik otkaza	
RMS	Čeono Bočno Aksijalno	% % %	Neprihvatljiv Neprihvatljiv Neprihvatljiv	
Napomena: Relativno visoka očitavanja vibracija govore o oštećenu površina ležajeva ili prisustvu nečistoća u ulju.				
OPŠTE STANJE GEOTEHNIČKE MASINE - ROTACIONE JEDINICE:				
Neophodno je obustaviti rad mašine i izvršiti defektažu rotacione jedinice kako bi se spriječili neželjeni otkazi.				

7. ZAKLJUČAK

Rad prikazuje jedan dobar primjer pravovremenog djelovanja pri identifikaciji i otklanjanju uzroka otkaza i sprečavanju havarija i dugotrajnih zastoja mašina. Primijenjenom metodom tehničke dijagnostike veoma efikasno su identifikovani nedostaci u radu kotrljajnih ležajeva na rotacionoj jedinici RH 50, geotehničke mašine tipa MUSTANG 4-N3. Stanje ležajeva je bilo neprihvatljivo i predstavlja visok rizik za havariju cjelokupnog sistema što je zahtijevalo momentalno zaustavljanje mašine i sprovođenje detaljnih analiza u cilju identifikacije uzroka otkaza. Pošto se radilo o novoj rotacionoj jedinici, koja je radila svega 670 m.č. i koja je remontovana na 24 m.č., vjerovatnoća za otkaz ležajeva bila je veoma mala.

Detaljna analiza je pokazala da je osnovni uzrok otkaza neadekvatno konstrukciono rješenje kućišta rotacione jedinice. Dno rotacione jedinice sa konusno-valjkastim ležajevima znatno je niže od ispusta za ulje, gdje bi trebalo da se koncentrišu nečistoće. To je uzrokovalo da nečistoće i opiljci koji su se našli u ulju izazovu blokadu donjih ležajeva (Sl.5). Takođe, čep za ispuštanje ulja iz rotacione jedinice nema magnetna svojstva, što predstavlja još jedan nedostatak u konstruktivnom rješenju.



Sl. 5 Izgled konusno valjkastog ležaja sa zaostalim opiljcima i nečistoćama

Prikazani primjer na najbolji način pokazuje kako se pravilnim korištenjem relativno prostih metoda tehničke dijagnostike može doći do pouzdane procjene stanja mašinskog sistema, kao i do efikasne identifikacije uzroka toga stanja.

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REINŽENJERING MAŠINSKE OPREME NA ROTORNOM BAGERU

Vojin Vukotić¹, Dragan Čabrilo²

Rezime: U sklopu rudnika sa površinskom eksploatacijom, najčešće se koristi kontinualna tehnologija. To podrazumijeva da nekoliko rudarskim mašina radi u nizu, a otkopana ruda ili jalovina ima kontinualni tok od mašine koja vrši kopanje, preko transportera do mašine koja otkopani medij ili odlaže na za to definisano odlagalište ili ga dovodi na drobilično postrojenje, gdje se vrši usitnjavanje istog.

Rotorni bager je najznačajnija mašina u takvom tehnološkom nizu, a u ovom radu je objekat istraživanja u smislu produženja radnog vijeka zahvatima na bageru kroz aktivnosti funkcije održavanja. Zadatak ove mašine je da rudu odnosno jalovinu otkopava iz bloka i dalje je rosleđuje na transportere sa pokretnom gumenom transportnom trakom.

Posao revitalizacije rotornog bagera realizovan je ove godine na jednom od bagera u sklopu rudnika „Gacko“ a rad ima pretenziju da prikaže pristup revitalizaciji i stečena iskustva sa tog projekta.

REENGINEERING OF MECHANICAL EQUIPMENT ON THE BUCKET WHEEL EXCAVATOR

Abstract: As part of the mine pit mining, the most commonly used continuous technologies. This implies that several of mining machines working in series, and the excavated ore or tailings, has continuous flow from digging machine through the conveyors to the machine that executes disposing of a medium at the defined stack, or it leads to the crushing plant.

Bucket wheel excavator is the most important machine in such a technological sequence, and this paper is the object of study in terms of service life extension interventions on the excavator, through its maintenance functions. The task of this machine is that the ore and waste digs out from a block and forwards to a belt conveyor.

Job revitalization of excavator was implemented this year in one of the excavators in the mine "Gacko", a paper tends to present the approach to revitalization and experience gained from this project.

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1. REVITALIZACIJA ROTORNOG BAGERA

Eksploatacija korisne ineralne sirovine na rudnicima sa površinskom eksploatacijom obavlja se gdje god je to tehnološki izvodljivo primjenom kontinualne tehnologije otkopavanja.

Osnovna prednost primjene navedenog načina rudarenja u odnosu na korištenje diskontinualne tehnologije jeste u jeftinijoj proizvodnji, odnosno nižim specifičnim finansijskim ulaganjima po jedinici iskopane rude.

Kao predmet interesovanja u ovom radu obrađen je rotorni bager ER 1250 17/1,5, SI1.

Glavne tehničke karakteristike ovog bagera su:

Teoretski kapacite	1250 m ³ /h
Dokazani kapacitet	480 m ³ /h
Prečnik rotornog točka	6,5 m
Broj vedrica na rotoru	9 kom.
Snaga elektromotora rotora	315 kW
Širina gumene trake transporterera	1200 mm
Brzina kretanja gumene trake	4,4 m/s
Pogonski napon	6000 V
Težina bagera	700 t
Visina otkopne etaže	17 m
Specifični otpor kopanja do	14 dN/cm ²



Sl.1 Rotorni bager ER 1250 17/1,5 prije revitalizacije

Bager je bio u redovnoj eksploataciji na PK Gacko od 1979. godine i našao se na kraju radnog vijeka (30÷35 godina) jer je vremenski i kapacitvni koeficijent iskorištenja došao ispod dozvoljenih granica.

U prošloj godini radni učinak bagera bio je od 150 do 200 m³/h, a pouzdanost bagera ispod 30 %, što je duplo manje od postignutog nivoa pouzdanosti u periodu od prije desetak godina.

Menadžment rudnika je bio u dilemi šta raditi sa mašinom čiji je radni vijek bio na zalasku. Bilo je neracionalno otpisati rotorni bager, a to je za sobom povlačilo odricanje od kontinualne tehnologije na rudniku kojom se dobro ovladalo za proteklih tridesetak godina rudarenja na PK Gacko, koja je davala dobre proizvodne rezultate uz relativno niske troškove proizvodnje.

Poznato je da u cijeni električne energije, ugalj učestvuje sa 60 %, te da u cijeni uglja, održavanje rudarske mehanizacije participira sa 35 do 40 %. Pored navedenog, poznato je da nov rotorni bager iz ove klase bagera košta preko deset miliona KM.

Ono što treba ovdje posebno istaći je, da svaka nabavka nove opreme iziskuje duge periode do puštanja u rad (izrada tenderske dokumentacije, tenderi, evalucioni period, izbor najboljeg ponuđača, ugovor, projektovanje, fabrikacija, montaža, puštanje u rad). Prema dosadašnjim iskustvima to je period od nekoliko godina, koji s obzirom na postojeće stanje sa proizvodnjom uglja na PK „Gračanica“ nije prihvatljivo.

Odlučeno je da se pristupi revitalizaciji postojećeg bagera sa ciljevima:

- Povećanje raspoloživosti i pouzdanosti mašine
- Poboljšanje tehničkih karakteristika i sigurnosti bagera
- Produženje radnog vijeka mašine

Dakle, riješeno je da se pristupi reinženjeringu bagera, tj. revitalizaciji, rekonstrukciji i modernizaciji bagerske jedinice, odnosno pristupi postupku produženja vijeka upotrebe bagera. Taj pristup podrazumijeva uključivanja novih, savremenih tehničkih rješenja, rekonstrukciju slabih mjesta uočenih na bageru tokom prethodne eksploatacije, te modernizaciju pogona i sklopova.

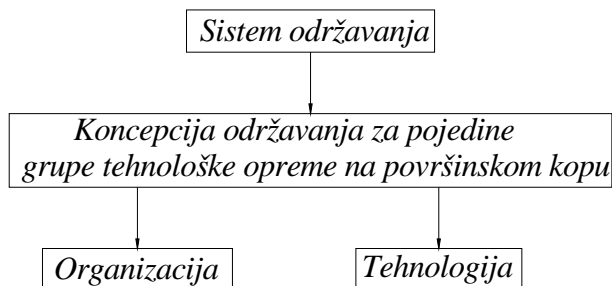
Akcije održavanja u sklopu pomenutog pristupa reinženjeringa bagera omogućio je razvoj novih naučnih disciplina, zasnovanih na sve ubrzanijoj primjeni teorije sistema, informatike i drugih srodnih grana sistemskih nauka. Posebno mjesto u okviru novih naučnih disciplina zauzimaju inženjerstvo pouzdanosti, inženjerstvo održavanja i inženjerstvo sigurnosti.

Inženjerstvo održavanja je naučna oblast koja je primjenjena na opremi površinskih kopova. Zbog heterogenosti angažovane opreme, ne može se govoriti o unificiranoj koncepciji održavanja na površinskom kopu. Jedan pristup važi za rotorne bagere, drugi za transportere i odlagače, treći za pomoćnu opremu, rovokopače, utovarače, buldozere, kamione i sl.

Može se zaključiti da su pri tome uslovno izdvojene dvije grupe problema, SI.2;

- Organizacija održavanja
- Tehnologija održavanja

Naravno, podrazumijeva se da rudnik raspolaže sa kvalitetnim i obučanim personalom (rukovaoci mašina, radnici održavanja) te stručnim obrazovanim menadžmentom.



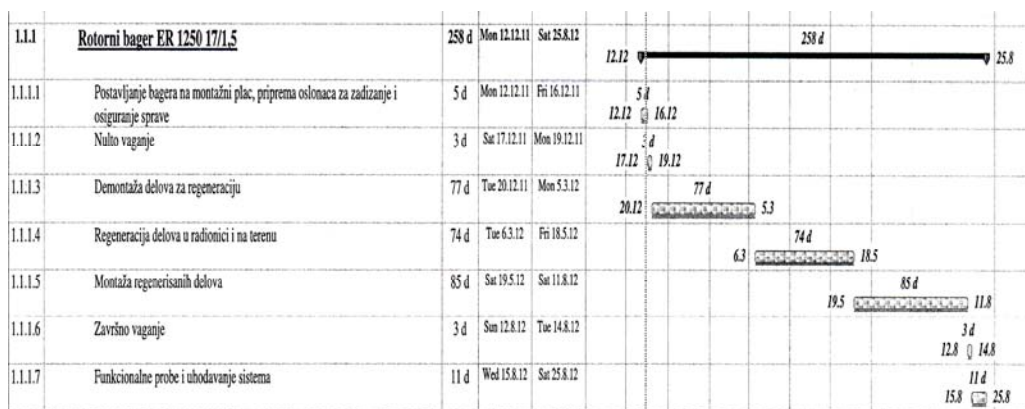
Sl.2 Održavanje tehnološke opreme na površinskom kopu

Osposobljavanje bagera, kroz održavanje ima za cilj produženje njihovog radnog vijeka uz ostvarivanje što optimalnijih veza tehničko-tehnoloških i ekonomskih parametara.

Odluka menadžmenta Rudnika da pristupi reinženjeringu rotornog bagera ER 1250/17 sretno se poklopila sa potrebom preseljenja bagera na novoprojektovani površinski kop, polje C, u sklopu PK „Gračanica“, rudnik Gacko, za što je potrebno oko godinu dana, a što istovremeno predstavlja vremenski period za revitalizaciju bagera.

Iskustva iz evropskih rudnika govore da je najbolji period za provođenje revitalizacije vrijeme kada su na rudniku veći zastoji zbog tehnoloških razloga.

Uz odluku da će se vršiti revitalizacija, odmah se pristupilo pripremi iste (defektaže i mjerenja na bgeru u toku rada i u zastoju mašina, naručivanje planiranih rezervnih dijelova, sklopova i materijala). Količina i raznovrsnost opreme koja će se revitalizovati na površinskom kopu ili u radionicama izvođača (u drugoj državi) iziskuje kompletnu posvećenost i organizaciji posla, kako bi se dotigli zadati rokovi. U tom cilju napravljen je i gantogram aktivnosti na revitalizaciji rotornog bagera, Sl.3.



Sl.3 Termin plan revitalizacije bagera

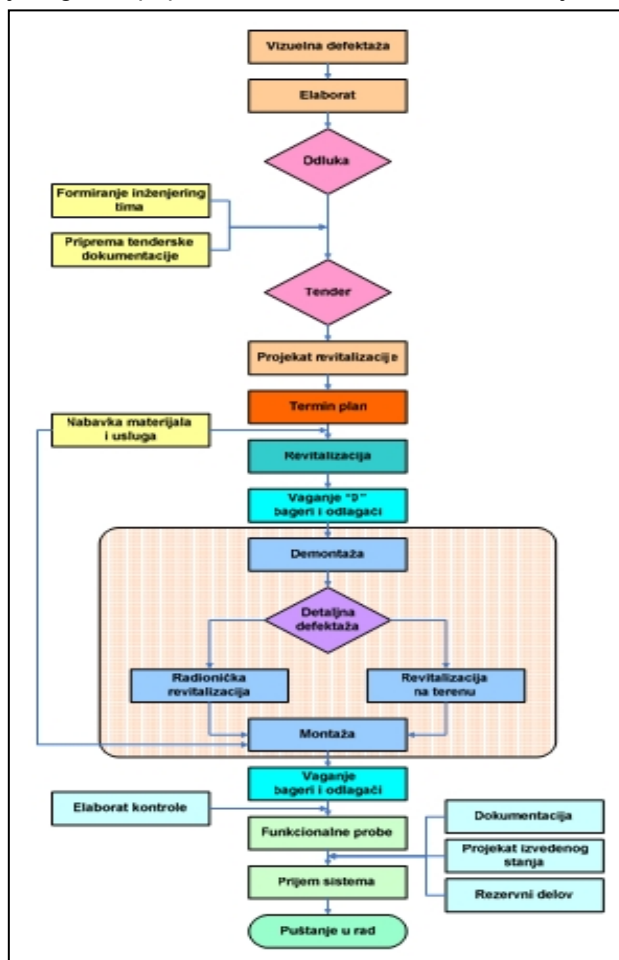
U pripremi revitalizacije bagera, u toku samog izvođenja zahvata, treba imati u vidu koliki je preostali vijek bagera, kakva će se konceptija održavanja primijeniti te projektovati vjerovatnoću da se tretirani rotorni bager prevede iz stanja U OTKAZU u

stanje U RADU u što kraćem vremenskom periodu i uz što prihvatljivije ekonomske resurse.

Projekat revitalizacije bagera odvijaće se prema aktivnostima predstavljenim u algoritmu toka revitalizacije bagera, Sl.4.

Prva aktivnost revitalizacije predstavlja vizuelna defektaža na terenu sa ciljem upoznavanja sa stanjem mašinske opreme i čelične konstrukcije na bageru predviđenom za revitalizaciju.

Na osnovu zaključaka donijetih nakon vizuelne defektaže, pristupa se izradi elaborata revitalizacije, na osnovu koga se donosi odluka o pristupanju revitalizaciji, formira se inženjering tim i priprema se tenderska dokumentacija.



Sl.4 Algoritam toka revitalizacije bagera

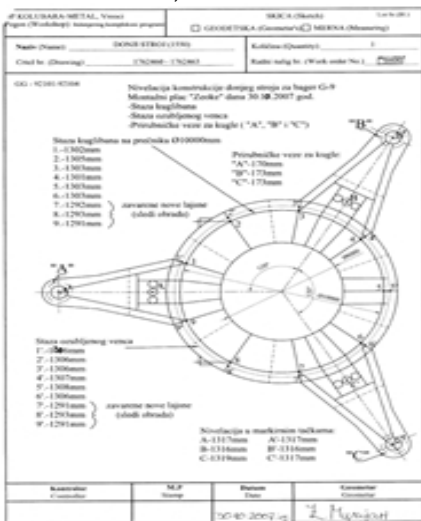
Nakon uspješno provedenog tendera i regulisanja obligacione dokumentacije sa izabranim izvođačem, pristupa se izradi termin plana aktivnosti na revitalizaciji, Sl.3. Prilikom izrade globalnog termin plana treba uzeti u obzir i eventualnu nabavku dijelova iz drugih zemalja, uključujući i vrijeme za realizaciju međunarodnih tendera.

Narednu aktivnost predstavlja izrada projekta revitalizacije mašinske opreme. Vrší se nabavka materijala i usluga neophodnih za izvođenje revitalizacije. Vrší se tzv. „nulto“ vaganje kako bi se dobio uvid u statičke karakteristike mašine i položaj težišta. Nakon ove operacije pristupa se demontaži bagera, skodanju i prevozu sklopova u radionice izvođača, rastavljanje sklopova uz defektažu svakog mašinskog dijela na osnovu Plana defektaže, SI.5, i Liste defektaže, SI.6.

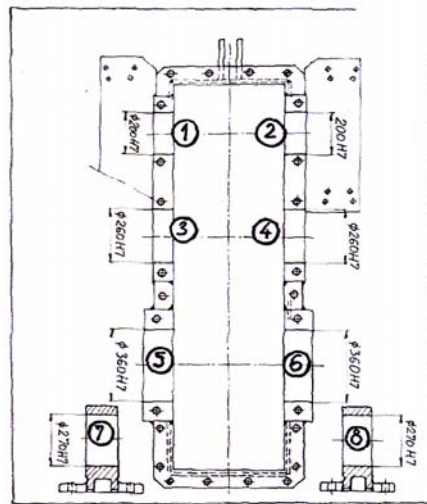
SI.5 Plan defektaže

SI.6 Lista defektaže

Defektaža ima cilj da nam pruži uvid u zatečeno stanje svakog sklopa na osnovu čega se donosi odluka o budućim aktivnostima koje treba da sklop dovedu u zahtjevano stanje. Rezultati defektaže se predstavljaju kroz Izvještaj o defektaži, SI.7 i Mjerno-kontrolni list, SI.8.



SI.7 Izvještaj o defektaži



SI.8 Mjerno-kontrolni list

Na osnovu tako formirane dokumentacije planiraju se vrste i obimi radovi koji će se preduzeti u toku revitalizacije kako bi se otklonili zatečeni nedostaci, tj. prepoznaju se sklopovi, dijelovi i elementi koji će biti obuhvaćeni radioničkom revitalizacijom, odnosno revitalizacijom na terenu. Izdaju se Radni nalozi i Tehnološki postupci uz Radne naloge. Situacija kada su sklopovi rastavljeni koristi se da se formira nedostajuća tehnička dokumentacija, kao npr. radionički crteži, tehnološke liste izrade i sl.

U toku izvođenja radova u radionici vrše se odgovarajuće probe regenerisanih i izrađenih dijelova i sklopova, kao i njihova antikorozivna zaštita, a zatim se otpremaju nazad na radilište, kako bi se pristupilo njihovoj montaži na bager.

Uporedo sa radioničkom revitalizacijom vrši se revitalizacija mašinske opreme i čelične konstrukcije na terenu, te završna antikorozivna zaštita po montaži prispjele opreme iz radionica skupa sa čeličnom konstrukcijom bagera. Na kraju se obavlja i završno vaganje radi utvrđivanja položaja težišta, odnosno korekcije istog.

Na slici 9 je prikazana fotografija bagera ERT 1250/17 poslije revitalizacije.



Sl. 9 Rotorni bager ER 1250/17 u završnoj fazi montaže

Na kraju, vrši se izrada Elaborata o provedenoj revitalizaciji, obavljaju funkcionalne probe bagera, te provjera i dokazivanje tehnoloških parametara. Završni čin na planu revitalizacije bagera je Zapisnik o primopredaji između investitora i izvođača na osnovu čega se rješavaju obligacioni odnosi i potpisuje okončana situacija radova.

2. ZAKLJUČAK

Osnovna poenta ovog rada je u tome da poruči stručnoj javnosti da su u novije doba razvijene metode i tehnološki postupci inženjerstva održavanja sa ciljem da skupe i složene tehničke sisteme ne treba otpisivati, odnosno izbacivati iz proizvodnje na kraju projektovanog radnog vijeka. Taj se period može produžiti za trećinu do polovinu nominalnog radnog vijeka koristeći metode inženjeringa, odnosno primjenom procesa revitalizacije na konkretni tehnički sistem.

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DIJAGNOSTIČKA OPREMA ZA PRAĆENJE FIZIČKO-HEMIJSKOG STANJA UTTO I STOU TRAKTORSKIH ULJA

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Darko Knežević⁴, Milija Kraišnik⁵

Rezime: U toku eksploatacije poljoprivrednih radnih mašina posebno traktora, neophodno je u određenim intervalima kontrolisati određene fizičko-hemijske parametre tečnosti za podmazivanje. U poljoprivrednoj tehnici koriste različiti tipovi ulja (mineralni i sintetički, u različitim viskoznim gradacijama) za podmazivanje pojedinih ali u nekim slučajevima i sklopova radnih mašina grupisanih u jednu celinu. U radu je dat detaljan opis opreme za brzo ispitivanje fizičko-hemijskih parametara svih tipova radnih fluida.

Ključne reči: dijagnostika, fizičko-hemijske karakteristike fluida

DIAGNOSTIC EQUIPMENT FOR EXAMINATION PHYSICAL AND CHEMICAL CHARACTERISTICS OF UTTO, STOU TRACTOR OILS

Abstract: During exploitation of agricultural machinery, especially tractors, it is necessary to periodically control certain physical and chemical parameters of a lubricant. Different types of lubricant oils are used by agricultural machines (mineral and synthetic, in different viscosity grades) for lubricating the individual but in some cases, assembled parts grouped into one whole. The article gives a detailed description of the equipment for rapid testing of physical-chemical parameters of all types of working fluids.

Key words: diagnostic, physical and chemical characteristics of the fluid

1. UVOD

U zavisnosti od porekla baznog ulja, u poljoprivrednoj tehnici se koriste različiti fluidi za podmazivanje motora, reduktora, hidrauličkih i upravljačkih sistema, sistema kočnica, itd. Sa ekoloških aspekata poželjno je da se u budućnosti koriste uglavnom biorazgradivi fluidi, čija je namena da podmazuju sklopove radne mašine bez motora (UTTO ulja koja podmazuju transmisiju – hidrauliku – mokre kočnice) ili sa motorom (STOU ulja koja podmazuju motor – transmisiju – hidrauliku – mokre kočnice - spojnice). U današnje vreme takva ulja su već dostupna na našem tržištu, u vidu ulja

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tipa UTTO (Universal Tractor Transmission Oils) i STOU (Super Tractor Oil Universal). Očigledna razlika između UTTO i STOU ulja je u tome što STOU ulja moraju da obezbede kvalitetno podmazivanje i motora koji rade na znatno višim temperaturama u odnosu na ostale sklopove radne mašine (menjač, diferencijal spojnica, kočnice).

Osnovne funkcije koje jedno UTTO ulje da ispuni je: da obezbedi kvalitetno podmazivanje, dizperzantno deterdžentnu funkciju (spiranje i zadržavanje čvrstih čestica u masi ulja), dobru oksidacionu i termičku stabilnost, zaptivanje, zaštita od korozije, kompatibilnost sa drugim materijalima kao i ekonomičnost primene, podnošenje visokih opterećenja i habanja (EP i AW karakteristike), dobre deemulzione karakteristike. STOU ulja imaju još oštrije zahteve u pogledu svojstava, jer ova ulja podmazuju i motore, tako da osim navedenih svojstava koja važe za UTTO ulja treba da zadovolje i dobro hlađenje, još bolje dizperzantno deterdžentna svojstva, poboljšane karakteristike viskoznosti zbog različitih temperaturnih režima eksploatacije (leto – zima), bolje oksidacione i termičke karakteristike, itd.

S obzirom na brojne funkcije koje treba da obavi, ulje poseduje veoma kompleksan hemijski sastav i u toku eksploatacije neophodno je povremeno ili u određenim vremenskim intervalima vršiti kontrolu određenih fizičko-hemijskih karakteristika ulja. Međutim, proizvođači radnih mašina i opreme imaju stav da se u određenim vremenskim intervalima treba menjati radni fluid, ali se pokazalo tokom eksperimenata da je korisno u zavisnosti od tipa mašina i uslova eksploatacije (izloženost prašini, uticaju vode kao i promenljivih radnih opterećenja) vršiti periodično uzorkovanje i ispitivanje određenih karakteristika ulja, čime se vek ulja u zavisnosti od fizičko-hemijskih karakteristika može produžiti ili u slučaju brze degradacije, zameniti ranije nego što je to potrebno prema preporuci proizvođača mašine i time sprečiti habanje kritičnih radnih elemenata sklopova mašine.

2. OSNOVNE FIZIČKO-HEMIJSKE OSOBINE ZA BRZO PRAĆENJE STANJA ULJA NA TERENU

U toku eksploatacije poljoprivredne mehanizacije, eksploatacioni vek ulja zavisi od više faktora, koji su već pomenuti, a jedan od važnijih je samo stanje radne mašine. UTTO ulja su namenjena za podmazivanje svih ostalih sklopova, osim motora i u tom pogledu spadaju u grupu ulja kod kojih je interval zamene duži, jer ovaj tip ulja nije toliko temperaturno opterećen kao što su STOU ulja. Kod STOU ulja veoma je bitno stanje u kom se nalazi motor radne mašine. U zavisnosti od stanja motora (da li je nov, razrađen ili je u stanju pred generalnim remontom) i određene fizičko-hemijske karakteristike ulja se brže ili sporije menjaju. Rabljeni motori po pravilu brže termički i kontaminaciono optereće ulje čime mu se vek eksploatacije drastično skraćuje. Zbog ovog osnovnog faktora, a takođe i faktora koji su predhodno navedeni, u toku eksploatacije ulja koristi se široko rasprostranjena oprema za ispitivanje nekih od karakteristika ulja. U radu je prikazana oprema tipa KITTIWAKE, proizvođača iz Velike Britanije, koja se može koristiti za širu primenu praćenja ulja u toku eksploatacije i brzo dijagnostifikovanje promena nekih od svojstava ulja. Osnovne karakteristike ulja koje se mogu pratiti sa ovim tipom opreme su:

Kinematska viskoznost - jedna od osnovnih fizičkih karakteristika ulja bitna za praćenje u toku eksploatacije vezana je za sposobnost ulja da kvalitetno vrši podmazivanje radnih elemenata u kontaktu i da se viskoznost ulja prilagodi promenama temperaturnog okruženja. Praćenje kinematske viskoznosti u toku

eksploatacije je veoma bitno, pogotovo kod visoko aditiviranih ulja (multigradnih ulja) kod kojih u početku upotrebe usled delovanja visokih opterećenja i pojave ekstremnih smičućih sila dolazi do cepanja polimera viskoznosti sa kojima je ulje aditivirano i do pada vrednosti kinematske viskoznosti za veličinu i do 30 %. Neophodno je reći da je to samo u početku, u toku dalje eksploatacije viskoznost se vraća na početnu vrednost. Takođe, oksidaciona stabilnost ulja direktno utiče na veličinu viskoznosti ulja. Na oksidacionu stabilnost ulja utiču direktno hemijske osobine ulja, odnosno dobar izbor baze ulja i određene grupe aditiva – antioksidanata.

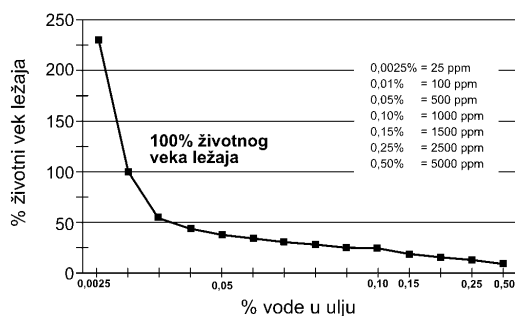
U slučaju rada motora ili drugih sklopova na višim temperaturama od dozvoljenih, oksidacija ulja je neminovna, stvaraju se sagoreli kiseli nusprodukti u vidu peroksida, karboksilne kiseline, aldehida i drugih, koji se kasnije u toku eksploatacije ulja polimerizuju i obrazuju smole i ostale čvrste taloge. Na taj način direktno utiče na povećanje vrednosti viskoznosti ulja, kao i povećano habanje određenih elemenata u sklopovima motora, reduktora i hidraulici. Viskoznost u toku eksploatacije po pravilu se samo može povećavati, izuzev prodora goriva ili rastvarača koji joj mogu oboriti vrednost. Dozvoljeno odstupanje kinematske viskoznosti od startne je $\pm 20\%$ za motorna ulja i $\pm 10\%$ za sve ostale tipove ulja (hidraulično, transmisiono....)

TBN - hemijska karakteristika ulja kojom se izražava ukupna vrednost baznog broja je TBN (Total Base Number). Ovaj broj definiše meru alkalnosti svih materijala u ulju koji pokazuje bazne reakcije. Vrednost baznog broja se izražava u mg KOH/g ulja. Kod novijih formulacija motornih ulja, bazni broj je manji u odnosu na starije tipove ulja, jer je sadržaj sumpora u gorivu i po nekoliko desetina puta manji u odnosu na starije tipove goriva. U toku eksploatacije, bazni broj ulja se postepeno «troši» u odnosu na početnu vrednost. Uloga baznog aditiva u ulju je da neutrališe kisele nusprodukte koji nastaju u toku sagorevanja goriva, tako što će da ih spere sa radnih elemenata motora, i disperguje u ulju. Dozvoljeni pad vrednosti TBN-a u motornom ulju je do 50 % od startne vrednosti.

TAN - karakteristika ulja, izričito važi za ulja koja podmazuju sve sklopove radne mašine (STOU ulja), je kiselinski stepen ulja – TAN (Total Acid Number). Definiše se kao mera ukupne kiselosti (sadržaja jakih i slabih kiselina) maziva i ulja. Karakteristično je da se ispituje kod svih tipova ulja osim motornih, jer je poznato da su jedino motorna ulja bazična. Izražava se u mg KOH/g uzorka ulja. Dozvoljeni porast kiselinskog broja je do 100 % u odnosu na startnu vrednost.

Sadržaj vode u ulju - prisustvo vode u ulju (motorno, transmisiono, hidraulično...) je veoma negativna pojava. Prisustvo vode u motornim uljima je svedeno na minimum pod uslovom da u unutrašnjost motora voda ne može da dospe iz sistema za hlađenje. Ona količina vode koja dospe preko atmosfere, vremenom pri radu motora na višim temperaturama ispari i ne utiče toliko na starenje i oksidaciju ulja. Kiseline koje se stvaraju u motornom ulju uglavnom su posledica sagorevanja goriva i vezivanja prisutne vlage u vazduhu za sumpor. Kod svih ostalih ulja (transmisiona, hidraulična...) koja rade u temperaturnim uslovima okoline ili na nešto malo povišenim temperaturama (40 - 60 °C) prisutna vlaga se postepeno vezuje za molekule ulja, vrši ispiranje prisutnih aditiva i stvara kisela jedinjenja čime povećava koroziono dejstvo ulja na elemente sklopova radnih mašina. Prisustvo vode manifestuje se pojavom emulzija mlečno bele boje koje polako prelaze u čvrste emulzije (pogotovo kod mineralnih i biorazgradivih ulja), koje uzrokuju povećanje viskoznosti i kiselosti ulja. U najkritičnije komponente u mehanici obično spadaju ležajevi. Negativni uticaj vode na

smanjenje veka korišćenja ležajeva ilustrovan je dijagramom firme Timken (slika 1), na kome je prikazan uticaj sadržaja vode na smanjenje veka korišćenja kotrljajućih ležajeva. Kao bazni sadržaj vode definisana je veličina od 0,01 % (100 ppm) i tada se kod proračunatog opterećenja i definisanog broja obrtaja, postiže 100 % životnog veka kotrljajućeg ležaja.



Sl. 1 Uticaj sadržaja vode na proračunati vek trajanja ležaja (Savić i Zirojević, 2003)

Dozvoljeni sadržaj vode u uljima za transmisiju, hidrauliku i sva ostala ulja osim motornih je do 500 ppm, odnosno 0.05 %; a za motorna ulja ove vrednosti su nešto veće i kreću se do 2000 ppm ili 0.2 %.

Čvrste čestice u ulju – prisustvo čvrstih čestica u ulju u vidu kontaminanata je veoma važan pokazatelj stanja ulja i radnih elemenata sklopova. Čvrste čestice su uvek prisutne u ulju, samo je pitanje u kojoj meri i količini. Mehanizam njihovog delovanja i uticaj na proces habanja, rad i vek radnih elemenata je višestruk i složen. Postoje dva načina prodiranja čvrstih čestica među radne elemente sklopova mašina (Savić i Jocanović, 2004):

- ✧ eksterni – spolja i
- ✧ interni – unutar sistema.

Unošenjem čvrstih čestica iz okoline (**eksterno**), najčešći je slučaj i predhodi ovom drugom, internom. Eksterno unošenje čestica je karakteristika onih sistema koji nemaju odgovarajuće zaptivanje ili sisteme za filtriranje vazduha iz okoline u kojoj rade. Čestice u ulju su najčešće prirodnog porekla (pesak, čestice kamena, oksida) i rezultat su rada mašine u zaprljanoj okolini i sagorevanja goriva i stvaranja taloga u ulju. Utiču nepovoljno na radne elemente (ležaje, osovine, zupčanike, hidraulične komponente...), jer izazivaju intenzivan proces habanja.

Interne čvrste čestice (produkti habanja) koje se nalaze u ulju su posledica delovanja eksternih čestica, jer njihovim delovanjem na radne elemente mehanizama dolazi do procesa habanja delova metala od kojih su izrađeni radni elementi i stvaranja novih internih čestica. Ove čestice najčešće vode poreklo od čelika, mesinga, bronz, cinka i u sklopovima mašine uzrokuju **intenzivno** habanje ležajeva, hidrauličnih komponenta, zupčanika, itd. Dozvoljeni sadržaj čvrstih čestica zavisi od najosetljivije komponente u sklopu mašine (ležaj, hidraulična pumpa, servoventili u LS regulaciji hidraulike...) i kod STOU tipa traktorskih ulja intenzitet unosa čvrstih čestica u uljnu masu daleko je brži u odnosu UTTO ulja, jer se sa STOU uljima podmazuju svi sklopovi traktora. Takođe, određen broj internih čvrstih čestica kod SUS motora

nastaje sagorevanjem goriva gde se stvara čađ i bitumenozne naslage.

Za određivanje čvrstih čestica u ulju (industrijska: hidraulično, transmisiono, turbinsko...) koriste se metode za merenje čvrstih čestica u tri dimenzije prema standardima: ISO 4406/99, NAS1638, SAE AS 4059:D, dok se za nesagorele čestice u motornom ulju koriste metode prema standardu: ASTM 893 i British Standard Specification IP 316. Dozvoljena maksimalna vrednost nerastvorenih čestica u motornom ulju je 2.5 %.

Svi predhodno pomenuti parametri, pokazuju, da prekoračenje bilo kojeg parametra van dozvoljenih granica, ukazuje na to da se fizičko-hemijske karakteristike ulja menjaju u toku eksploatacije. Upotrebom ulja koje nije odgovarajućih karakteristika i čiji su parametri van dozvoljenih granica, rizikuju se znatna oštećenja i kvarovi na samoj mašini.

3. KITTIWAKE – OPREMA ZA ISPITIVANJE FIZIČKO-HEMIJSKIH KARAKTERISTIKA NA TERENU

Oprema koja je korišćena u dijagnostifikovanju UTTO i STOU ulja je test uljni centar tipa **OTC - K1-100 – KW – Kittiwake** (www.kittiwake.com, 2003), slika 2. Oprema se sastoji iz dve osnovne elektronske jedinice: jedne za merenje kinematske viskoznosti (slika 2, poz. 1) koja spada u viskozimetre sa kuglom (Höppler – ov tip viskozimetra) i druge koja se sastoji od senzorsko-računarske jedinice (slika 2, poz. 2) sa displejom koja služi za merenje hemijskih karakteristika TBN-a, TAN-a, sadržaja vode u ulju i sadržaja nerastvorenih čestica (čađi i asfaltnih ostataka u motornom ulju). Svaka od hemijskih karakteristika koja se ispituje (TBN, TAN, voda i nerastvorene čestice u ulju) poseduje određenu mernu ćeliju koja se postavlja na senzorsku-računarsku jedinicu.



Sl. 2 Elektronski uređaj za merenje fizičko hemijskih karakteristika ulja - KITTIWAKE

1.viskozimetar, 2.računarska jedinica, 3.merna ćelija za merenje TBN-a, 4. merna ćelija za merenje TAN-a. 5. merna ćelija za mernje vode, 6. merna ćelija za merenje nerastvorenih čestica

Merenje kinematske viskoznosti

Za merenje kinematske viskoznosti na 40 °C, koristi se potpuno elektronski opremljen viskozimetar, koji se sastoji od elektronske jedinice povezane sa sensorima smeštenim u aluminijumskoj cevi na oba kraja i grejačem za zagrevanje ulja na 40 °C (slika 2, poz.1). Senzori mere brzinu kretanja metalne kugle od jednog na drugi kraj. Zagrevanje ulja vrši se automatski tako da je udeo ljudske greške sveden na minimum.

Tabela. 1 Tehničke karakteristike viskozimetra sa grejačem ulja na 40 °C

Parametar	Opis
Merni opseg kinematske viskoznosti	20 – 810 mm ² /s
Temperaturni opseg merenja	40 °C
Vreme potrebno za ispitivanje	5 - 10 min
Temperatura eksploatacije uređaja	10 – 50 °C
Tipovi fluida	Svi, osim fosfat estera – hem.agresivan
Očitavanje	Samostalno, digitalno na ekranu
Tip opreme	Prenosna, za terenske uslove
Tačnost	±3 %

Tačnost uređaja je na visokom nivou od ±3 %. Komparativno su rađene analize ulja na elektronskom uređaju sa rezultatima iz ovlašćenih laboratorija, gde je uređaj pokazao visoku tačnost rezultata za merenje kinematske viskoznosti na 40 °C. Kod motornih ulja je potrebno da se uradi merenje kinematske viskoznosti i na 100 °C, ali se to radi u laboratorijskim uslovima u specijalnim uljnim kadama gde se temperatura ulja održava i temperira na 100 °C. Ovaj uređaj nije namenjen za merenje viskoznosti na 100 °C.

Merenje baznog broja motornog ulja (TBN)

Merenje se obavlja na senzorsko - računarskoj jedinici sa displejom koja služi za merenje hemijskih karakteristika (slika 2, pozicija 2). Za merenje TBN-a koristi se specijalna merna ćelija (slika 2, pozicija 3) u koju se sipa određena vrsta reagensa (tip B) i uzorak novog ulja koji se mora sačuvati prilikom sipanja novog ulja u karter motora. Izmerena referentna vrednost se upoređuje sa referentnom vrednošću novog ulja koje se unose u računarsku jedinicu, a rezultati komparativne metode se prikazuju na displeju računarske jedinice.

Tabela. 2. Tehničke karakteristike uređaja za merenje baznog broja motornog ulja–TBN

Parametar	Opis
Merni opseg za merenje baznog broja	0 – 55 mg KOH
Vreme potrebno za ispitivanje	3 min
Temperatura eksploatacije uređaja	10 – 50 °C
Tipovi fluida	Sve vrste motornih ulja
Očitavanje	Samostalno, digitalno na ekranu
Tip opreme	Prenosna, za terenske uslove
Tačnost	± 5 %

Merenje kiselinskog broja ulja (TAN)

Merenje kiselinskog broja se radi kod svih tipova ulja, u zadnje vreme i kod motornih, jer se sa praćenjem rasta kiselina u karteru motora kod ulja u eksploataciji, najbolje indukuje nivo oksidacije ulja. Za merenje TAN-a koristi se specijalna merna

ćelija (slika 2, pozicija 4) koja se postavlja na senzorsko-računarsku jedinicu. Ćelija radi merenje na principu kolorimetrijske analize. Očitavanje rezultata izmerene vrednosti se vrši na displeju.

Tabela. 3. Tehničke karakteristike uređaja za merenje kiselinskog broja ulja – TAN

Parametar	Opis
Merni opseg merenje kiselinskog broja	0 – 3 mg KOH TAN prema ASTM D 664/IP177
Vreme potrebno za ispitivanje	3 min
Temperatura eksploatacije uređaja	10 – 50 °C
Tipovi fluida	Sve vrste ulja
Očitavanje	Samostalno, digitalno na ekranu
Tip opreme	Prenosna, za terenske uslove
Tačnost	± 0.2 TAN

Merenje sadržaja vode u ulju

Isto kao i kod predhodnih metoda, za merenje vode se koristi posebna merna ćelija (slika 2, pozicija 5). Koriste se dve vrste reagenasa sa ciljem dobijanja što tačnijih rezultata. Očitavanje rezultata je takođe digitalno na displeju računarske jedinice.

Tabela 4. Tehničke karakteristike uređaja za merenje sadržaja vode u ulju

Parametar	Opis
Merni opseg merenje sadržaja vode u ulju	0 – 3000 ppm prema IP386 0-3 %
Vreme potrebno za ispitivanje	10 - 20 min
Temperatura eksploatacije uređaja	10 – 50 °C
Tipovi fluida	Sve vrste ulja
Očitavanje	Samostalno, digitalno na ekranu
Tip opreme	Prenosna, za terenske uslove
Tačnost	± 50 ppm

Merenje nerastvorenih čestica u ulju

Kontrolu nerastvorenih čestica u ulju potrebno je vršiti samo kod motornih ulja. Metodom KITTIWAKE, meri se ukupan sadržaj nerastvorenih materijala (čvrsti kontaminanti internog i eksternog porekla, čađ i dr.) do kritične vrednosti od 2.5 % za traktorska ulja. Oprema se sastoji od posebne merne ćelije (slika 2, pozicija 6). Prednost primene ove metode je brzina izvođenja dijagnostike stanja ulja. Druga slična metoda je ručnog tipa, gde se kap ulja nakapa na filterski papir, tretita n-pentanom i ostavi da miruje 24 časa, a posle se vizuelnom kontrolom ili pod mikroskopom posmatra veličina i boja mrlje. Na osnovu toga se određuje prisustvo nerastvorenih čestica. Mana metode uljne mrlje je subjektivnost tehničara i vreme trajanja dijagnostike (24 sata).

Tabela 5. Tehničke karakteristike uređaja tipa KITTIWAKE za merenje nerastvorenih čestica u motornom ulju

Parametar	Opis
Merni opseg merenje sadržaja nerastvorenih čestica u motornom ulju	0 – 3.5 % prema IP316
Vreme potrebno za ispitivanje	1 min
Temperatura eksploatacije uređaja	10 – 50 °C
Tipovi fluida	Sve vrste motornih i rezidualnih ulja
Očitavanje	Samostalno, digitalno na ekranu
Tip opreme	Prenosna, za terenske uslove
Tačnost	± 0.1 %

Trodimenzionalni uređaji za merenje veličine i broja čvrstih čestica u hidrauličnim i transmisionim uljima su dosta skuplji. Takvi uređaji omogućuju merenje kontaminacije ulja čvrstim česticama i na osnovu izmerenog broja i najkritičnije komponente u sistemu određuje se stepen čistoće ulja, odnosno da li je ulje na zadovoljavajućem nivou u pogledu broja čestica (Jocanović, 2006). Ovakvi uređaji nisu namenjeni za dijagnostifikovanje fizičko-hemijskih karakteristika ulja, već utvrđuju prisustvo kontaminanata u ulju. Uređaji za merenje čvrstih čestica u ulju imaju opravdanost upotrebe samo kod UTTO ulja koja se mogu duže eksploatisati u odnosu na STOU ulja.

4. METODE ZA ISPITIVANJE FIZIČKO-HEMIJSKIH KARAKTERISTIKA ULJA

Razvijeno je više metoda za ispitivanje ulja u toku eksploatacije (koja se odnose i na traktorska UTTO i STOU ulja). Ispitivanje motornih ulja od ispitivanja industrijskih ulja je delimično različito, a ono sledi iz sledećeg (Savić i drugi, 2006):

- hemizam motornih ulja je sasvim drugačiji od industrijskih - samo jedna od nekoliko bitnih razlika: motorno ulje je bazično, a industrijsko ulje je kiselo;
- motorno ulje je u toku aktivne funkcije izloženo delovanju visokih temperatura (oko 150 °C), sumpora i produkata sagorevanja;
- motorno ulje je u toku aktivne funkcije izloženo delovanju visokih naprezanja na smicanje;
- u motornom ulju nalazi se višestruko veća količina aditiva od količine aditiva u visokopterećenom industrijskom ulju (hidraulična, transmisiona i dr.);
- uljna punjenja motornim uljima su po pravilu mala (osim kod brodskih motora);
- motorna ulja su u principu namenjena za kratkotrajnu upotrebu (tendencija produženja veka upotrebe) – npr. vek traktorskog ulja je od 250 do 500 radnih časova (u zavisnosti od porekla i tipa ulja) i obavezno se menja jednom godišnje, a industrijska ulja, posebno ona većih punjenja imaju znatno duže intervale zamene kod neprekidnog rada, od 1 do 20 godina i duže;
- proizvođači motora propisuju intervale zamene ulja, tako da je to dodatno ograničenje.

Iz izloženog bi se mogao izvesti **pogrešan zaključak**:

- da se motorna ulja ne ispituju u toku eksploatacije, jer je sve definisano zahtevom proizvođača motora i izjavom proizvođača motornog ulja o kvalitetnom nivou koga ono zadovoljava.

U prilog shvatanju, da se i **motorna ulja selektivno ispituju u toku veka korišćenja** govori i činjenica da se u sistemima podmazivanja motora teških kamiona, ugrađuju uređaji za ocenu promene karakteristika i elektronski sistemi signalizacije da je vrednost neke od merenih karakteristika izašla iz dozvoljenog okvira (Savić i drugi, 2006).

Postupci i oprema za ispitivanje svih vrsta ulja može se podeliti na nekoliko načina:

- a) analiza veličine i strukture uljne mrlje na filter papiru – samo za dijagnostiku motornih ulja (Savić i drugi, 2006; Majdan i drugi, 2010);
- b) merenje promene električne provodljivosti - dijagnostika motornih ulja (Savić i drugi, 2006; Rajković, 2001; Northern Technologies, 2002);
- c) merenje promene strukturnih promena hemijsko-elektronskim metodama (Savić i Jocanović, 2004; www.kittiwake.com; Savić i drugi, 2006; Majdan i drugi, 2010; www.hydac.com);
- d) klasične laboratorijske analize (Savić i Zirojević, 2003; Savić i Jocanović, 2004; Jocanović, 2006; Savić i drugi, 2006);
- e) nekonvencionalne tehnike (Savić i drugi, 2006).

ad a) Uljna mrlja - Opisana u poslednjem podpoglavlju, poglavlja 3.

ad b) Merenje dielektrične konstante - Ova metoda je razvijena na bazi merenja izolacionih karakteristika motornog ulja. Paralelno sa procesom oksidacije, povećanjem sadržaja vode, goriva i čvrstih čestica, elektroizolacione karakteristike ulja se pogoršavaju. Korelaciona metoda koja upoređuje uzorak novog ulja sa uzorkom ulja iz eksploatacije. Proizvođači uređaja definišu oblike karakterističnih krivih linija za svaki kontaminant (kiselina, voda, gorivo, čvrsta čestica) i vrednost najveće dozvoljene promene dielektrične konstante.

Na principu merenja dielektrične konstante izrađeno je više različitih mernih uređaja koji se ugrađuju direktno u sisteme podmazivanja motora većih snaga. Uređaj je stalno u funkciji, tako da se jedna ili više karakteristika neprekidno mere i pored sa polaznom vrednošću. Ukoliko se neka od karakteristika promeni pre propisanog roka zamene ulja (po pravilu on se podudara sa definisanim intervalom servisiranja motora), ulje se menja

ad c) Hemijsko elektronska metoda - I ova metoda ispitivanja spada u grupu nestandardnih, brzih postupaka ispitivanja. Jedna od složenijih konstrukcija je proizvodnje KITTIWAKE. Uređaj je elektronski, izmerene vrednosti se proračunavaju u računaru koji je integrisan unutar uređaja, a dobijene vrednosti se očitaju na displeju. Opisan u tački 3. Postoje slični tipovi uređaja ali manualnog tipa kao što je HYDAC, HYDROTECHIK i dr. Treba napomenuti da je navedena oprema i metode kojima se ispituju određeni fizičko hemijski parametri svoj kvalitet i tačnost potvrdila na eksperimentalnim ispitivanjima sprovedenim na terenu.

ad d) Laboratorijske metode - U ovu grupu spadaju standardne metode ispitivanja fizičko hemijskih karakteristika. Širok je izbor karakteristika koje se mogu ispitati u laboratoriji, njihova selekcija se vrši u odnosu na cilj ispitivanja, tip ulja i ekonomičnost celokupnog procesa korišćenja uljnog punjenja.

ad e) Nekonvencionalne metode ispitivanja - U ovoj grupi metoda postoji nekoliko uređaja kojima se definiše sadržaj oksida i metala u ulju poreklom iz aditiva ili iz produkata habanja. Ovo ispitivanje se realizuje na aparaturama koje se nazivaju opštim imenom spektrometar, a u skladu sa postupkom ispitivanja mogu biti: diferencijalni IC, atomski apsorpcioni ili atomski emisioni spektrometar. Često se koristi uređaj za diferencijalnu Furijeovu infracrvenu spektrometriju (FTIR - AST E 2412).

Ove metode se koriste uglavnom za ispitivanje ulja koja se koriste u teškim komercijalnim vozilima (teretni kamioni, autobusi, mehanizacija, hidraulični sistemi).

5. ZAKLJUČAK

Radom je data sveobuhvatna analiza mogućih rešenja za praćenje i dijagnostifikovanje važnijih fizičko-hemijskih parametara traktorskih STOU i UTTO ulja u eksploataciji. Akcenat je dat na prikazu opreme za brzu dijagnostiku fizičko-hemijskih karakteristika tipa OTC - K1-100 – KW – Kittiwake.

Prednost primene KITTIWAKE opreme je u:

- **tačnosti** – u toku eksploatacije i komparacije sa laboratorijskim analizama dokazana je tačnost svih uređaja za merenje određenih karakteristika ulja, čak i u oštrijim granicama u odnosu na granice postavljene od strane proizvođača opreme (pod uslovom da se poštuje procedura merenja),
- **jednostavnosti** - koraci za ispitivanje bilo koje karakteristike ulja svedeni su na minimum, a rezultati se očitavaju na displeju računarske jedinice,
- **brzini** – sve analize se obavljaju za veoma kratko vreme (maksimalno 20 minuta),
- **pouzdanosti** – oprema je robusna i otporna na terenske uslove eksploatacije kao i na temperaturne oscilacije okoline,
- **moгуčnosti primene** – primenjiva je za sve vrste motornih i industrijskih ulja,
- **ekonomičnosti** – cena ispitivanja karakteristika je višestruko manja u odnosu na cenu laboratorijskih analiza.

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SISTEM SIGURNOSNIH SENZORA NA ŽIČARI „OGORJELICA 1“

Marko Šolaja¹, Vladimir Gluhović²

Rezime: Isklopiva šestosjeda žicara „OGORJELICA“ je primjer vrhunske svjetske tehnologije kosog transporta. Proizvod je italijanske firme LEITNER, koja ima višedecenijsku tradiciju na polju izrade sistema kosog transporta. „Ogorjelica“ je isklopiva žicara, što znaci da se korpe prilikom ulaska u stanicu odvajaju od vučno-nosećeg užeta i nezavisno od užeta nastavljaju da se kreću kroz stanicu. Zbog te karakteristike ima kompleksan sistem automatskog upravljanja i sigurnosnih sistema koji omogućavaju sinhronizaciju svih pomoćnih i osnovnih kretanja žičare. Sistem sigurnosnih senzora na žičari čine senzori koji su postavljeni na obrtnom i povratnom točku žičare, senzori koji registruju pozicioniranja uzeta i korpe i omogućavaju kačenje korpe na vučno-nosivo uže, i sigurnosni senzori na nosećim stubovima žičare koji služe za zaustavljanja žičare u slučaju kvara, ili u slučaju nepovoljnih vremenskih prilika. U ovom radu su obrađeni senzorski sistemi zahvaljujuci kojem se preko posebnog softvera prate radni parametri žičare. Uloga senzorskih sistema je jedan od ključnih parametara za siguran i bezbjedan rad žičare.

Ključne riječi: Sigurnost žičare, sigurnost prolaza, lomljivi štap, sigurnosna žica, CPS senzori.

SYSTEM OF SAFETY SENSORS ON CHAIRLIFT „OGORJELICA 1“

Abstract: Detachable chairlifts "Ogorjelica" is an example of the world's top technology of ropeways. „Ogorjelica“ is the product of LEITNER, the Italian company, which has a long tradition in the field of system design of ropeways. "Ogorjelica" is detachable chairlift, which means that the chairs, when entering the station separate from the rope and independent from the rope continues to move through the station. Because of these characteristics, has a complex system of automatic control and security systems that allow synchronization of all primary and secondary trends of chairlift. A system of safety sensors on the chair-lifts are sensors that are mounted on the rotating wheel and return wheel of chairlift, positioning sensors, which register the rope and chairs and gripping chairs on the rope, and safety sensors on the pillars line of chairlift serving the chairlift stop in case of failure, or in case of inclement weather. In this publication are presented sensor systems, through which is possible monitoring of operating parameters of the chairlift. The role of sensors systems is one of the key parameters for the safe and secure operation of the chairlifts.

Keywords: Security of lifts, anticollision, snap bar, wire cutter, CPS sensors.

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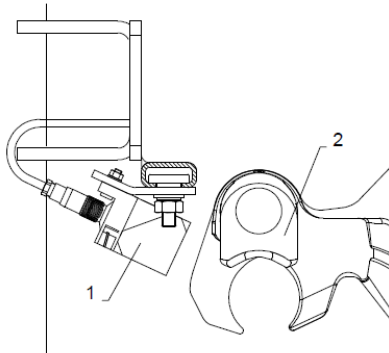
1. UVOD

Sistemi kosog transporta su tehnički sistemi koji služe za transport ljudi na skijalištima. Da bi se izbjegle potencijalne neprijatnosti, kao što su zaustavljanje žičare u toku rada, neophodno je da se prate svi radni parametri i da se po mogućnosti u hodu otklanjaju sve nepravilnosti u radu, što se postiže jednom grupom senzora koji prate radne parametre žičare i zahvaljujući podacima koji se dobijaju od njih, moguće je izvršiti korekcije, da bi sistem nesmetano funkcionisao. Drugi dio senzorskih sistema žičare su senzori koji služe za zaustavljanje žičare u slučaju nagle promjene radnih parametara ili ako vremenske prilike izadju van propisanih granica, sve u svrhu zaštite putnika kosog transporta. U ovom radu će biti predstavljeni senzorski sistemi koji postoje na žičari uz opis njihove funkcije i načina rada. U toku eksploatacije sistema uočeni su parametri koji nisu obuhvaćeni sistemom monitoringa, pa je u redu izneseno i rešenje pomoću koga se i ti parametri mogu pratiti, i na vrijeme korigovati.

2. SIGURNOSNI SISTEMI NA ŽIČARI

Sigurnost prolaza

Sigurnost prolaza ima funkciju kontrole procesa kretanja vozila u stanicama uz pomoć prekidača bez dodira (takozvani BERO) (Sl.1). Raspored tih prekidača (1) je takav da je svuda gdje je to potrebno moguće izvršiti kontrolu odstojanja vozila. Prekidači bez dodira su u stanicama označeni oznakama P1, P2, P3, ... Pn.

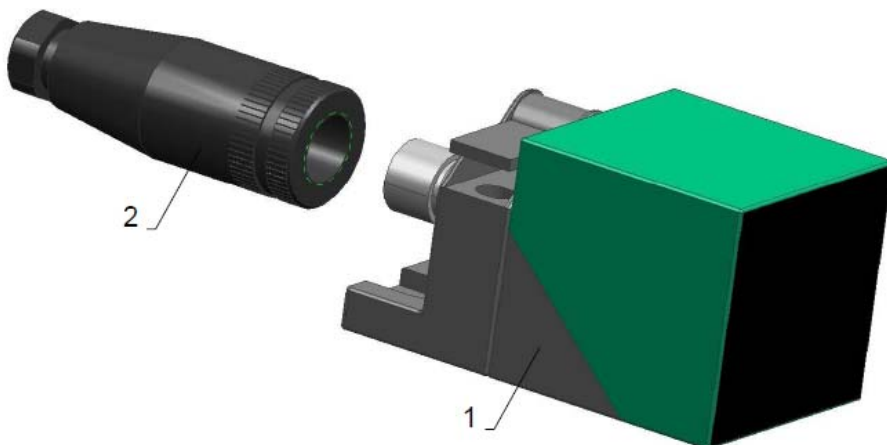


Sl.1 Položaj prekidača bez dodira [1]

Sigurnost prolaza ima funkciju kontrole procesa kretanja vozila u stanicama uz pomoć prekidača bez dodira (takozvani BERO) (Sl.1). Raspored tih prekidača (1) je takav da je svuda gdje je to potrebno moguće izvršiti kontrolu odstojanja vozila. Prekidači bez dodira su u stanicama označeni oznakama P1, P2, P3, ... Pn.

Vozila aktiviraju uz pomoć stezaljke užeta (2) prekidač bez dodira (1) i kroz to signaliziraju ulaz u zonu kontrole, odnosno izlaz iz kontrolne zone. Kao zona kontrole podrazumjeva se predio između dva prekidača (1). Sigurnost prolaza je nezavisna od brzine vozila žičare. Kao jedinica mjerenja uzima se dužina pogonskog užeta između dva vozila. Dužina koju pogonsko uže prolazi mjeri se sa koturom za skretanje uz pomoći davača impulsa. Ako se broj impulsa u zoni kontrole razlikuje od zadane vrijednosti, onda se žičara zaustavlja [1].

X = Prekidači bez dodira se postavljaju na rastiranje X od stezaljke užeta.
Maksimum: 15 mm
Minimum: 10 mm



Sl.2 Prekidač bez dodira [1]

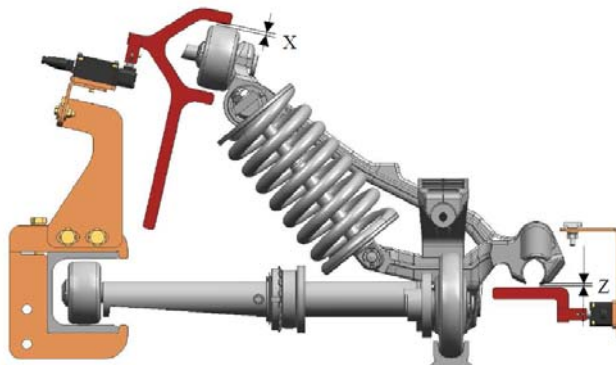
1. Induktivni približni prekidač PEPPERL+FUCHS NBB20-L2-A2-V1
2. Utikač IFM ELECTRONIC E11508

Kontrole u stanici

Kontrolama u stanici se smatraju ti prekidači koji u stanici provjeravaju sledeće:

- vertikalni i horizontalni položaj pogonskog užeta,
- poziciju stezaljke užeta u predjelu spojnice,
- položaj stezaljke užeta

Kontrole u stanici sastoje se od nekoliko prekidača koji su opremljeni sa profilnim limom (blendom). Oblik i položaj su prilagodjeni kontrolnim funkcijama. Kao dodatna kontrola odnosno, sigurnost preko stezaljke užeta prolazi jedan kablovski kanal koji prečava da stezaljka užeta izklizne iz šina žičare. Strugači leda na ulazu skidaju led da ne bi došlo do pogrešne procjene geometrije stezaljke. Na izlaznoj strani je postavljen jedan uređaj za prinudno pozicioniranje pogonskog užeta. Taj uređaj funkcioniše kao papučica za hvatanje užeta i može po potrebi da podigne pogonsko uže. Pri nedozvoljenom položaju užeta ili stezaljke užeta prebacuje se (pomjera se) profilni lim (blenda). Pri tome se aktivira granični prekidač koji je pričvršćen za profilni lim i žičara se zaustavlja. Oznaka prekidača koji je prouzrokovao zaustavljanje žičare pokazuje se na kontrolnom monitoru. Ako se uključe više prekidača onda su i oni prikazani na kontrolnom monitoru. Vožnja može da se nastavi posle ručnog vraćanja profilnog lima u prvobitni položaj.



Sl.3 Položaj profilnih lomiva prekidača [1]

Senzori baterije koturova

Žičara je opremljena sa dva različita komplementarna strujna kola:

- Strujno kolo sa integriranim senzorima koji moraju da se zamene nakon aktiviranja, kao što su npr. lomljivi štapovi ili sigurnosne žice: ovo strujno kolo omogućava sigurnost, aktiviranje jednog senzora rouzrokuje isključivanje žičare.
- CPS strujno kolo (Cable Position Sensor) sa integriranim inuktivnim senzorima: omogućava zapisivanje grešaka i dijagnozu.

Ova dva strujna kola nisu međusobno povezana.

Lomljivi štap i sigurnosna žica su dva senzora koji moraju da se zamijene nakon aktiviranja. Ako su postavljeni na bateriji koturova onda oni kroz prekid strujnog kola bilježe svaku grešku na užetu ili na koturovima užeta. Senzori su na jednom kablju sa sigurnosnim strujnim kolom povezani u seriji. Vrsta senzora zavisi od vrste baterije koturova i od funkcije koja treba da se ispuni[1].

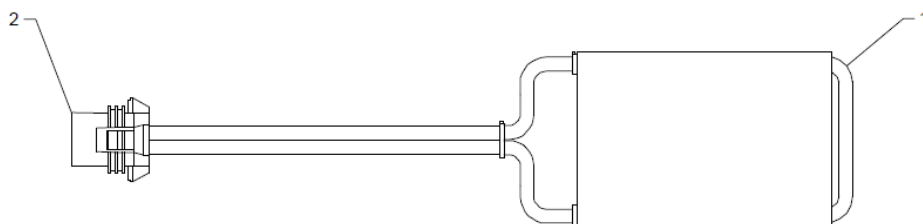


Sl.4 Lomljivi štap za jedno sigurnosno strujno kolo [1]

Ova vrsta senzora je jedan mali jednodijelni sklop koji je opremljen sa lomljivim štapom (1). Senzor se uz pomoć utikača (2) uključuje u mrežu. Ako dodje do greške onda se štap lomi i to

- kroz uže,
- kroz papučicu za hvatanje užeta (baterije nosećih koturova),
- ili kroz sigurnosni lim (baterije gornjih koturova).

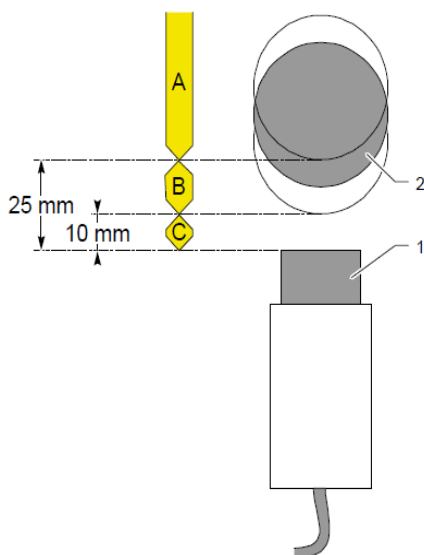
Postavljanje senzora koji je pričvršćen uz pomoć dva vijka koji su osigurani od ispadanja (3) je veoma brzo i jednostavno.



Sl.5 Sigurnosna žica za jedno sigurnosno strujno kolo [1]

Ova vrsta senzora se sastoji od jednog bloka kroz koji prolazi žica (1). Blok je tako dimenzionisan da omogućava registrovanje grešaka na čitavoj širini gumenog uložka kotura. Senzor se uz pomoć utikača (2) uključuje u mrežu. Ako dolazi do greške onda se žica prekida kroz trenje koje nastaje između užeta i bloka senzora. Ovaj sistem ima tu prednost da je otporan na udarce i na niske temperature. Senzor se uglavnom koristi za registrovanje blokiranja koturova užeta ili za registrovanje eventualnih gubitaka na baterijama nosećih ili gornjih koturova [1].

CPS Senzori

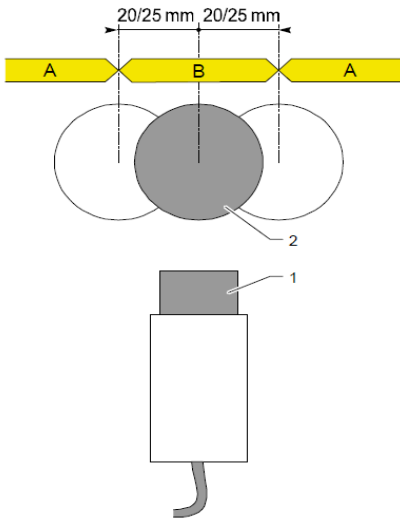


CPS senzori su induktivni senzori bez dodira, koji generišu različite podatke o položaju užeta. Ti podaci se uz pomoć kutija za obradu podataka šalju dalje i prenose uz pomoć busa za prenos podataka do centralne jedinice koja se nalazi u blizini ormara sa prekidačima. Ako dodje do javljanja greške onda je kroz analizu podataka moguće izvršiti preciznu dijagnozu o mjestu, i o vrsti greške.

Senzor (1) prepoznaje vertikalni položaj užeta (2) i može da šalje tri različite vrste podatka:

- Zona A: Uže ne postoji ili je previše daleko od senzora
- Zona B: Vertikalni položaj užeta je u redu
- Zona C: Uže je previše blizu senzoru

Sl.6 Vertikalno pomijeranje užeta [2]



Svaki senzor prepoznaje horizontalno pomijeranje užeta (npr. zbog vjetra) i može da šalje dvije vrste podataka:

- Zona A: Horizontalno pomijeranje je previše veliko
- Zona B: Horizontalno pomijeranje je dozvoljeno. [2]

CPS senzori su od strujnog udara (munje) zaštićeni kroz elektro kutije, koje se nalaze na bateriji koturova u blizini svakog senzora i na stubu.

Sl.7 Horizontalno pomijeranje užeta [2]

3. ZAKLJUČAK

Zbog ekstreminih uslova i posla koji obavlja sistem kosog transporta, senzorski sistemi imaju najbitiju ulogu za sigurnost sistema. Na šestosjedojoj žičari "OGORJELICA" trenutno ne postoji CPS senzori za položaj užeta, tako da ne postoji načini da se prati odstupanje položaja užeta na liniji. Tu ulogu su preuzeli prekidači sa blendom u povratnoj i pogonskoj stanici, koji ispunjavaju propisane sigurnosne protokole, ali zbog povećanja sigurnosti preporučujemo ugradnju istih. Prilikom pripreme ovog rada primjećeno je da sigurnosne žice koje registruju ispadanje užeta i blokiranje kotura, nisu u mogućnosti da blagovremeno obavijeste monitoring sistem da je kolut blokiran, jer da bi došlo do loma senzora potrebno je da uže izvjesno vrijeme guli gumenu oblogu točka dok je ne uništi dovoljno da slomije zicu senzora. Način na koji može da se prevaziđe taj problem je da se na svaki kotur posebno postave detektori okretanja kotura, koji bi u slučaju blokade kotura, zaustavljali rad žičare dok se ne odblokira kotur, i time spriječili uništavanje gumene obloge kotura.

LITERATURA

- [1] Tehnička dokumentacija šestosjede žičare „Ogorjelica“,
- [2] LEITNER Ropeways tehničke specifikacije
- [3] <http://en.leitner-ropeways.com>



UPRAVLJANJE PRITISKOM U SISTEMIMA VODOSNABDIJEVANJA

Goran Orašanin¹, Dalibor Vlaški²

Rezime: Vodovodni sistemi su veliki potrošači električne energije koja se troši u svakoj od faza proizvodnje i distribucije vode. Gubici vode kroz različite vidove curenja u vodovodnim sistemima utiču na povećanu potrošnju energije. Uticaj gubitaka kroz curenja u vodovodnim mrežama su izraženiji pri registrovanim visokim pritiscima. Jedan od načina za njihovo smanjenje je implementacija upravljanja pritiskom u vodovodnim sistemima. Stalnom kontrolom pritiska u sistemu vodosnabdijevanja, smanjuje se količina izgubljene vode kroz curenja, a time se indirektno utiče na smanjenje potrošnje električne energije. Vodovodna preduzeća moraju održavati visoke standarde pri provođenju programa upravljanja pritiskom u distributivnim mrežama, jer se tako smanjuje rizik postizanja negativnog poslovnog rezultata. Takođe, kontrolom pritiska se obezbjeđuje urednije i sigurnije vodosnabdijevanje, čuvaju se resursi i povećava poslovna i operativna efikasnost. U ovom radu su razmatrana neka od ključnih pitanja koja se moraju uzeti u obzir prilikom provođenja programa upravljanja pritiskom u vodovodnim sistemima. S ciljem dobijanja reprezentativnih podataka u toku izrade ovog rada, izvršena su terenska ispitivanja i provedena potrebna mjerenja ključnih parametara (pritiska) u ograničenoj mjernoj oblasti sistema vodosnabdijevanja Tilava.

Ključne riječi: upravljanje pritiskom, sistemi vodosnabdijevanja, ograničena mjerna oblast.

PRESSURE MANAGEMENT IN THE WATER SUPPLY SYSTEMS

Abstract: *Water supply systems consume large amounts of energy. Energy is spent both in each of the water production phases and the water distribution. The loss of water through the various forms of leakages in the water supply system results in increased energy consumption. The impact of the water loss through leakages is more evident in the registered high pressures. One of the ways to reduce those is to implement a pressure management in the water supply systems. The permanent control of the pressure in the water supply system enables reduction of the quantity of the lost water, and indirectly affects electrical energy consumption. Water utilities must maintain high standards in the implementation of the programme of pressure management in the distribution networks, because that is the way to lower the risk of the negative revenues. Also, the pressure control enables more regular and safer*

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water supply, preserve the resources and increases revenues and operative efficiency. This paper considers some of the key issues that must be taken into account when implementing the pressure management in the water supply systems. In order to get reliable data when writing this paper, field research and required measuring of the key parameters was done. These parameter is the water pressure on the sample of the water supply system (district metered area - DMA) Tilava.

Keywords: pressure management, water supply systems, district metered area.

1. UVOD

Vodovodni sistemi su potrošači električne energije koja se troši u svakoj od faza proizvodnje i transporta vode. Prije nego što stigne na krajnje odredište voda je možda pumpana od izvora do postrojenja za prečišćavanje vode, gdje se troši dodatna energija za tretman. Nakon tretmana, voda može biti pumpana u rezervoar prečišćene vode i može se zahtijevati i dodatno pumpanje u transportni ili distributivni sistem. Dakle, vidi se da ovi procesi zahtijevaju značajne količine energije. Energija se gubi iz različitih razloga: neefikasne i loše dizajnirane pumpne stanice, nedovoljno održavane infrastrukture, starosti infrastrukture, visokog pritiska u sistemu, neefikasnog korišćenja vode i sl.

Ako se prosječni svjetski gubitak vode procjenjuje na 30%, to znači da se i isti dio energije gubi. Imajući u vidu uzroke potrošnje energije, ušteda se može ostvariti od 20 do 30% od trenutne potrošnje [1].

S druge strane, mnogi gradovi u BiH i regiji se suočavaju sa rastućim problemom obezbjeđivanja dovoljnih količina vode potrošačima. U mnogim slučajevima to zahtijeva izgradnje nove i skupe infrastrukture sa sve ozbiljnijim posljedicama po životnu sredinu. Imajući u vidu povećanje svijesti o zaštiti životne sredine i potreba o upravljanju raspoloživim resursima na efikasniji način, čuvanje vode i upravljanje potrošnjom treba da postane trend vodovodnih preduzeća.

Da bi vodovodni sistemi mogli da zadovolje potrošnju, moraju postepeno mijenjati svoje prioritete: umjesto stalnog širenja i otvaranja novih izvorišta, okretati se unutrašnjim rezervama: smanjenju gubitaka iz mreže i smanjenju neracionalne upotrebe vode kod svojih potrošača. Na taj način se povećava i ekonomska efikasnost vodovoda, jer je investicija u sanaciju protoka od 1 l/s, koji se gubi iz mreže, od 20 do 40 puta manja od investicije u otvaranje novih pogona za proizvodnju i distribuciju [8].

Upravljanje pritiskom u vodovodnim sistemima je jedan od načina upravljanja potrošnjom vode, a istodobno i smanjenje potrošnje energije kroz smanjenje gubitaka vode. Količina vode koja je izgubljena kroz curenja u velikoj mjeri zavisi od visine pritiska. Zato, upravljanje pritiskom je bitan dio upravljanja gubicima vode. Lambert je 2001. godine opisao relevantne interakcije pritisak - curenje i osnove upravljanja pritiskom. Osnovni princip u upravljanju pritiskom je da se izbjegavaju velike varijacije pritiska jer mogu dovesti do veće stope curenja [2].

Formula 1: Veza između pritiska i curenja

$$\frac{L_1}{L_0} = \left(\frac{P_1}{P_0}\right)^{N_1}$$

Gdje je: L_0 – stopa curenja na pritisku P_0 ; L_1 – stopa curenja na pritisku P_1 ; P_0 – početni pritisak; P_1 – promjenjeni pritisak i N_1 – koeficijent.

Važno je naglasiti da odnos pritisaka (P_1/P_0), a ne razlika među pritiscima ima uticaj u formuli 1. Vrijednost eksponenta N_1 može da varira od 0,5 za 'fiksna područja' curenja do 1,5 za 'varijabilna' područja curenja. Generalno, velika curenja iz metalnih

cijevi imaju eksponente N_1 koji su bliži vrijednosti 0,5, a mala 'pozadinska' curenja i velika curenja iz nemetalnih cijevi obično imaju eksponent 1,5 ili veći [3].

2. KONCEPT UPRAVLJANJA PRITISKOM

Vodovodni sistemi su generalno dizajnirani da pruže uslugu potrošačima u nekom dogovorenom nivou, koji se često definiše kao minimalni nivo pritiska na kritičnoj tački koja je najmanja tačka pritiska u sistemu. Ovaj kritičan pritisak se najčešće javlja u periodu vršnih opterećenja koja se obično javljaju i traju u kratkom vremenskom periodu, tako da ostatak vremena sistemi često rade na pritisacima znatno većim nego što je potrebno [5].

Upravljanje pritiskom u vodosnabdijevanju nije jednostavan zadatak, jer postoje razni faktori koje treba razmotriti. Isti program upravljanja pritiskom ne može se primjeniti na svim sistemima vodosnabdijevanja, jer se vodovodni sistemi razlikuju jedan od drugog. Mora se imati na umu da kada se smanjuju curenja kroz upravljanje pritiskom neophodno je da se održi nivo usluga za potrošače, kao i potreban pritisak u mreži za gašenje požara (hidrantska mreža) [5].

U distributivnoj mreži uvijek mora biti obezbjeđen minimalni pritisak za uredno vodosnabdijevanje kritičnih tačaka. Vodovodi sami po sebi definišu minimalne pritiske u vodosnabdijevanju. Takođe, propisani uslovi za obezbjeđenje dovoljnog pritiska u hidrantskoj mreži (u slučaju požara) diktiraju minimalni pritisak. Minimalni pritisak takođe, zavisi i od razlike visina i zahtjeva potrošača.

Kontrola pritiska obuhvata podešavanje pritiska vode u vodovodnim sistemima na optimalan nivo i može biti profitabilna, ne samo u postojećim distributivnim sistemima nego i u novim i planiranim mrežama. Optimalan nivo pritiska podrazumijeva obezbjeđivanje efikasnog vodosnabdijevanja potrošača uz istovremeno smanjenje nepotrebno visokog pritiska i smanjenja curenja u distributivnoj mreži.

Maksimalni pritisak, pogotovo u minimalnoj noćnoj potrošnji, je mnogo veći u odnosu na dnevni pritisak kada je i povećana potrošnja. Ta razlika predstavlja potencijal za smanjenje pritiska i na taj način smanjenje gubitaka vode i smanjenje potrošnje energije. Za uvođenje regulacije pritiska u sistem, treba se sprovesti niz mjera i aktivnosti prije same implementacije:

- Analizirati koja su područja prihvatljiva za uvođenje regulacije pritiska,
- Analizirati potrošnju i potrebe za vodom (vrsta potrošača i njihova potrošnja),
- Izvršiti terenska mjerenja protoka i pritiska u potencijalnom području,
- Testirati pritisak i protok na modelu i analizirati posljedice na potrošnju,
- Identifikovati odgovarajuće ventile i kontrolne uređaje,
- Odrediti režim rada ventila radi postizanja željenih rezultata i
- Analizirati isplativost ugradnje regulacionog ventila.

2.1 Metode kontrole pritiska

Smanjenju pritiska se može pristupiti korišćenjem različitih tehničkih rješenja, međutim postignuti optimalan pritisak nije uvijek jednostavan zadatak. Svaki podsistem vodovodnog sistema je drugačiji i ima svoja specifična ograničenja, što znači da u svakom podsistemu se upravljanje pritiskom mora prilagođavati [10]. Generalno, načini kontrole pritiska su:

- Fiksni ventil za regulaciju pritiska,
- Ventil zasnovan na vremenu,
- Ventil na bazi protoka,
- Daljinski kontrolisan ventil i
- Kontrola pumpe (podešavanje minimalnog i maksimalnog pritiska).

Fiksni ventil: Fiksni ventil za regulaciju pritiska je najosnovniji način kontrole pritiska gdje se pritisak na izlazu iz ventila održava na izabranom nivou u svakom trenutku. Ovo je najjednostavniji oblik upravljanja pritiskom, jer podrazumjeva korišćenje ventila bez dodatne opreme. Prednosti ovog oblika kontrole pritiska su:

- Relativno jednostavna instalacija jer je potreban samo regulator pritiska;
- Cijena je relativno niska jer nema dodatne opreme;
- Održavanje je relativno jednostavno.

Nedostatak fiksnog ventila se ogleda u tome što ventil nije fleksibilan tj. ne postoji mogućnost prilagođavanja smanjenja pritiska npr. u noćnoj potrošnji kada su pritisci i najveći pa se sa ovim ventilom ne mogu ostvariti rezultati maksimalne uštede resursa.

Vremenski regulisan pritisak: Izlazni pritisak iz vremenski kontrolisanog ventila se podesi, obično, da se pritisak smanji u toku noći kada su protoci niski, a pritisci visoki. Vremenski kontrolisan ventil je efikasan kao i fiksni ventil, s tim da ima dodatni uređaj za dodatno smanjenje pritiska u npr. noćnim satima. Prednosti ugradnje ovog ventila su:

- Kontrolom se obezbeđuje veća fleksibilnost pritiska u sistemu. Pritisak se može podesiti u određeno vrijeme i time dovoditi do veće štednje;
- Elektronski regulator je jeftiniji od skupljih protokom regulisanih regulatora;
- Direktno se povezuje na ventil;
- Kontroler je relativno jednostavan za rukovanje i održavanje.

Glavni nedostatak vremenski kontrolisanog pritiska je da ne reaguje na zahtjeve za vodom i to može predstavljati problem u slučaju požara kada se zahtijeva odgovarajući pritisak za gašenje. Opcija vremenski kontrolisanog pritiska je skuplja od fiksnog ventila, ali ne zahtijeva visok nivo stručnosti za rukovanje i održavanje.

Ventil na bazi protoka: Kod ventila na bazi protoka pritisak se može podesiti za različite protoke u cilju održavanja minimalnog pritiska u sistemu na trenutnom protoku, ili da se poveća kada je protok prekoračen (npr. gašenje požara). Ovaj vid kontrole pritiska je fleksibilniji u odnosu na prethodna dva ventila i obično obezbeđuje veće uštede. Elektronski regulatori su skuplji, a ključna prednost je što ne ometa urednost vodosnabdijevanja u slučaju požara.

Daljinski kontrolisan ventil: Najsavremenija vrsta ventila je ta gdje se izlazni pritisak stalno podešava preko telemetrije od senzora u jednoj ili više kritičnih tačaka u zoni da bi pritisak ostao na određenom nivou. Ovaj vid kontrole pritiska podrazumijeva kontrolu pritiska na krajevima mreže odnosno na kritičnim tačkama i to je najkomplikovaniji vid kontrole pritiska.

Kontrola pumpe: Kontrolom pumpe (podešavanje minimalnog i maksimalnog pritiska) se kontroliše pritisak u slučajevima kada pumpa direktno dostavlja vodu u

distributivnu mrežu. Pumpnim stanicama i drugim kontrolisanim objektima se obično upravlja primjenom jedne ili kombinacijom sljedećih opcija:

- Kontrola pritiska: Pumpa se uključuje kada se smanji pritisak u mreži zbog povećanja potrošnje, a prestaje sa radom kada se smanji potrošnja i poveća pritisak u sistemu.
- Kontrola nivoa: Pumpa se uključuje i zaustavlja prema varijaciji nivoa vode u rezervoaru.
- Vremenska kontrola: Pumpa se uključuje i zaustavlja u fiksnim satima u toku dana.

Potrebno je napomenuti da postoje i brojni drugi oblici kontrole pritiska za smanjenje gubitaka u distributivnim sistemima. Postoje i kontrolori kao dodaci uređajima zasnovanih na jednostavnom smanjenju poprečnog presjeka protoka. Bez obzira koji se pristup kontrole pritiska uvodi u sistem, njegovom primjenom pa i u kratkom periodu smanjiće se curenja i potrošnja vode.

2.2 Efekti kontrole pritiska

Svako upravljanje pritiskom ima svoje prednosti i nedostatke. Ključan je izbor najprikladnijeg oblika kontrole pritiska za određeni sistem ili podsistem, a on takođe podrazumijeva i finansijske i tehničke mogućnosti vodovodnog preduzeća.

Smanjenje gubitaka vode kontrolom pritiska nije jedina korist, jer smanjenjem pritiska neke vrste potrošnje će biti manje (potrošnja iz slavina, tuševa, sistema za navodnjavanje i sl.), a i novonastala curenja koja inače izaziva visok pritisak se rjeđe pojavljuju. Prednosti kontrole pritiska se ogledaju i u produženom vijeku cijevi, spojnice i armatura, jer varijacije u pritisku izazivaju oštećenja. Svi ovi pozitivni efekti kontrole pritiska obično rezultuju visokom štednjom vode i na taj način imaju i kratko vrijeme otplate. Pored ovih pozitivnih efekata, kontrola pritiska indirektno doprinosi:

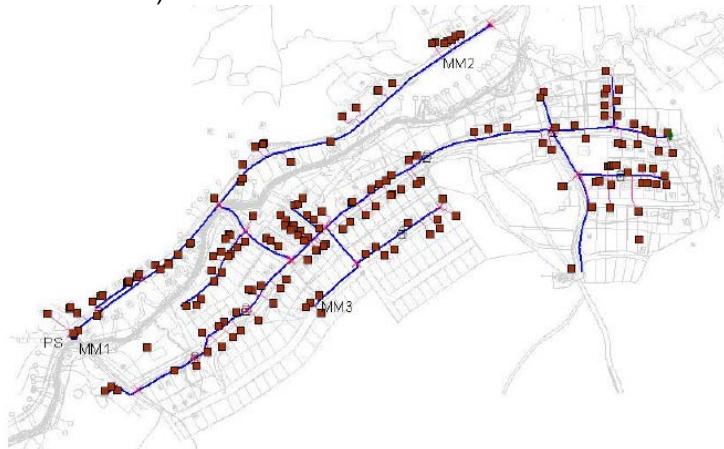
- Povećanju broja domaćinstava pristupu javnog vodosnabdijevanja;
- Povećanju trajanja vodosnabdijevanja (bez redukcija vode u kritičnim periodima);
- Jednako vodosnabdijevanje svih potrošača;
- Smanjenje troškova proizvodnje i potrošnje energije.

3. STUDIJA SLUČAJA

Slika 1 prikazuje formiranu ograničenu mjernu oblast sistema vodosnabdijevanja Tilava sa ciljem ispitivanja metode upravljanja pritiskom. Ograničena mjerna oblast je zatvorena mjerna oblast sa jednim ulazom vode u sistem, odnosno u hidrauličkom smislu vodosnabdijevanje je zatvoreno. Sistem se vodom napaja putem pumpne stanice tj. voda se direktno pumpa u mrežu što je i interesantno za analizu pritisaka. Pumpna stanica je podešena na ulazni pritisak u sistem od 5,5 do 7,5 bar-a. Krajnje i kritične tačke podsistema su na 570 m.n.m³ (mjerno mjesto 2-MM2) i 574 m.n.m. (mjerno mjesto 3-MM3), pumpna stanica je na 550,5 m.n.m (mjerno mjesto 1-MM1). Karakteristike mjerne oblasti su: broj stanovnika – cca 700; broj

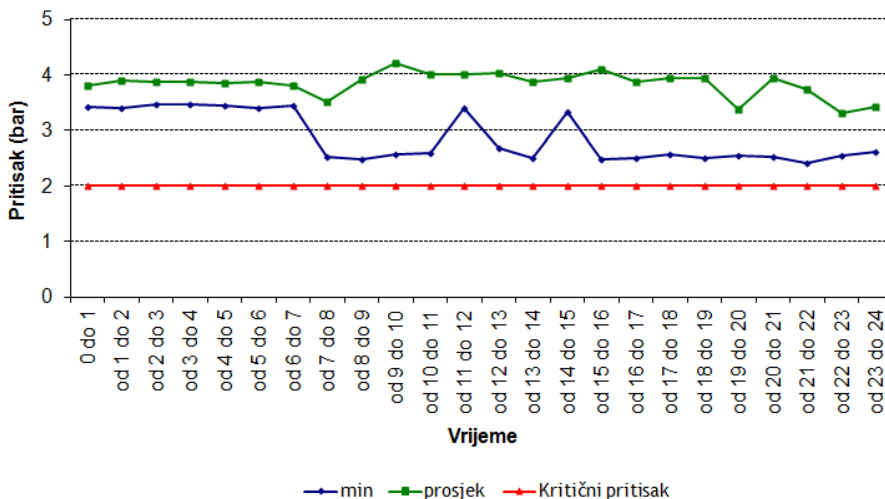
³m.n.m – metara nad morem

priključaka – 188; dužina mreže – 3.603 m; cjevovod je od polietilena⁴ različitih prečnika (PE 63 – PE 160).



Slika 1 Ograničena mjerna oblast vodovodnog sistema Tilava

Nakon izvršenih mjerenja⁵ utvrđeno je na mjernom mjestu MM3 i MM2 (kritične tačke sistema) da je izmjerena vrijednost pritiska veća od minimalno potrebnog pritiska (Slika 2).

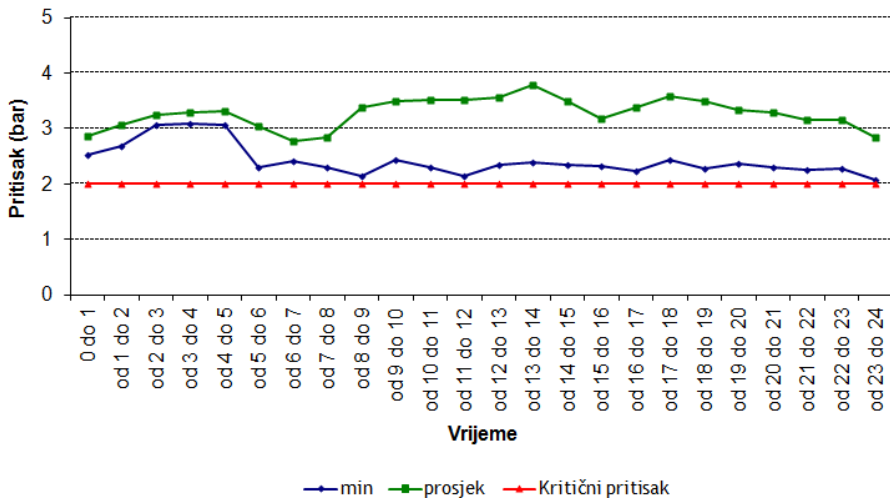


Slika 2 Pritisak na MM 3 (Mjerenje 1)

Pritisak na pumpnoj stanici je bio podešen na vrijednost od 5,5 do 7,5 bar-a. Smanjenjem odnosno regulacijom minimalnog i maksimalnog pritiska (4,7 do 6,8 bar-a) u kritičnoj tački vrijednost pritiska se smanjila i približila minimalno potrebnom pritisku (Slika 3).

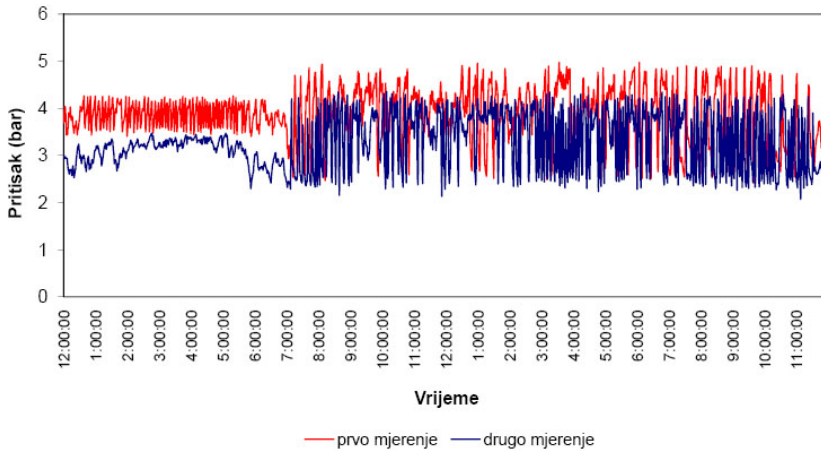
⁴Polietilen - PE, eng. polyethylene

⁵Mjerenje je vršeno 24 sata.



Slika 3 Pritisak na MM 3 (Mjerenje 2)

Slika 4 daje komperativni prikaz 24-satnog mjerenja na mjernom mjestu 3 (MM3) prije i poslije kontrole pritiska.



Slika 4 Poređenje pritiska na MM 3

Tabela 1 prikazuje poređenja vrijednosti minimalnog, maksimalnog i prosječnog pritiska na karakterističnim mjestima u ograničenoj mjernoj oblasti. Prosječni pritisak u podsistemu sa 4,68 bar-a je smanjenj na 4,13 bar-a.

Tabela 1 Poređenja vrijednosti pritiska u podsistemu

	Mjerenje 1			Mjerenje 2		
	Max	Min	Prosječni	Max	Min	Prosječni
MM 1	7,49	5,5	6,22	6,87	4,76	5,68
MM 2	5,23	2,78	4,14	4,65	2,58	4,65
MM3	4,98	2,41	3,84	4,35	2,07	3,27

Na osnovu odnosa pritiska iz formule 1, te proračunatog bilansa količina vode analiziranog podsistema za prvo i drugo mjerenje, potvrđuje se da je curenje (gubici vode) u podsistemu smanjeno za 13,7% (sa 41,02 m³/dan na 35,38 m³/dan).

4. ZAKLJUČAK

Na osnovu rezultata razmatranih u studiji slučaja jasno je da je upravljanje pritiskom efikasan način za smanjenje potrošnje električne energije kao i obezbjeđivanja urednog i sigurnog vodosnabdijevanja.

Pored smanjenja potrošnje, smanjenja gubitaka vode u sistemu, upravljanjem pritiskom se ostvaruju i značajne ekonomske uštede u kratkom vremenskom periodu. Dodatna beneficija upravljanja pritiskom je i produženje vijeka trajanja infrastrukture (mreže) vodovodnog sistema.

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ZNAČAJ INFORMACIONOG SISTEMA ODRŽAVANJA PROIZVODNIH SISTEMA

Rajko Tanasijević¹

Rezime: Bez primjene informatičke podrške danas je nezamislivo održavanje proizvodnih sistema, jer je nemoguće obezbjediti efektivno i kvalitetno održavanje. Zato se danas sve više pažnje poklanja projektovanju i realizaciji informacionog sistema u održavanju kod proizvodnih sistema. Kod posmatranog proizvodnih sistema nije uveden informacioni sistem, što predstavlja veliki problem u održavanju. Zbog toga je u ovome radu predložena strategija održavanja, informacioni sistem održavanja, faze informacionog sistem, ciljevi i zadaci, odgovarajući modeli i BSP metoda za dugoročno planiranje razvoja informacionog sistema. Ovim je omogućeno pravovremeno dobijanje tačnih informacija, tačna obrada i distribucija informacija odgovarajućim funkcijama u održavanju.

Ključne riječi: održavanje, informacija, informacioni sistem, modeli, BSP metoda

IMPORTANCE OF MAINTENANCE BY MEANS OF INFORMATION SYSTEM PRODUCTION SYSTEM

Abstract: Without the application of IT support today is unthinkable maintain production systems, because it is impossible to provide effective and quality maintenance. That is why today, more attention is paid to the design and implementation of information systems in the maintenance of the production systems. In the reported production systems is introduced information system, a major problem in the maintenance. Therefore, in this paper, a maintenance strategy, information system maintenance phases of an information system, goals and objectives, appropriate models and BSP methods for long-term planning of information systems development. This enables timely accurate information, processing and distribution of accurate information in maintaining proper function.

Keywords: maintenance, information, information systems, models, methods BSP

1. UVOD

Potreba o održavanju prisutna je od samog početka razvoja i korišćenja mašina u raznim oblastima privrede i ekonomije. Tako se održavanju i ranije poklanjala određena pažnja. Međutim, ne dovoljno. Održavanje je često bilo posmatrano izdvojeno, više ili manje nazavisno od drugih sistema u preduzeću.

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Preduzeća su sve više pažnje posvećivala proizvodnji nego održavanju, a i projektanti koji su projektovali sisteme manje su poklanjali pažnju održavanju istih. Dugo vremena održavanje industrijskih postrojenja bilo je prikazivano isključivo kao mjesto troškova, kao pomoćna, neproizvodna djelatnost u reproduktivnom lancu u preduzeću.

Iz takvog pristupa je proizilazilo mnoštvo problema, kao što su tehničko-tehnološki, ekonomski i drugi problemi. Ali, situacija u današnje vrijeme je dosta bolja. Danas u preduzećima o održavanju se sve više govori i poklanja se sve veća pažnja [1].

Da bi se omogućilo stalno ocjenjivanje i efikasno upravljanje tehničkim sistemima, a posebno preduzimanje aktivnosti koje treba da poboljšaju rad sistema, sa stanovišta postavljene funkcije kriterijuma ili drugih zahtjeva nužno je da se sva zbivanja u životu sistema permanentno prate, da se o svim relevantnim događajima i postupcima stalno prikupljaju odgovarajući podaci [2]. Ovo je zadatak informacionog sistema.

Informacioni sistem predstavlja jedan od bitnih i najvažnijih elemenata u održavanju i pomaže preduzećima da dobiju, prenesu, obrade sačuvaju i distribuiraju informacije na jednom mjestu.

Zbog toga se projektovanju i realizaciji informacionog sistema u održavanju poklanja posebna pažnja, čime se obezbjeđuje efektivno i kvalitetno održavanje [1].

2. INFORMACIONI SISTEM ODRŽAVANJA

Svaki tehnički sistem, pa i sistem održavanja, ma kako da je projektovan i izveden može se stalno usavršavati i poboljšavati. Potreba za usavršavanjem i poboljšanjem postoji ukoliko se izvedeni sistem ne ponaša prema unaprijed postavljenim zahtjevima. Da bi se omogućilo stalno ocjenjivanje i efikasno upravljanje sistemom održavanja, potrebno je da se sva zbivanja permanentno prate, i da se o svim relevantnim događajima i postupcima stalno prikupljaju odgovarajući podaci. Ovo je zadatak informacionog sistema u održavanju.

Informacioni sistem u održavanju mašina, uređaja, postrojenja i drugih tehničkih sistema predstavlja jedan od bitnih i najvažnijih elemenata ukupne logističke podrške [2].

Takođe, informacioni sistem mora da bude realan sistem koji će se sastojati od stvarnih elemenata, procesa i tokova.

Zato se projektovanju i realizaciji informacionog sistema u održavanju poklanja posebna pažnja, jer bez promišljene i ciljno projektovane informatičke podrške se ne može obezbjeđiti kvalitetno održavanje.

Osnovni cilj i zadatak informacionog sistema u održavanju je [3]:

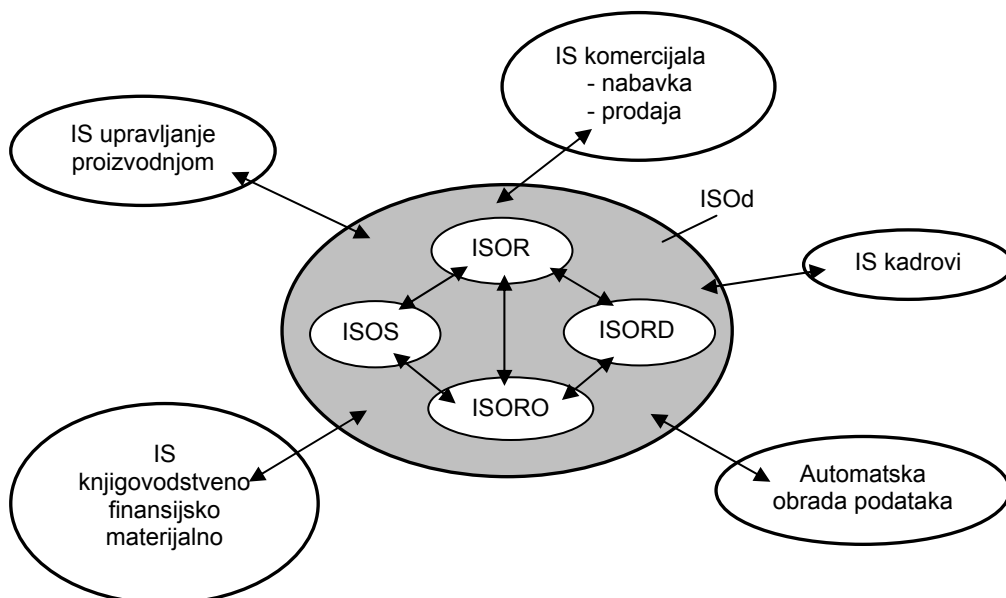
- permanentno dobijanje podataka koje analizom daju informacije o svim bitnim performansama sistema, o ostvarenim učincima i drugim rezultatima rada, o pouzdanosti, održavanju, troškovima, elementima logističke podrške, itd. i
- obezbjeđenje potpune "istorije" posmatranog tehničkog sistema, koja treba da ima odlučujući uticaj na razvoj novih sistema iste namjene i sličnosti, ali poboljšanih karakteristika.

Razradom ovih osnovnih zadataka treba da se definišu bliži zahtjevi koje treba zadovoljiti projektom i realizacijom informacionog sistema u održavanju. Ovo neposredno zavisi od vrste posmatranog tehničkog sistema.

Prilikom uvođenja informacionog sistema preduzeća ostvaruju određene prednosti, kao što su povećanje produktivnosti (smanjiti troškove i povećati produktivnost), poboljšanje kvaliteta, bolje i kvalitetnije održavanje, bolji pristup informacijama itd.

Informacioni sistem održavanja (ISOd) prikazan je na slici 1., a sastoji se od osnovnih podsistema [4]:

- informacioni sistem za izvođenje radova održavanja (ISOR),
- informacioni sistem za upravljanje radovima u radionicama (ISORO),
- informacioni sistem za upravljanje osnovnim sredstvima (održavanja), (ISOS), i
- informacioni sistem za upravljanje zalihama rezervnih dijelova i materijala (ISORD).



Sl. 1 Informacioni sistem održavanja u vezi sa IS preduzeća [4]

Na slici 1. je prikazan informacioni sistem održavanja sa informacionim sistemom preduzeća i osnovni podsistemi informacionog sistema. Svaki od ovih podsistema informacionog sistema u funkciji održavanja ima svoju namjenu i specifičnost.

3. STRATEGIJA ODRŽAVANJA POSMATRANOG PROIZVODNOG SISTEMA

Glavni i jedini razlog što se u posmatranom proizvodnom sistemu poklanja malo pažnje održavanju je prije svega neznanje, nestručnost, neorganizovanost i što ne postoji volja za tim. Osoblje koje je zaduženo za održavanje u posmatranom proizvodnom sistemu često nemaju uticaja na donošenje odluka, što predstavlja veliki problem.

Osim toga u posmatranom proizvodnom sistemu nije uveden informacioni sistem, što otežava postupak održavanja. Posmatrani proizvodni sistem nema tačan

uvid o održavanju, što sektoru održavanja i menadžmentu preduzeća stvara ogromne probleme, kao što su: ne postoji tačan uvid o troškovima nabavke, o izmjeni pokvarenih dijelova itd.

Potrebno je definisati ciljeve u svakom pogonu, zatim treba definisati put kako će se to ostvariti, izabrati odgovarajuće resurse koji su potrebni za svaku aktivnost i da postoji dobra koordinacija između svih timova koji učestvuju u održavanju. Takođe, je potrebno izvršiti održavanje svih pogona unutar proizvodnog sistema, održavanje instalisane opreme unutar proizvodnog sistema i čišćenje svih pogona unutar proizvodnog sistema.

Kako oprema u posmatranom proizvodnom sistemu obuhvata mašinsku i elektro opremu, potreban je poseban pristup u izboru strategije održavanja za svu opremu. Za svaku od izabranih strategija potrebna je informatička podrška za uspješan i kvalitetan rad sektora održavanja u posmatranom proizvodnom sistemu.

4. PRIMJENA INFORMACIONOG SISTEMA U POSMATRANOM PROIZVODNOM SISTEMU

U ovome dijelu će biti opisane faze uvođenja informacionog sistema, modeli, ciljevi i zadaci, grafički prikaz informacionog sistema i metoda BSP za dugoročno planiranje razvoja informacionog sistema za posmatrani proizvodni sistem.

U svakom pogonu posmatranog proizvodnog sistema, bez obzira ko sa tim pogonom da upravlja, može da se ugradi informacioni sistem, koji će osigurati sve povratne informacije i omogućiti ocjenjivanje svakoga pogona. Takve informacije će itekako pomoći sektoru održavanja za donošenje odluka, koji će imati uvid u cjelokupno održavanje.

Sa ovakvim načinom upravljanja dolazi se do podataka koje omogućavaju tačno definisanje parametara kod odlučivanja o potrebi za održavanje svih pogona, definisanju i uvođenju potrebne instalisane opreme i dr.

Informacioni sistem održavanja kod posmatranog proizvodnog sistema moguće je implementirati, tj. izvesti u praksi kroz četiri faze koje su prikazane u tabeli 1.

Tabela 1 *Informacioni sistem održavanja kod posmatranog proizvodnog sistema prikazan kroz četiri faze*

FAZA 1. Pripremanje osnovnih podataka	FAZA 2. Pripremanje tehnoloških podataka
<ul style="list-style-type: none"> - Organizovanje i pripremanje zajedničkih podataka (struktura preduzeća, kapaciteti i kadrovi). - Organizovanje i pripremanje svih tehničkih podataka. - Utvrditi i dopuniti podatke o svim rezervnim dijelovima i komponentama. 	<ul style="list-style-type: none"> - Iz raspoložive tehničke dokumentacije potrebno je izvršiti dopunu o osnovnim tehničkim podacima. - Unos raspoloživih podataka. - Izvršiti kodiranje za svu opremu.
FAZA 3. Pripremanje radne dokumentacije	FAZA 4. Praćenje kvarova i popravka istih
<ul style="list-style-type: none"> - Analizirati postojeća dokumenata. - Izvršiti opis rada s dokumentom. - Način kako nastaje dokument. - Dati hodogram toka. 	<ul style="list-style-type: none"> - Pregled radne opreme i njena učinkovitost. - Izbor strategije održavanja. - Troškovi održavanja.

Preporučuje se, da se informacioni sistem održavanja kod posmatranog proizvodnog sistema treba uraditi modularno. Prednost ovakvog sistema je što se može koristiti na razne oblike organizovanja funkcije održavanja (centralizovano, decentralizovano i kombinovano održavanje), kao i na različite strategije održavanja. Takođe, ovakav sistem ostavlja mogućnost da se u posmatranom proizvodnom sistemu uvede funkcija održavanja modularno uzimajući pri tom u obzir prije svega organizacijske, finansijske i kadrovske mogućnosti korisnika, počev s informatizacijom skladišta, pa do uvođenja podsistema održavanja po stanju. Pri tome, moduli (6 modula) informacionog sistema održavanja posmatranog proizvodnog sistema mogu biti: troškovi održavanja, tekuće održavanje, podaci o svim mašinama, podaci o opremi, kontrolni pregledi i preventivno održavanje, što je prikazano u tabeli 2.

Tabela 2 Moduli informacionog sistema održavanja posmatranog proizvodnog sistema

MODUL 1: Troškovi održavanja Ovakav modul bi sadržio podatke i programe koji bi pratili sve troškove održavanja po svim vrstama održavanja počev od preventivnog održavanja, kontrolnih pregleda, tekućeg održavanja i planskih popravki.	MODUL 2: Tekuće održavanje U ovom modulu bi se nalazili programi i podaci koji bi zabilježili ili evidentirali sva oštećenja i kvarove koji bi nastali na opremi. Na osnovu tih podataka dobili bi se podaci o pouzdanosti radne opreme. Takođe, ovaj model bi omogućavao izdavanje radnih naloga za popravke, izvještavao o obavljenim radovima, zatim koliko se utrošilo materijala i rezervnih dijelova i koliko se vremena utrošilo po jednom radnom nalogu.
MODUL 3: Podaci o svim mašinama U ovom modulu bi se nalazili programi i podaci koji bi omogućavali tačan uvid koja je mašina u pitanju, kako se zove, šifra mašine, ko je proizvođač mašine, kada je mašina kupljena, životni vijek mašine.	MODUL 4: Podaci o opremi U ovome modulu bi se nalazili programi i podaci kojima bi se definisala oprema za održavanje. To bi obuhvalato: osnovne tehničke podatke, mjesto ugradnje i kada je ugrađena, evidenciju zamjene dijelova, opremu ispisati po hierarhiji i ko su proizvođači rezervnih dijelova.
MODUL 5: Kontrolni pregledi U ovom modulu bi se nalazili programi i podaci koji bi omogućavali organizovanje i pravovremeno praćenje kontrolnih pregleda.	MODUL 6: Preventivno održavanje U ovom modulu bi se nalazili programi i podaci koji bi omogućavali organizovanje i praćenje preventivnog održavanja.

Pored navedenih faza i modela, informacioni sistem održavanja posmatranog proizvodnog sistema bi morao da riješi neke od zadataka:

- definisati osnovne i tehničke podatke o svakoj mašini, tj. obezbjediti potpunu istoriju o svakoj mašini,
- definisati poziciju svakog elementa u tehnološkom procesu,
- planirati i pratiti pregled mašina (dnevno, periodično, sedmično i mjesečno), troškove pregleda i planirati i pratiti mjerenje i ispitivanje mašina.

- izvršiti evidentiranje obavljenih radova,
- pratiti prijavljene kvarove,
- provjeriti kakvo je stanje komponenti na skladištu,
- pratiti tekuće troškove, i
- na kraju dobiti ukupne troškove održavanja.

Pored navedenih osnovnih zadataka i njihovom razradom potrebno je definisati bliže zahtjeve, a ti zahtjeve treba da se zadovolje prvo projektom, pa onda realizacijom informacionog sistema za posmatrani proizvodni sistem. Ovi zahtjevi se mogu iskazati na sljedeći način [5]: stalni uvid u stvarne performanse sistema koji se posmatra, u vidu informacija nužnih za upravljanje i planiranje procesom rada i održavanja, uključujući i elemente logističke podrške, snabdjevanje, obuku radnika i drugih izvršilaca, itd.; ukazivanje na potrebne i moguće mjere poboljšanja, odnosno na korektivne aktivnosti i podešavanja, kako za dijelove sistema koji se već nalaze u radu ili koji tek treba da se uključe u posmatrani sistem, tako i za sve komponente i dijelove sistema održavanja, snabdjevanja, elemente logističke podrške, snabdjevanje rezervnim dijelovima, itd.; identifikacija oblika, uzroka i mogućih mehanizama nastajanja otkaza, kao i definisanja metoda koji će obezbjediti bolje osnove za analizu otkaza i preduzimanje mjera koje će smanjiti vjerovatnoću njihove pojave; informisanje proizvođača posmatranog sistema o njihovim stvarnim performansama, odnosno definisanje zahtjeva za razvoj novih sistema iste vrste, za sljedeće porudžbine i nabavke; ukazivanje na pravce daljeg razvoja informacionog sistema, primjenjenih metoda i organizacije baze podataka, kako bi se ostvarilo sigurnije predviđanje budućih događaja, odnosno bolje upravljanje i planiranje rada posmatranih tehničkih sistema.

Na slici 2. je predložen i prikazan informacioni sistem za posmatrani proizvodni sistem. Informacioni sistem je projektovan pomoću računara. Za projektovanje informacionog sistema pomoću računara u posljednjih nekoliko godina je stvoren velemali broj alata. Ti alati se zovu Computer Aided Software Design (CASE).

Za analizu i projektovanje ovakvog informacionog sistema korištena su tri alata: riječnik podataka koji sadrži tabelaran pregled svih podataka, hodogram dokumenata i program za obradu podataka uključujući baze podataka ili sistem baze podataka.

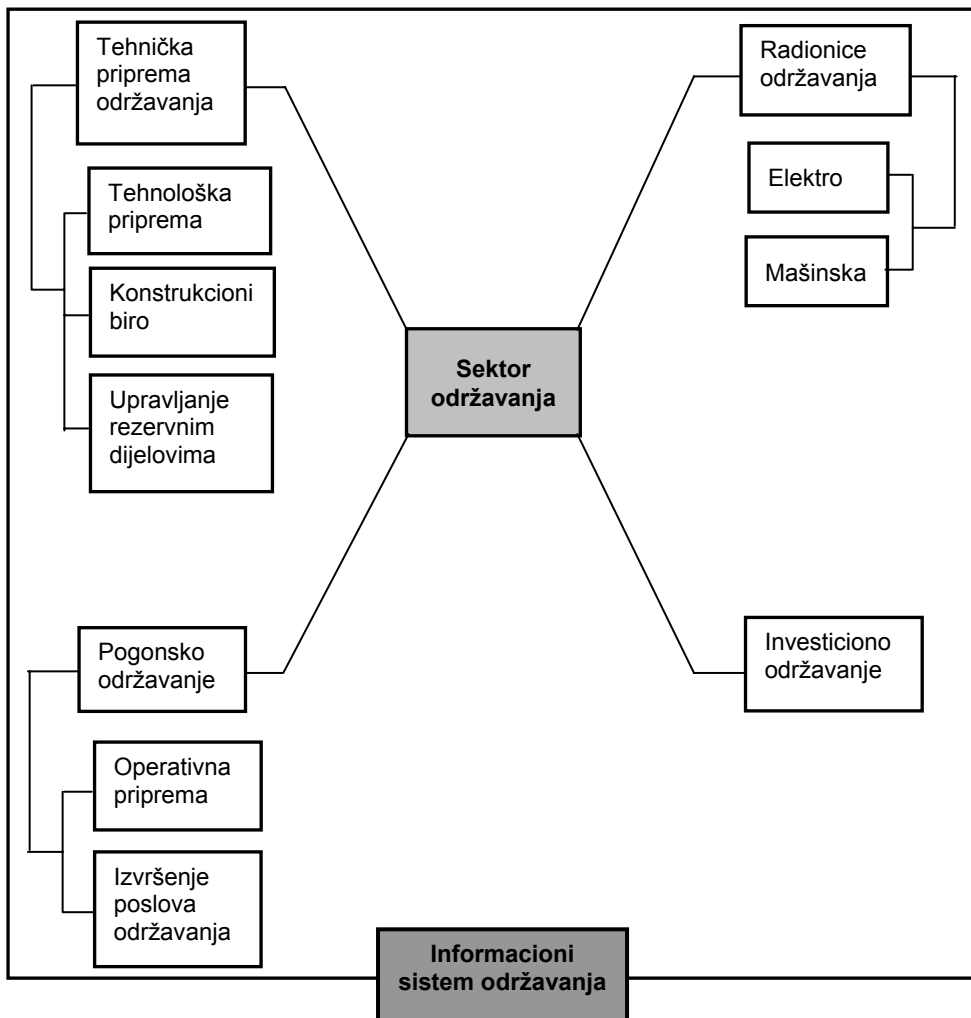
Baza podataka ili sistem baza podataka predstavlja suštinu ne samo ovog informacionog sistema, nego i svih informacionih sistema.

Sa slike se vidi da ovakav informacioni sistem predstavlja organizacionu i funkcionalnu povezanost svih elemenata održavanja kao sistema, koja vidi logistiku u vidu finansijsko materijalnih i opštih poslova.

Takođe, ovakav informacioni sistem povezuje postupke prikupljanja, kretanja, obrade podataka i informacija u jedinstvenom sistemu planiranja i upravljanja radovima na održavanju. Sistem je koncipiran tako da maksimalno odgovori sljedećim osnovnim zadacima [1]:

- održavanju stalne veze između funkcija proizvodnje i održavanju u cilju usaglašavanja njihovih aktivnosti koje su motivisane često suprotnim zahtjevima, vodeći računa o obezbjeđenju maksimalne sigurnosti izvršilaca angažovanih na radovima održavanja,
- brizi o blagovremenom izvršenju rokova po pojedinim radnim zadacima, uz istovremeno postizanje mogućeg optimalnog iskorišćenja raspoloživih mašinskih, ljudskih i materijalnih resursa,

- obezbjeđenju mogućnosti brzog informisanja po svim pitanjima u vezi sa operativnim planom rada i stanjem realizacije pojedinih radnih zadataka uključujući i pitanje kontinuiranog ažuriranja operativnog plana rada,
- neprekidno prati ključne varijable procesa održavanja kao što su broj mašina u otkazu, troškovi korektivnog održavanja, troškovi preventivnog održavanja i sl., i
- dostavljanju informacija rukovodstvu i organima upravljanja radi ocjene efikasnosti rada pojedinih grupa, a u cilju da se omogući besprijekorno funkcionisanje svih segmenata u sistemu.



Sl. 2 Informacioni sistem održavanja

Pri uvođenju i korišćenju ovakvog informacionog sistema se ne smije zapostaviti planiranje i upravljanje njihovim razvojem. Razvoju ovakvog informacionog

sistema je najbolje pristupiti preko neke dobro definisane formalne i standardne metodologije razvoja. Pri tome, metode planiranja i upravljanja razvojem ovakvog informacionog sistema moraju da budu dijelovi standardne metodologija razvoja informacionih sistema.

Firma IBM je razvila metodu BSP (Business System Planning) za dugoročno planiranje razvoja informacionog sistema. Kod ove metode se planiranje i analiza obavljaju od vrha ka dnu, dok se projektovanje i uvođenje obavljaju od dna ka vrhu.

Osnovne aktivnosti u metodi BSP su slijedeće [6]: davanje saglasnosti, priprema za BSP studiju, definisanje poslovnih procesa, definisanje klasa podataka, analiza postojećeg IS, sagledavanje vizija rukovodstva, izrada materijala o nalazima i zaključcima intervjuja, definisanje arhitekture IS, definisanje prioriteta razvoja IS, organizovanje funkcije razvoja IS, definisanje plana razvoja IS.

Ovakva metoda se predlaže za dugoročno planiranje i razvoj informacionog sistema održavanja za posmatrani proizvodni sistem.

5. ZAKLJUČAK

Danas je skoro nezamislivo održavanje proizvodnih sistema bez informatičke podrške. Kod posmatranog proizvodnog sistema koji se nalazi na jednoj lokaciji nije uveden informacioni sistem, što sektoru održavanja i menadžmentu preduzeća stvara velike teškoće, jer nemaju tačan uvid o održavanju.

Zato se u ovom radu predlažu određene faze poboljšanja u održavanju posmatranog sistema uz primjenu informacionog sistema, modeli i BSP metoda za dugoročno planiranje razvoja informacionog sistema.

Ovakav način održavanja uz primjenu informacionog sistema bi omogućio da se smanje prije svega troškovi poslovnja. Isto tako ovakvim informacioni sistem je izvršeno povezivanje svi dijelovi održavanja u jednu funkcionalnu cjelinu za dobijanje tačnih informacija, pravovremenu i tačnu obradu informacija sektoru održavanja što je i bio cilj rada.

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Faculty of Mechanical Engineering

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Session VIII ***STUDENT SECTION***



PRIMJENA VIRTUALNE INSTRUMENTACIJE U NADZORU MAŠINSKIH SISTEMA

Zoran Radović¹, Željko Batinić², Nemanja Prorok³, Srđan Vasković⁴

Rezime: Promjene u pristupu pri razvoju sistema za nadzor stanja mašinskih sistema je direktni rezultat konstatnog napretka na polju informacionih tehnologija i interneta. Ovaj rad predstavlja neke od prednosti primjene virtualne instrumentacije u nadzoru stanja mašinskih sistema kao i neke osnovne smjernice za njenu praktičnu implementaciju. Stalni nadzor vibracija na probnom stolu za dinamička ispitivanja je praktični primjer implemetacije virtualne instrumentacije.

Ključne riječi: Vibracije, virtualni instrument, nadzor stanja mašinskih sistema, online monitoring

APPLICATION OF VIRTUAL INSTRUMENTATION IN MONITORING OF MECHANICAL SYSTEMS

Abstract: Changes in aproach for developing of systems for machine condition monitoring is the direct result of constant advances in the field of information technologies and internet. This paper presents some the benefits of virtual instrumentation approach to condition monitoring as well as some basic guidelines for its practical implemntation. Online monitoring, based on vibration measuremenst of the Demonstrative bench for dynamical testing is given as a practical example of this approach implementation.

Keywords: Vibration, virtual instrument, condition measurement, online monitoring

1. UVOD

Virtualna instrumentacija predstavlja novi pristup u projektovanju i izradi mjerno-nadzornih instrumenata koja se zasniva na korištenju standardnog PC računara, specijalnih hardverskih komponenti za akviziciju i digitalizaciju signala i namjenskog softvera koji omogućuje prikupljanje, obradu i prikaz rezultata mjerenja u odgovarajućem obliku. Ovakav pristup projektovanju mjerno-nadzornog sistema omogućava iskorištavanje osnovnih resursa PC računara u smislu njihove mogućnosti obrade velikog broja podataka u kratkom vremenu, prezentacije i vizuelizacije dobijenih rezultata na monitoru, memorisanja podataka, povezivanja i komunikacije sa ostalim informacionim sistemima i sl.

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Sve ovo olakšava rad korisnicima ovakvih sistema i pruža neke sasvim nove mogućnosti prvenstveno na polju nadzora, zaštite, dijagnostike i održavanja mašinskih sistema.

Fleksibilnost ovih sistema, odnosno prilagodljivost virtuelnog instrumenta potrebama korisnika nadzora konkretnog sistema, daje upravo softverska komponenta, iz tih razloga se ona i izdvaja kao najznačajnija komponenta sistema.

Krajni cilj ovoga rada bio je projektovanje virtuelnih instrumenta, korištenjem paketa za grafičko programiranje - LabVIEW-a, u svrhu nadzora rada mašinskih sistema.

2. ULOGA I ZNAČAJ NADZORA MAŠINSKIH SISTEMA

Glavni cilj monitoringa mašinskih sistema je postizanje veće stabilnosti rada sistema, te rano otkrivanje mjesta i uzroka kvara u cilju prventivnog djelovanja u toku eksploatacije. Takođe primjena odgovarajućeg sistema nadzora i prikupljanja informacija o radu i stanju mašinskog sistema vrlo je bitna zbog analize kvarova i mogućnosti predviđanja njihove pojave.

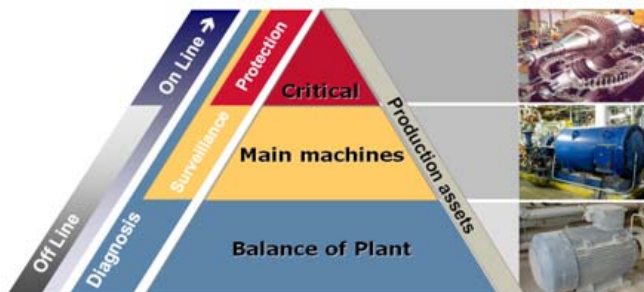
3. PERIODIČNI I STALNI NADZOR MAŠINSKIH SISTEMA

Sa stanovišta periodičnosti prikupljanja podataka i analize, sistem za nadzor može biti definisan kao:

- **OFFLINE sistem:** Odnosno sistem za vremenski periodično prikupljanje podataka i njihovu analizu. Ovo prikupljanje podataka i analizu izvršavaju specijalisti odgovarajuće struke i odgovorno osoblje za održavanje. Periodičnost uzimanja podataka (mjerjenja) bi trebalo da zavisi od trenutnog stanja mašina i opreme, uslova i režima rada, različitih propisa i standarada, te preporuka proizvođača i sl.
- **ONLINE sistemi:** Odnosno sistem za stalni nadzor. Ovaj sistem se zasniva na permanentno instaliranoj opremi za mjerenje i analizu stanja mašine.

U zavisnosti od uloge i značaja pojedinih mašina (uređaja) za njihov nadzor primjenjuju se različiti sistemi.

Na primjer mašine koje su od najvećeg značaja za proizvodnju zahtjevaju online monitoring sistem (odnosno sistem stalnog nadzora), kao i neki sistem stalne zaštite, nadzora i dijagnostike. Ovo se takođe odnosi i na one dijelove postrojenja čiji otkazi mogu da izazovu povrede radnika, životne sredine i sl. Jednim imenom ovu grupu nazivamo **kritičnim mašinama**.



Sl. 1 Područje primjene ONLINE i OFFLINE

U drugu ruku, monitoring stanja jednostavnih i manje odgovornih mašina. može biti bazirano na ručnim analizatorima i periodičnim mjerenjima i analizama.

Takođe prilikom izbora odgovarajuće strategije nadzora za specifičnu grupu mašina neki dodatni parametri bi trebalo biti uzeti u obzir. Neki od njih bi mogli biti: položaj i pristupačnost mašine, potreba za zaustavljanjem procesa da bi se pristupilo mjerenju, bezbjednost osoblja koje vrši kontrolu, raspoloživost dovoljno obučenog kadra, brzina povrata investicije...

Takođe odabir odgovarajuće tehnike zahtjeva dodatnu analizu tipa i namjene mašine nad kojom se vrši nadzor.

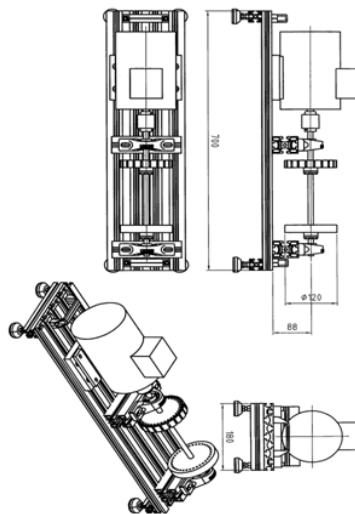
4. PRIMJER IZRADE SOFTVERA VIRTUELNOG INSTRUMENTA ZA NADZOR VIBRACIJA NA PROBNOM STOLU ZA DINAMIČKA ISPITIVANJA

Praktična demonstracija primjene virtualne instrumentacije i LabVIEW razvojnog okruženja prikazana je na primjeru rešavanja sledećeg zadatka:

4.1. Postavka zadatka

Za probni sto za dinamička ispitivanja koji je prikazan na slici 2. potrebno je napraviti sistem za nadzor vibracija prema sledećim zahtjevima:

- Sistem treba biti baziran na PC računaru
- Obrada ulaznog signala i prikaz rezultata mora biti u realnom vremenu
- Da vrši monitoring trenutnog nivoa vibracija, RMS-a, vrijednost CREST i PEAK faktora brzine, ubrzanja i pomjeranja, kao i njihov trend (promjenu u vremenu)
- Da daje upozorenje u slučaju prekoračenja dozvoljenih granica V_{RMS} -a
- Da daje prikaz spektra kao i njegovu promjenu u vremenu (kaskadni dijagram)
- Prati nivo vibracija, amplitudu i fazu 1X, 2X, 5X, 10X i 20X harmonika
- Da postoji mogućnost snimanja (čuvanja) izmjerenih veličina



Sl. 2. Probni sto za dinamička ispitivanja [2]

4.2. Senzori i mjerna oprema

Za rješavanje zadatak problema na rasplaganju je korištena sledeća oprema:

- Piezo-električni akcelorometar **METRIX SA6200A** čiji su osnovni podatci dati na slici 3.
- Foto senzor **BALLUFF BOS5k** (sl.4.)
- **CompactDAQ USB** Data Aquisition sistem sa pripadajućim modulima (sl.5.)

Dynamics:

Accuracy: 2% (Repeatability)

Sensitivity ($\pm 5\%$): 100 mV/g

Frequency Response:

3 to 1.5 KHz ($\pm 5\%$)

1.5 Hz to 2.5 KHz ($\pm 10\%$)

0.5 Hz to 10 KHz ($\pm 3\text{dB}$)

Resonant Frequency: 13 KHz

Cross Axis Sensitivity: $<5\%$

Measurement Range: $>50\text{ g}$

Resolution: 0.002 g

Electrical:

Case Isolation: 108 ohms

Excitation Current: 2 to 20 mA

Excitation Voltage: 18 to 28 VDC, Polarity Indifferent

Full Scale Output Voltage: ± 5 volts

Output Bias: 8 to 12 volts

Settling Time: 5 seconds max.

Transient Protection: RFI & ESD

Mechanical:

Case Material: 303 SS

Connector Type: See "How to Select C"

Hermetic Seal: Welded

Mounting Stud: 1/4-28 UNF or M6 X 1.0 (P/N 3719-007)

Sensing Element: Quartz

Sensing Structure: Shear

Weight: 91 gm (3.1 oz)

Environmental:

Shock Limit: 5,000 g

Temperature Range: -54°C to $+121^{\circ}\text{C}$

Electromagnetic Compatibility: CE Certified

Hazardous Area Certification: See How To Select "A"

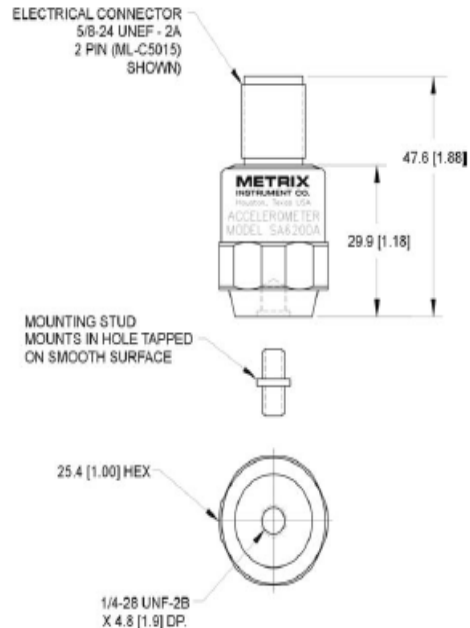
Features

- Wide Frequency Response
- Hermetic S.S. Case
- Polarity Indifferent

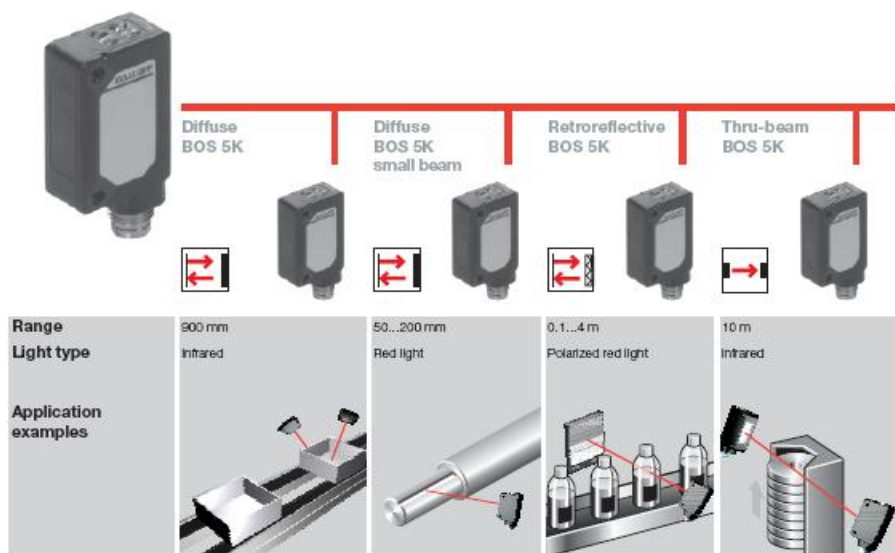
Applications

- Motors
- Gear Boxes
- Paper Machines
- Process Pumps
- Large Fans
- Rotor Blade Pass Sensing
- Turbocharger Engine Vibration
- Cooling Tower Fans

Outline & Dimensions



Sl. 3. Osnovne karakteristike METRIX SA6200A



Please specify in ordering code
 Output: **P** for PNP, **N** for NPN
 Connection: **S75** for connector
01 for 1 m cable
 Example: BOS 5K-PS-ID10-**S75**
 BOS 5K-NS-ID10-**01**

		BOS 5K-S-ID10-...	BOS 5K-O-ID10-...	BOS 5K-O-ID10-...S	BOS 5K-S-RD11-...	BOS 5K-O-RD11-...	BOS 5K-S-PR10-...	BOS 5K-O-PR10-...S	BOS 5K-S-X10-...	BOS 5K-O-X10-...S
Range										
Diffuse	0.9 m	■	■							
Diffuse small beam	0.05...0.2 m			■	■					
Retroreflective (with R11 reflector)	0.1...4 m				■	■				
Thru-beam (emitter and receiver)	10 m						■	■	■	■
Electrical data										
Supply voltage U_s	10...30 V DC	■	■	■	■	■	■	■	■	■
Ripple	≤ 2 V DC	■	■	■	■	■	■	■	■	■
No-load supply current I_s max.	≤ 30 mA	■	■	■	■	■	■	■	■	■
	Emitter ≤ 15 mA	■	■	■	■	■	■	■	■	■
	Receiver ≤ 20 mA	■	■	■	■	■	■	■	■	■
Output	PNP or NPN	■	■	■	■	■	■	■	■	■
Output current	≤ 100 mA	■	■	■	■	■	■	■	■	■
Switching type	dark-on	■	■	■	■	■	■	■	■	■
	light-on	■	■	■	■	■	■	■	■	■
Voltage drop U_s at I_s	≤ 1.2 V DC	■	■	■	■	■	■	■	■	■
Settings	Potentiometer 270°	■	■	■	■	■	■	■	■	■
Optical data										
Light type	Infrared	■	■							
	Red light			■	■					
	Polarized red light					■	■	■	■	■
Display										
Supply voltage indicator	LED yellow	■	■	■	■	■	■	■	■	■
Stability indicator	LED green	■	■	■	■	■	■	■	■	■
Time data										
Response time	≤ 1 ms	■	■	■	■	■	■	■	■	■
Mechanical data										
Connection	Connector M8x1, 4-pin	■	■	■	■	■	■	■	■	■
	Cable	■	■	■	■	■	■	■	■	■
Housing material	PC/PBT	■	■	■	■	■	■	■	■	■
Lens material	PC	■	■	■	■	■	■	■	■	■
	PMMA	■	■	■	■	■	■	■	■	■
Weight	with connector 10 g	■	■	■	■	■	■	■	■	■
	with cable 80 g	■	■	■	■	■	■	■	■	■
Ambient data										
Degree of protection	IP 67	■	■	■	■	■	■	■	■	■
Short circuit protected		■	■	■	■	■	■	■	■	■
Permissible ambient light	Sunlight max. 10,000 Lux	■	■	■	■	■	■	■	■	■
	Artificial light max. 5,000 Lux	■	■	■	■	■	■	■	■	■
Ambient temperature range T_a	-25...+55 °C	■	■	■	■	■	■	■	■	■

Sl. 4 Osnovne karakteristike BALLUFF BOS5K senzora [8]

NI CompactDAQ USB Data Acquisition System

NI CompactDAQ

NI cDAQ-9172

- Accepts up to 8 C Series I/O modules
- Compact (25 by 9 by 9 cm)
- Hi-Speed USB connection to PC
- 11 to 30 V power supply included

NI C Series Modules

- Sensor-specific signal conditioning per module
- Up to 24-bit resolution
- Up to 3.2 MS/s per chassis
- Up to 256 channels per chassis

Operating Systems

- Windows 2000/XP

Recommended Software

- LabVIEW
- LabWindows/CVI
- Measurement Studio
- VI Logger

Measurement Services Software (included)

- NI-DAQmx driver
- Measurement & Automation Explorer



Overview

National Instruments NI CompactDAQ brings the simplicity of USB to sensor and electrical measurements on the benchtop, in the field, and on the production line. By combining the ease of use and low cost of a data logger with the performance and flexibility of modular instrumentation, NI CompactDAQ delivers fast, accurate measurements in a small, simple, and affordable system. Flexible software options make it easy to use NI CompactDAQ to log data for simple experiments or to develop a fully automated test or control system. The modular design can measure up to 256 channels of electrical, physical, mechanical, or acoustical signals in a single system. In addition, per-channel analog-to-digital converters and individually isolated modules ensure fast, accurate, and safe measurements.

Key Features

- Small, modular data acquisition system for industrial measurements
- Hi-Speed USB plug-and-play connectivity to PC
- Hot-swappable, autodetectable C Series I/O modules with direct sensor and signal connectivity
- NI-DAQmx API that provides powerful and easy-to-use programming interface
- Up to 2,300 V_{rms} isolation (withstand)
- NI CompactDAQ environmental certifications and ratings:
 - 0 to 55 °C operating temperature
 - 30 g shock rating (operating)
- PXI vibration specification
- International safety, EMC, and environmental certifications

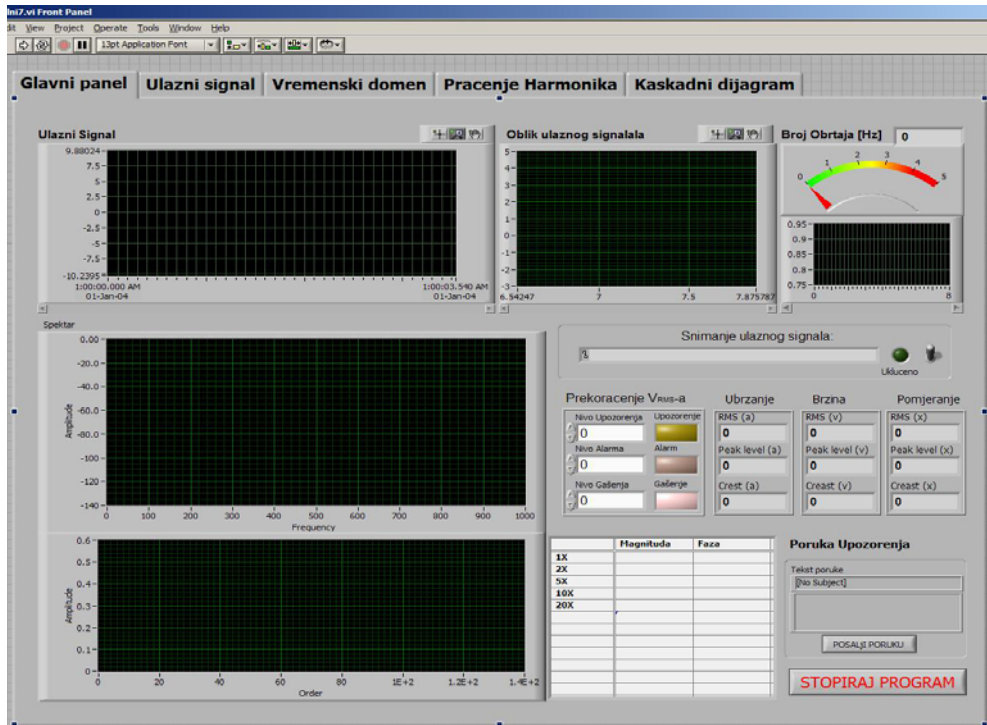
C Series Modules

Type of Signal	Signal	Module	Channels	Special Features	Connectivity
Analog Input	Thermocouple	NI 9211	4 DI	24-bit delta-sigma, 14 S/s, differential (J, K, R, S, T, N, E, and B thermocouple types)	Screw terminal
	IEPE sensors (accelerometer, microphone)	NI 9233	4 SE	24-bit, 50 kS/s, simultaneous, IEPE conditioning	BNC
		General-purpose (± 200 mV to ± 10 V)	NI 9205	32 SE/16 DI	16-bit, 250 kS/s
	NI 9206		16 DI	16-bit, 250 kS/s, 600 VDC Cat. I bank isolation	Spring terminal
	NI 9215		4 DI	16-bit, 100 kS/s/ch, simultaneous, differential	Screw terminal or BNC
General-purpose (± 60 mV)	NI 9211	4 DI	24-bit, 14 S/s, differential	Screw terminal	
	NI 9237	4	24-bit, 50 kS/s/ch	RJ 45	
Analog Output	General-purpose (± 10 V)	NI 9263	4 SE	16-bit, 100 kS/s/ch, simultaneous	Screw terminal
Digital Input	Bidirectional 5 V TTL	NI 9401	8	5 V TTL, ultrahigh-speed, bidirectional, 30 V protection	25-pin D-Sub
	24 V sinking	NI 9421	8	10 kS/s, 24 V logic, 40 V protection	Screw terminal or 25-pin D-Sub
Digital Output	Bidirectional 5 V TTL	NI 9401	8	5 V TTL, ultrahigh-speed, bidirectional, 30 V protection	25-pin D-Sub
	24 V sourcing	NI 9472	8	10 kS/s, 24 V logic, 750 mA max per ch, 30 V protection, short-circuit-proof	Screw terminal or 25-pin D-Sub
Relay	Electromechanical, Form A (SPST)	NI 9461	4	30 VDC (2 A), 60 VDC (1 A), 250 VAC (2 A) electromechanical Form A (SPST)	Screw terminal
Counter, Pulse Generation	Counter/timer/PWM/pulse generation (TTL)	NI 9401	8	5 V TTL, ultrahigh-speed, bidirectional, 30 V protection	25-pin D-Sub
	PWM/pulse generation (24 V)	NI 9472	8	10 kS/s, 24 V logic, 750 mA max per ch, 30 V protection, short-circuit-proof	Screw terminal or 25-pin D-Sub

Sl. 5. Osnovne karakteristike NI CompactDAQ9172 sistema i njegovih modula[5]

4.3. Riješenje VI-a

Za razvoj aplikacije virtualne instrumentacije korišteno je **LabVIEW 8.6.0.** razvojno okruženje sa dodatnim **LabVIEW SignalExpress 3.0** i **Sound and Vibration Measurement Tool Set**-om. [3,4,5,6]

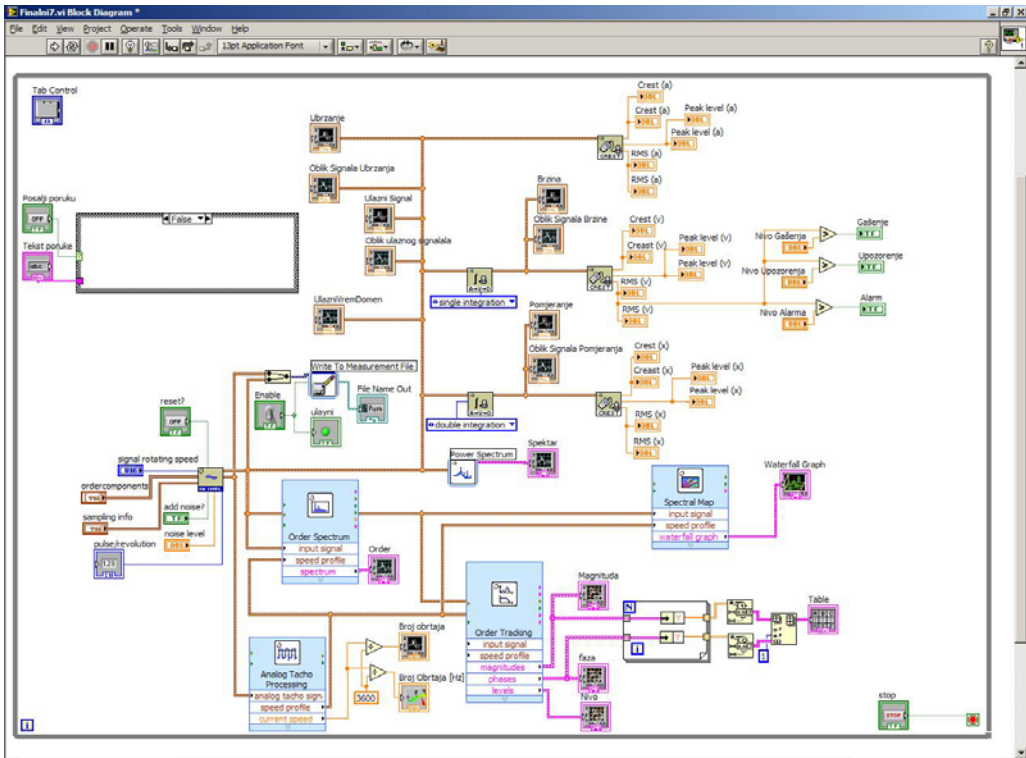


Sl. 6 Front panel VI-a

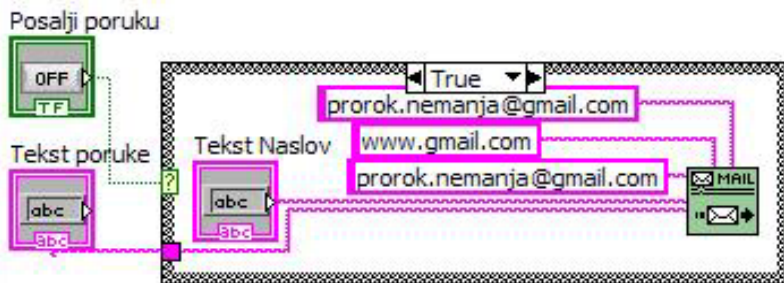
Sa ciljem postavljanja što jednostavnijeg i preglednijeg korisničkog interfejsa front panel VI-a je podjeljen u pet tabova – odnosno pet zasebnih prikaza ekrana. Na slici 6. se vidi aktivan prvi odnosno **Glavni panel**. Prilikom koncipiranja izgleda glavnog panela vođeno je računa da on daje pregledan prikaz svih važnijih informacija naznačenih u postavci zadatka. Odnosno osnovna zamisao je da operater na ekranu svog PC-a najveći dio vremena ima aktiviranu upravo ovu stranicu.

Za detaljniju analizu ulaznog signala, promjene u vremenu RMS-a, PEAK i CREST faktora za brzinu ubrzanje i pomjeranje, te promjenu u vremenu amplitude faze i nivoa vibracija za karakteristične harmonike kao i za prikaz kaskadnog dijagrama koriste se preostala četiri tab-a.

Odgovarajući blok dijagram prikazan je na slici 7.



Sl. 7 Block diagram



Sl. 8. Dio blok dijagrama koji izvršava naredbu slanja email-a (aktivno)stanje)

5. ZAKLJUČAK

Virtualni instrumenti koriste resurse personalnog kompjutera (procesor, napajanje, memoriju, magistrale,...) a upravljanje, obrada i prikazivanje podataka zasniva se na softveru koji zajedno sa modularnim hardverskim delom, čini moćnu platformu koja je u stanju da konkuriše tradicionalnom instrumentu gotovo po svakom pitanju.

U kratkim crtama najznačajnije prednosti ovakvog pristupa su:

- Tradicionalni Instrumenti imaju fiksirane karakteristike koje se ne mogu menjati niti prilagođavati konkretnoj situaciji.
- Tradicionalni Instrumenti najčešće koriste najklasičnije metode za rešavanje određenih vrsta problema ili za analizu signala. Nema mogućnosti izbora algoritma za Harmonijsku analizu, najčešće je to samo Digitalna Furijeova Transformacija (DFT). Merenje frekvencije se najčešće odvija samo metodom merenja vremena potrebnog za prolazak signala kroz nulu. Ne postoji mogućnost uključivanja adaptivnog filtriranja mernog signala pre njegove obrade, radi eliminisanja šuma.
- Virtualni Instrumenti se veoma lako mogu spajati između sebe ili u mreže a takođe je lako spajanje i na Internet. Podaci se mogu slati samo kada se dogodi neka promena mernog signala i ne mora se odlaziti na mesto merenja.
- Akvizicija podataka spojena je sa analizom i prezentacijom u jednu celinu u jednom uređaju.
- Postoji mogućnost primene različitih mernih metoda nad istim problemom i istim mernim signalom, radi provere koja metoda snajviše odgovara datom problemu. Gotovo svakog dana negde u svjetu se publikuju različite metode analize i li dijagnostike koje se onda vrlo lako realizuju i testiraju sa Virtualnim Instrumentom.
- Postoji mogućnost da se jednom utvrđeni i testirani mjerni (ili dijagnostički) algoritam ugradi u jeftini ARM mikroprocesorski sistem koji onda trajno ostaje priključen na mejrnom mestu. Ovakav uređaj je moguće posle spojiti na postojeće SCADA sisteme.
- Konceptom Virtualne Instrumentacije je moguće jedan problem rešiti preko različitih mjernih kartica-uređaja, kao što je moguće i sa jednim mejrnim uređajem rešiti veći broj različitih mjernih zadataka.
- LabVIEW poseduje veliku bazu podprograma koju je moguće odmah primjeniti u realizaciji odgovarajućeg mejrnog problema.
- VI poseduje veoma jaku informatičku bazu tako da se podaci veoma lako mogu prosljediti na različite programske pakete gde se naknadno mogu prikazati i analizirati. Takav jedan programski paket je recimo Excel koji vec u sebi sadrži mnoge ugrađene funkcije za numeričku analizu.
- Kod VI postoji mogućnost brzog prenosa podataka preko Interneta za vremenski kritične aplikacije.

Zahvaljujući pogodnostima koje pruža primjena virtuelnih instrumenata moguće je prikupljati podatke potrebne za dijagnostiku ne samo na licu mjesta nego i sa udaljenosti, te vršiti potrebnu ekspertizu u nekom udaljenom dijagnostičkom centru. Što u nekim slučajevima može znatno da umanji ukupne troškove održavanja.

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KONSTRUKCIONO RJEŠENJE UGRADNJE GASA (LPG) NA MOTOCIKL

Nikola Vučetić¹

Rezime: Ljudi već odavno koriste prevozna sredstva pogonjena raznim vrstama goriva. Često korišćeno prevožno sredstvo jeste i motocikl koji zbog sve intenzivnije upotrebe i zbog velike potrošnje goriva otvara pitanja za pronalaženje odgovarajućih alternativnih pogonskih fluida. Ova problematika je dovela do ideje za ugradnju pogonskog gasa u motocikl. Cilj ovoga rada jeste da se kroz sprovođenje ankete kupaca, kroz nesvjesne želje kupaca, kao i kroz vrednovanje određenih varijanti motocikala sa gasom dodje do one optimalne koja se usvaja i da se prikaže samo konstrukciono rješenje ovoga sistema. Rješenje se odlikuje nizom pozitivnih osobina, ekonomskom isplativošću, a sa aspekta zaštite životne sredine ima veliku prednost u odnosu na konvencionalno pogonsko gorivo.

Ključne riječi: motocikl, pogonski gas

CONSTRUCTIONAL SOLUTION FOR INSTALLATION OF GAS (LPG) ON MOTORCYCLE

Abstract: People have long used vehicles powered by different fuel type. Commonly used means of transportation is the motorcycle due to the increased use due to high fuel consumption raises questions for finding the right alternative drive fluid. This problem has led to the idea for the installation of gas to drive a motorcycle. The aim of this paper is to conduct the survey of customers, through the unconscious desires of customers, as well as the valuation of certain varieties of motorcycles with gas reaches the optimal ones to be adopted and to display only the constructive solution of this system. The solution is characterized by a number of positive characteristics, economic profitability, and in terms of environmental protection has a major advantage over conventional fuel.

Keywords: motorcycle, drive gas

1. UVOD

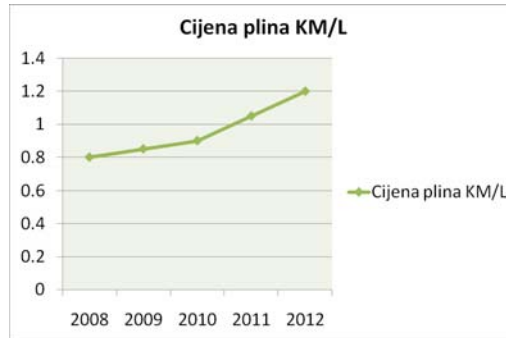
Ljudi već odavno koriste prevozna sredstva pogonjena raznim vrstama goriva. Često korišćeno prevožno sredstvo jeste i motocikl koji zbog sve intenzivnije upotrebe i zbog velike potrošnje goriva otvara pitanja za pronalaženje odgovarajućih alternativnih pogonskih fluida. Ova problematika je dovela do ideje za ugradnju pogonskog gasa u motocikl. U svijetu se svakodnevno bilježi porast cijena goriva (slika 1), što je slucaj i

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sa pogonskim gasom (slika 2), ali u dosta nižem stepenu i čija je cijena trenutno više nego upola manja.



Sl. 1. Rast cijena goriva u periodu 2008-2012. god.



Sl. 2. Rast cijena gasa u periodu 2008-2012. god.

2. ANKETA, NESVJESNE ŽELJE KUPACA I LISTA ZAHTJEVA

2.1. Anketa

Anketa je naziv za skup postupaka kojim se prikupljaju izjave osoba kako bi se saznala njihova mišljenja, stavovi, način ponašanja i interesi. Mogu se raditi za statistiku, za istraživanje tržišta, za medicinske potrebe ili ispitivanje javnog mišljenja. Tako je u okviru ovoga rada izvršeno anketiranje određenog broja ispitanika. Svi ispitanici su podijeljeni u tri grupe (tabela 1), s obzirom na sličnost datih odgovora. Pitanja koja su korišćena za anketiranje kupaca usmjerena su na dobijanje što preciznijeg odgovora, kao i raspoloživosti kupaca za ugradnjom ovoga sistema. Neka od njih su:

- Koliko često vozite svoj motocikl?
- Koliko kilometara pređete u toku sezone?
- Kolika je potrošnja Vašeg motocikla na pređenih 100 km?
- Da li Vam je bitna snaga motocikla u gradskoj vožnji?
- Da li rast cijena goriva utiče na manje korišćenje motocikla?

- Da li biste željeli da ugradite plin u svoj motocikl?
- Koliku zapreminu rezervoara za gas biste željeli?
- Gdje biste željeli da se taj rezervoar nalazi?
- Da li biste željeli da Vam plinska boca bude na mjestu koje ne oduzima postojeći kapacitet predviđen za smještaj stvari u motociklu?
- Koliko ste spremni da izdvojite novca za ovakav sistem?

Tabela 1. Anketiranje ispitanika i odgovori

	Grupa I	Grupa II	Grupa III
1.	Svaki dan	3-4 puta sedmično	Po potrebi
2.	Oko 15000 km	Oko 7000 km	Oko 3000 km
3.	5-6 L	Preko 10 L	3 L
4.	Ne	Da	Ne
5.	Da	Da	Da
6.	Da	Da	Ne
7.	15-ak L	7-8 L	5 L
8.	Ispod sjedišta	U sklopu postojećeg	Svejedno
9.	Da	Da	Da
10.	800 KM	500 KM	300 KM

Ispitivanje koje je urađeno putem ankete omogućilo je da se sama ideja ovoga sistema potkrijepi činjenicama da je potrebno izvršiti ugradnju plina u motocikl, a sve s ciljem smanjenja troškova korisnicima.

2.2. Nesvjesne želje kupaca

Nesvjesne želje kupaca vezane za konstrukciju ovoga sistema su:

- Da rezervoar plina ne zauzima već postojeći prostor motocikla za prtljag,
- Da plin ne utiče nepovoljno na rad agregata motocikla,
- Bezbjednost u radu i
- Lako održavanje.

2.3. Lista zahtjeva

Lista zahtjeva je osnovni dokument za razvoj proizvoda. Dominantni konstrukcioni parametri sistema biće definisani kroz listu zahtjeva. Zahtjevi vezani za sistem se mogu podijeliti na:

- Opšte funkcije sistema,
- Funkcionalne zahtjeve,

- Ekonomske zahtjeve,
- Ergonomske zahtjeve,
- Tehnološke zahtjeve,
- Estetske zahtjeve i
- Zahtjeve održavanja.

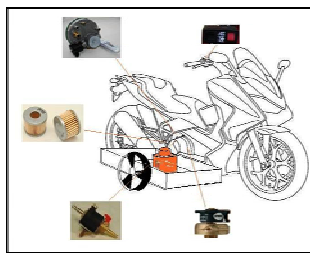
3. VARIJANTNA RJEŠENJA I IZBOR OPTIMALNE VARIJANTE

Da bi se uopšte razmatrala varijantna rješenja i izvršilo njihovo vrednovanje, vrši se prvo denivelacija globalne funkcije motocikla na gas (LPG), slika 3. Osnovna funkcija motocikla na gas,tj. njegova ugradnja, se dijeli na dvije podfunkcije: instalaciju i kretanje. Instalaciju čine sve komponente i dijelovi koji ulaze u sastav ovoga sistema, a kretanje čini niz funkcija potrebnih za obavljanje one najvažnije, a to je omogućavanje vožnje.

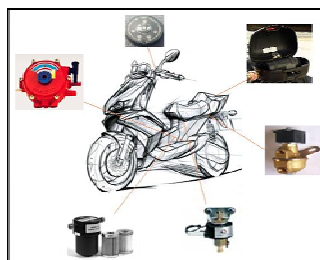


Sl. 3. Denivelacija globalne funkcije

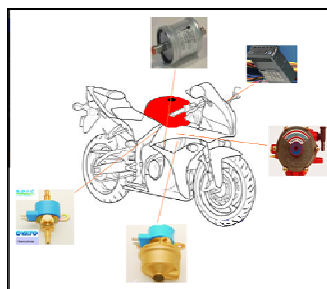
Nakon toga se formira morfološka matrica iz koje, kombinacijom izvršilaca, dobijamo varijantna rješenja. Svaka varijanta je karakteristična po određenim osobinama, a cilj je izabrati onu koja je optimalna. Iz morfološke matrice su se pojavila tri konceptijska rješenja: varijanta 1, varijanta 2 i varijanta 3, prikazane slikama 4,5 i 6.



Sl. 4. *Varijanta 1*



Sl. 5. *Varijanta 2*



Sl. 6. *Varijanta 3*

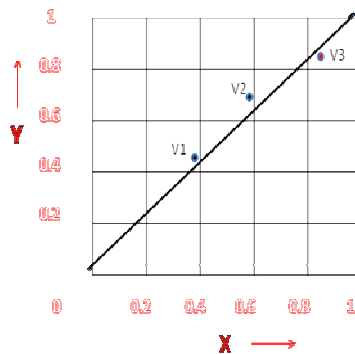
Svaka od navedene tri varijante je izvedena sa komponentama koje se odlikuju svojim pozitivnim i negativnim stranama, a najzanimljiviji detalj u svakoj od njih jeste položaj rezervoara za gas. U prvoj varijanti se nalazi na pomoćnoj prikolici u vidu boce pričvršćene za njeno dno. To je varijanta koja nije povoljna zbog mase boce i fizičke smetnje u toku vožnje, kao i zbog sigurnosnih razloga, jer je, u slučaju nezgode, plinska boca prva na udaru. Varijanta 2 je povoljnija po pitanju položaja rezervoara gasa u odnosu na varijantu 1, međutim, ovim položajem rezervoara se gubi kompletan prostor namijenjen za odlaganje sigurnosne kacige i prtljaga. U smislu položaja rezervoara, varijanta br. 3 je najpovoljnija. Rezervoar za gas je smješten u sklopu postojećeg rezervoara za benzin i odvojen od njega odgovarajućom pregradom. Ovako se ne zauzima nikakav dodatni prostor na motociklu i motocikl ostaje estetski netaknut.

Optimalno rješenje se bira iz niza predloženih varijanti. Vrednovanje se zasniva na subjektivnoj procjeni u kom stepenu je zadovoljen svaki od zahtjeva. Obrada rezultata vrednovanja sastoji se u izračunavanju srednjih vrijednosti subjektivnih

ocjena. Za svaku od varijanti $j=1\dots k$, određuje se tehnička koordinata $X_i=0\dots 1$ i ekonomska koordinata $Y_i=0\dots 1$, na osnovu ocjena p_j ($j=1\dots n$), po obrascima:

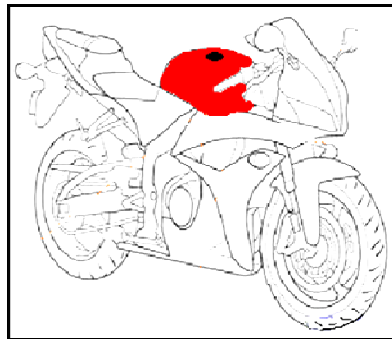
$$y_i = \frac{p_1 + p_2 + \dots + p_n}{n \cdot p_{max}} = \frac{\sum_{j=1}^n p_j}{n \cdot p_{max}}, \quad x_i = \frac{p_1 + p_2 + \dots + p_n}{n \cdot p_{max}} = \frac{\sum_{j=1}^n p_j}{n \cdot p_{max}}$$

Optimalno rješenje je ono koje približno jednako zadovoljava oba kriterijuma, tehnički i ekonomski, a pokazatelji tehničke i ekonomske dobrote su dovoljno visoki, slika 7.



Sl. 7. Varijantna rješenja

Kao što se vidi sa slike 7, usvojena varijanta je varijanta 3 (slika 8).

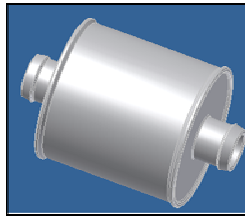


Sl. 8. Usvojena varijanta

4. MODELOVANE KOMPONENTE KOJE ULAZE U SASTAV SISTEMA

U ovom poglavlju je dat prikaz modelovanih komponenata koje ulaze u sastav sistema, a to su: filter, ventili, isparivač, prekidač i rezervoar.

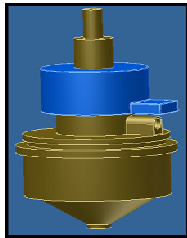
Filter (slika 9) služi za sakupljanje nečistoća reda veličine 3-5 μm .



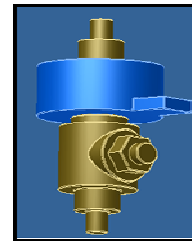
Sl. 9. *Filter*

Ventili o kojima se govori su elektromagnetni (slika 10) i multi ventil (slika 11). Elektromagnetni ventil ima zadatak da bude zatvoren i da sprečava plin da pod pritiskom dođe do isparivača u slučaju kada je motocikl ugašen. U njemu se nalazi i filter koji sakuplja nečistoće iz plina. Multi ventil se ugrađuje direktno na plinski rezervoar. Namjena mu je višestruka:

- Sigurnosni ventil, ispušta višak plina u atmosferu ako se pojavi previsok pritisak,
- Sprečava nekontrolisano isticanje plina usljed kvarova na cijevima ili isparivaču,
- Sprečava punjenje plinskog rezervoara više od 80% i
- Zatvara plin u rezervoaru u slučaju popravke ili udarca na motocikl.



Sl. 10. *Elektromagnetni ventil*



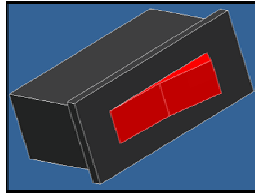
Sl. 11. *Multi ventil*

Isparivač (slika 12) ima zadatak da plin iz rezervoara plina, koji se nalazi u tečnom stanju, prevede u gasovito stanje pri ulasku u radni agregat motocikla. Ovo se odvija tako što kroz isparivač kruži topla tečnost iz agregata i zagrijava ga. Isparivač ima još jednu ulogu, a to je snižavanje pritiska plina iz rezervoara na radnu vrijednost, jer je poznato da na dijelu između isparivača i agregata nema povišenog pritiska, tj. vlada atmosferski pritisak.



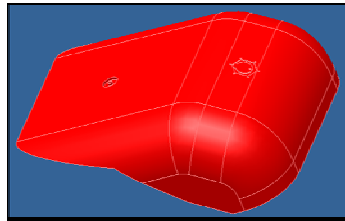
Sl. 12. *Isparivač*

Prekidač (slika 13) služi za prebacivanje sa položaja plin na položaj benzin i obrnuto.

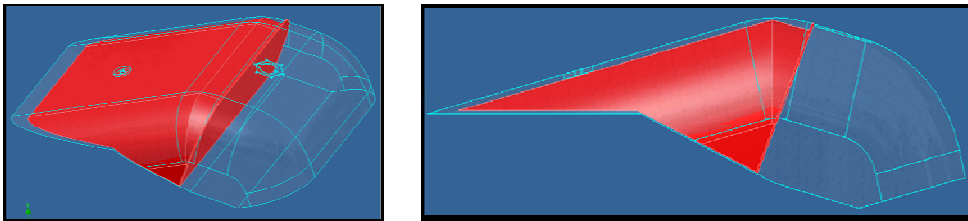


Sl. 13. *Prekidač*

Na slikama 14. i 15. prikazani su rezervoari plina i benzina, kao i položaj rezervoara plina unutar postojećeg rezervoara na motociklu.



Sl. 14. *Rezervoar za plin*



Sl. 15. *Položaj rezervoara za plin u sklopu postojećeg*

Princip rada sistema se odvija tako što se plin puni preko priključka u rezervoar. Plin u rezervoaru je u tečnom stanju pod pritiskom. Preko sistema cijevi plin dolazi do isparivača, gdje uz pomoć toplote motora prelazi iz tečnog u gasovito stanje. Isparivač ujedno ima i funkciju redukcije pritiska. Iz isparivača plin ide u motor preko mješača koji je dimenzionisan za svaki agregat. Pogrešno je mišljenje da plin ide pod pritiskom u motor. Od isparivača do motora nema pritiska. Motor vakuumom usisava plin.

5. EKONOMSKA ISPLATIVOST SISTEMA

S obzirom na cijenu komponenti koje ulaze u sastav datog sistema (slika 16),

<i>Cijena komponenti:</i>	
>	<i>filter za prečišćavanje 15KM</i>
>	<i>ventil za plin 30KM</i>
>	<i>EM ventil 25KM</i>
>	<i>isparivač 95KM</i>
>	<i>rezervoar 140KM</i>
>	<i>taster 10KM</i>
>	<i>ugradnja i ostalo 150KM</i>
	<hr/> 465KM
	+ 175KM atest
	<hr/> 640KM

Sl. 16. Cijene komponenti

te na osnovu prosječne potrošnje motocikla na pređenih 100km (slika 17) i na osnovu broja pređenih kilometara motocikla u toku jedne sezone (slika 18),

<i>18l = 12l plina + 6l benzina</i>
<i>6l benzina = 100km</i>
<i>12l plina = 12 · 0.8 ≈ 10l plina</i>
<i>10l plina = 150km</i>

Sl. 17. Potrošnja motocikla

<i>10 000km = 700l benzina · 2.40KM = 1680KM</i>
<i>10 000km = 850l plina · 1.20KM = 1020KM</i>
<hr/>
<i>= 660KM</i>

Sl. 18. Pređeni kilometri u toku jedne sezone

dolazi se do zaključka da se jedan ovakav sistem otplati za manje od šest mjeseci.

6. ZAKLJUČAK

Kroz ovaj rad prikazano je konstruktivno rješenje ugradnje plina na motocikl. Vršeći anketu, uzimajući u obzir nesvjesne želje kupaca i listu zahtjeva, došlo se do zaključka da su ispitanici pozitivno orijentisani ka ovome sistemu. Dobio se potvrđan odgovor i za njegovu ugradnju, sa ograničenjima na cijenu i zahtjevima korisnika za bezbjednošću i što lakšim načinom održavanja. Ovo je rezultat dobrih strana ugradnje plina i njegovih prednosti, među kojima su:

- Tiši i mirniji rad agregata,
- Povećan vijek trajanja motora za oko 35%,
- Potrpuno sagorijevanje smješe plin-vazduh u cilindrima motora,
- Produžen životni vijek ulja,
- Nema stvaranja korozije,
- Udvostručuje se vijek katalizatora i

- Čistiji izduvni gasovi.
Izduvni gasovi iz motocikla koji se kreće na LPG emituju:
- 75% manje CO,
- 85% manje ugljenvodonika,
- 40% manje NO i
- 87% manje uništenje ozona u odnosu na korišćenje benzina.

Najvažnija činjenica jeste da, nakon ugradnje ovoga sistem, motocikl ostaje estetski potuno netaknut.

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- [3] < www.zamateh.hr >



RECIKLAŽA MOTORNIH VOZILA NA KRAJU ŽIVOTNOG CIKLUSA

Nikola Vučetić¹

Rezime: *Motorna vozila su tehničko-tehnološka dostignuća koja su omogućila intenzivan transport ljudi i roba i koja predstavljaju jedan od najvećih zagađivača planete, počev od procesa proizvodnje, pa sve do kraja njihovog životnog ciklusa. Osnovni cilj ovoga rada je da se, po završetku životnog vijeka vozila, prikaže proces reciklaže sa odgovarajućim tehnologijama, kao i ekonomska studija u upravljanju reciklažom motornih vozila. Sekundarna proizvodnja emituje manja zagađenja nego primarna, što je od izuzetnog značaja posmatrano sa ekološkog aspekta. Pored toga, reciklaža ima izuzetan značaj u uštedi sirovina vrednijih metala u koje se ubrajaju čelik, nerđajući čelik, bakar i aluminijum. Zahvaljujući primjeni reciklaže u automobilskoj industriji, smanjuje se zavisnost svjetskog tržišta od stvarnih rezervi metala.*

Ključne riječi: motorna vozila, reciklaža

END OF LIFE MOTOR VEHICLES RECYCLING

Abstract: *Motor vehicles are the technical and technological advances that have enabled the intensive transport of people and goods and that is one of the biggest polluters of the planet, from the manufacturing process through to the end of their life cycle. The main objective of this paper is to show the recycling process at the end of life vehicles with appropriate technologies and economic studies in the recycling of motor vehicles handling performance. Secondary production emits less pollution than the primary, which is very important for the environment. However, recycling is of great importance in saving valuable metal materials that include steel, stainless steel, copper and aluminum. Thanks to the application in the automotive recycling industry, dependence on the world market than the actual reserves of the metal decreases.*

Keywords: motor vehicles, recycling

1. UVOD

Istorija ljudske civilizacije je zabilježila mnogo kriza kao što su ratovi, epidemije, manjak hrane i prirodne katastrofe. Za razliku od ovih kriza, koje su uglavnom bile manje ili više lokalnog karaktera, čovječanstvo se danas suočava i sa ekološkom krizom koja je globalnog karaktera i prijeti kolapsom cjelokupnog ekosistema planete Zemlje kao posljedice korišćenja prirodnih resursa, zagađenja vazduha, vode, zemljišta, globalne promjene klime i velike količine otpada. Zbog navedenog, velika pažnja se mora posvetiti postupcima reciklaže nastalog otpada.

Inače, reciklaža predstavlja skup aktivnosti kojima se obezbjeđuje ponovno

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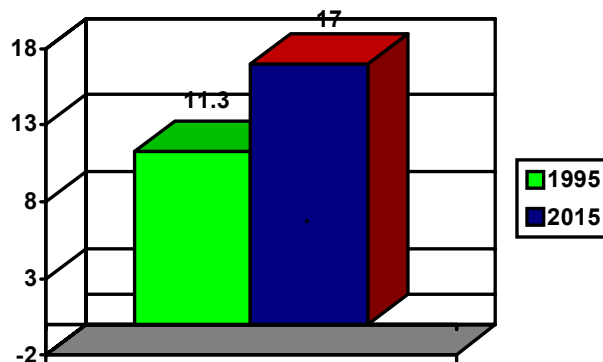
korišćenje otpadnih materijala. Izraz, odnosno pojam reciklaža, potiče od engleske riječi „*recycling*“, što u slobodnom prevodu znači „ponovno korišćenje“ i podrazumijeva kružni ciklus u kome se otpadni materijal ponovo koristi, umjesto da se konačno zbrinjava spaljivanjem ili odlaganjem na deponije otpada. Simbol reciklaže predstavlja Mobiusovu petlju koja sadrži tri povezane strelice u obliku trougla sa zaobljenim uglovima, slika 1.



Sl. 1 Simbol za reciklažu [1]

Jedan od problema današnjice jeste i otpad starih motornih vozila čiji je količina u stalnom porastu. Motorna vozila su tehničko-tehnološka dostignuća koja su omogućila intenzivan transport ljudi i roba, pa je, zahvaljujući toj mobilnosti, došlo do ubrzanog razvoja ljudske civilizacije. Međutim, kao neosporno civilizacijsko dostignuće i dobro, vozila su i jedan od najvećih zagađivača planete, počev od procesa proizvodnje, pa sve do kraja njihovog životnog ciklusa. Ogromne količine automobilske otpada danas predstavljaju veliki problem u svim zemljama svijeta. Motorno vozilo na kraju životnog ciklusa je izvor velikog broja raznovrsnih materijala. To je i logično, s obzirom na to da je sastavljeno od preko 10.000 komponenti sa različitim ulogama na vozilu, od proizvodnje energije i pokretanja vozila do obezbjeđenja sigurnosti i komfora u vožnji.

Prema dostupnim podacima, broj odbačenih automobila u Evropskoj Uniji 1995. godine je iznosio 11,3 miliona, a procjene su da će 2015. godine dostići cifru od 17 miliona, slika 2.



Sl. 2. Broj odbačenih automobila u EU x10⁶

2. OSNOVNI ELEMENTI I PROCES RECIKLAŽE MOTORNIH VOZILA

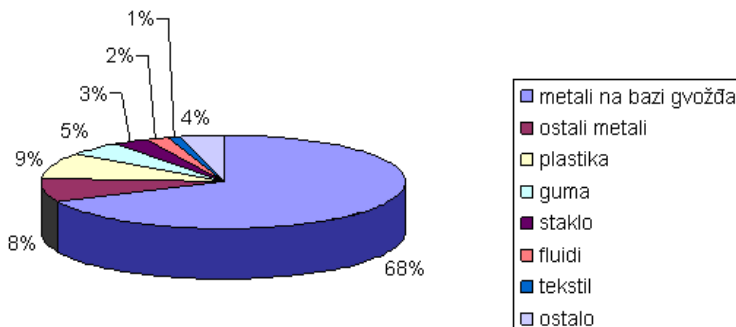
2.1. Osnovni sastavni elementi motornog vozila

Pod pojmom otpadno vozilo, prema literaturi [6], podrazumijevaju se vozila:

- *kategorije M1*—motorna vozila za prevoz putnika koja, osim sjedišta vozača, imaju još najviše osam sjedišta,
- *kategorije N1*—motorna vozila za prevoz tereta čija najveća dozvoljena masa nije veća od 3,5 t,
- *motorna vozila na tri točka* (osim motornih tricikala—vozila kategorije L5) koja su otpad po „Zakonu o otpadu“, što znači da ih vlasnik odbacuje.

Automobil je proizvod visoke složenosti za čiju se proizvodnju koristi više stotina različitih tehnologija i u koji se ugrađuje oko 15 hiljada različitih dijelova. Dijelovi automobila se proizvode od različitih materijala. Danas je u ukupnoj masi putničkog automobila dominantna zastupljenost livenog gvožđa i čelika, ali je i učešće drugih materijala respektabilno, pogotovo kada se uzme u obzir njihova komercijalna vrijednost.

Prosječan udio pojedinih vrsta materijala u ukupnoj masi prosječnog putničkog automobila je dat na slici 3.



Sl. 3. Udio pojedinih vrsta materijala u ukupnoj masi prosječnog putničkog automobila

U sastav putničkog automobila ulaze i radni fluidi pod kojima se podrazumijevaju sve tečnosti koje su sadržane u vozilu i služe za podmazivanje (ulja), tečnosti za hlađenje motora, tečnosti za kondicioniranje vazduha, ulja za kočenje, ulja za hidraulične prenosnike i dr.

Prije rastavljanja motornog vozila na komponente, vrši se odstaranjanje radnih fluida. U sabirna sredstva ispušta se motorno ulje, transmisiono ulje, kočiona tečnost, tečnost za hlađenje i zaštitu motora, tečnost za pranje stakla, zaostalo gorivo (benzin, dizel, tečni naftni gas i dr.), a potom se ovi fluidi skladište u propisno obilježene i uskladištene posude. Radni fluidi se dalje upućuju na preradu.

U tabeli 1. dat je prosječan sadržaj ostatka pogonskih tečnosti i sredstava za podmazivanje u starim putničkim vozilima.

Tabela 1. *Prosječan sadržaj ostatka pogonskih tečnosti i sredstava za podmazivanje u starim putničkim vozilima*

Radni fluid	Količina [l]
Motorno ulje	4
Ulje za mjenjače i diferencijale	0,5
Ulje za transmisiju	2,0
Pogonsko gorivo (benzin, dizel i dr.)	10,0
Tečnost za hlađenje i zaštitu motora	7,0
Kočiona tečnost	0,7
Tečnost za pranje stakla	3,0
Masti za podmazivanje	1,0

2.2. Proces reciklaže motornih vozila

Pri procesu proizvodnje, u toku eksploatacije, kao i po isteku životnog ciklusa vozila, stvara se otpad kojim se degradira životna sredina. Potencijal otpada motornih vozila je značajan, pa ga treba ponovo koristiti kao sekundarnu sirovinu. Izbor tehnologije za korišćenje otpada motornih vozila zavisi od mnogo faktora, a najvažniji su: cijena, količina, vrsta, kvalitet i lokacija gdje se nalazi otpad. Integralna i održiva reciklaža motornih vozila podrazumijeva primjenu principa održivog razvoja na cjelokupni životni ciklus motornog vozila, od razvoja i proizvodnje, pa do kraja njegovog životnog ciklusa, odnosno reciklaže. Ovakav model daje rješenja koja minimizuju količinu otpada kroz čitav životni ciklus motornog vozila, omogućavajući ponovnu upotrebu dijelova (motor, mjenjač i dr.), kao i potpunu reciklažu nekih materijala motornog vozila (fluidi, guma, plastika i dr.).

Svako vozilo može doživjeti kraj radnog vijeka na dva načina:

- prvi je kad se vozilo potpuno ošteti, što može biti rezultat nesreće, poplava, požara i dr;
- drugi je kad prirodnim putem dočeka kraj radnog vijeka [1].

Prilikom planiranja reciklaže starih motornih vozila mora se uzeti u obzir:

- dostignuti tehničko-tehnološki nivo reciklaže u ovoj oblasti, a posebno nemagnetičnih materijala i njihovo ponovno korišćenje;
- mogućnost korišćenja novih materijala pri proizvodnji novih vozila;
- mogućnost ponovnog korišćenja pojedinih materijala dobijenih reciklažom;
- način zbrinjavanja ostataka otpada nakon procesa reciklaže;
- organizacija sakupljanja starih motornih vozila i dr. [1].

Reciklaža vozila na kraju životnog ciklusa se obavlja hronološki, obično u šest ključnih faza:

- predaja vozila na reciklažu,
- odstranjivanje radnih fluida,
- rastavljanje vozila na komponente,
- sječenje,

- sortiranje i
- prerada [1].

Predaja starih motornih vozila na reciklažu obuhvata prijem i evidentiranje osnovnih podataka o vozilu. Osnovni podaci koje je potrebno evidentirati su vrsta, broj karoserije, snaga, godina proizvodnje i dr. Takođe, u ovoj fazi se vrši privremeno skladištenje i priprema vozila za naredne faze obrade (npr. pranje).

Prije rastavljanja motornog vozila na komponente, vrši se odstaranjivanje radnih fluida.

Nakon odstranjivanja radnih fluida slijedi rastavljanje vozila na komponente i dijelove kao što su akumulator, točkovi, pneumatici, motor, branici, radio-aparat, elektro prekidači, reduktor, alternator, plastični dijelovi i komponente, staklo i dr. Posebno se vodi računa pri demontaži komponenata koje sadrže opasne supstancije. Demontaža starih motornih vozila može se vršiti ručno, mehanički i djelimično automatskim postupcima. Obično se koriste sljedeći koncepti demontaže starih vozila:

- bez ograničenja na vrstu i model i
- sa ograničenjem za pojedine vrste i modele vozila.

Ukoliko se koristi koncept sa ograničenjem na vrstu i model vozila, može se primijeniti demontaža sa odgovarajućim stepenom automatizacije procesa.

Stara motorna vozila mogu se demontirati pojedinačno ili na pokretnoj traci. Demontaža na pokretnoj traci se može vršiti u postrojenjima koja su namijenjena za pojedine vrste i modele vozila.

U tabeli 2. dat je udio iskorišćenja korisnih komponenata pri reciklaži starih motornih vozila u Njemačkoj u 1997. i 2000. godini.

Tabela 2. Iskorišćenje korisnih komponenata pri reciklaži starih motornih vozila u Njemačkoj

Korisne komponente	% iskorišćenja	
	1997. god.	2000. god.
Čelik	100	100
Nemetalni materijali	85	90
Plastične mase (bez elastomera)	20	80
Guma	70	80
Elastomeri	20	50
Staklo	30	60
Ostale komponente	30	50

Nakon rastavljanja na komponente vrši se sječenje karoserije vozila. Pri sječenju nastaje nehomogen otpadni materijal koji je potrebno sortirati. Dijelovi od metala se odvajaju pomoću standardnih magneta, dok se odvajanje dijelova koji nisu od metala (plastika, staklo, pjena i dr.) vrši pneumatski.

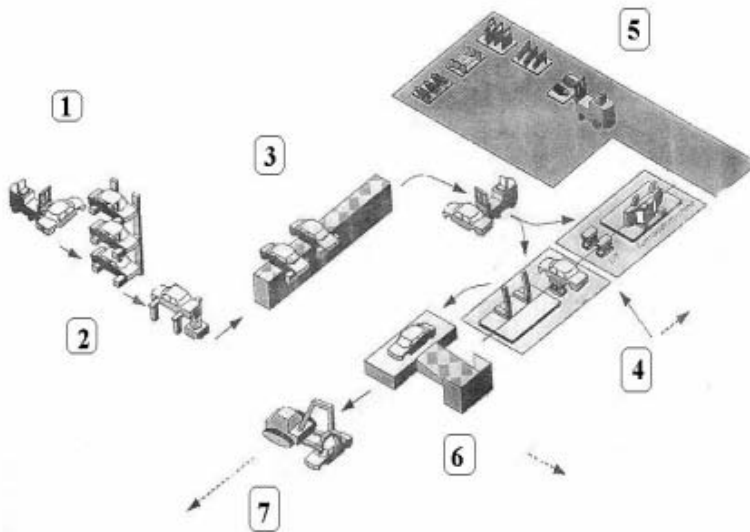
Posljednja faza reciklaže starih motornih vozila je prerada otpadnih materijala dobijenih procesom sječenja i sortiranja. Ovi materijali se recikliraju u industrijskim postrojenjima i nakon toga se ponovo koriste pri proizvodnji motornih vozila ili nekih drugih proizvoda.

3. TEHNOLOGIJE RECIKLAŽE AUTOMOBILA

Trenutno se primjenjuju dvije tehnologije reciklaže automobila, koje se razlikuju u samom načinu sortiranja materijala koji sačinjavaju automobil. Prva tehnologija se zasniva na optičkoj separaciji, dok druga tehnologija koristi kombinaciju više metoda (usitnjavanje, gravitacijske i specijalne metode separacije).

3.1 Metoda optičke separacije

Ova tehnologija se zasniva na tome da se optičkom metodom, tj. ručno, odvajaju sastavni dijelovi automobila (guma, staklo, plastika i dr.), a metalni dijelovi ostaju na kraju. Zatim, metalni dijelovi odlaze u presu radi smanjenja zapremine i lakšeg daljeg transporta. Svi dobijeni dijelovi predstavljaju gotove proizvode metode optičke (ručne) separacije i kao takvi odlaze na dalju preradu. Automobili se transportuju do prihvatnog skladišta (1), zatim se transportuju do mjesta (2) gdje se vrši tretman goriva, guma i akumulatora. Gorivo se skladišti u rezervoarima i dalje nalazi primjenu kao energent, a akumulatori i guma idu na dalju preradu. Dalje, automobil se transportuje do platforme (3) za istakanje ulja i ostalih fluida, koji se uz odgovarajući oprez i smještaj dalje transportuju do postrojenja za preradu istih. Zatim, automobil se transportuje do platforme (4) gdje se vrši demontaža korisnih dijelova (dijelovi koji se koriste kao rezervni dijelovi) i koji se skladište u hangaru (5). Ostatak automobila ide do platforme (6) na kojoj se vrši demontaža nemetalnih dijelova (plastika, staklo, koža, tekstil, drvo i dr.), kao što je prikazano na slici 4.



Sl. 4. Postrojenje za optičku (ručnu) separaciju automobila [2]

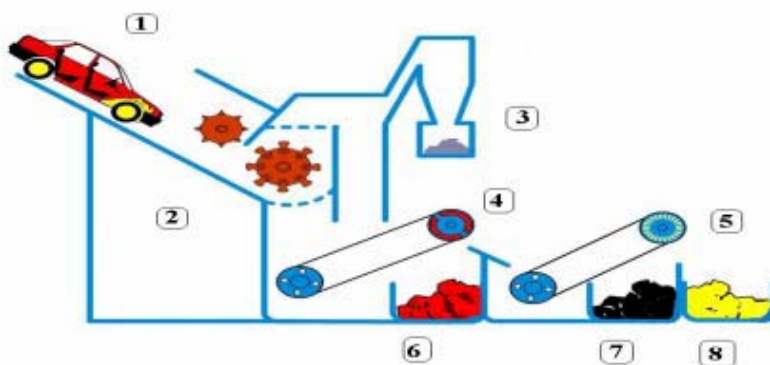
3.2 Kombinovana metoda separacije

Ova tehnologija se zasniva na tome da se cijeli automobil usitnjava u specijalnim drobilicama, a zatim se dobijeni proizvod usitnjavanja dalje tretira nekom od poznatih metoda separacije (gravitacijske ili specijalne metode).

Dobijeni proizvodi predstavljaju gotove proizvode kombinovane metode separacije i kao takvi odlaze na dalju preradu.

Automobil se doprema do mjesta (1) gdje se vrši ispuštanje svih fluida i demontaža akumulatora i guma prije drobljenja. Proces se nastavlja u drobilici (2) gdje se vrši drobljenje cijelog automobila. Postrojenje za drobljenje posjeduje i sistem za otprašivanje (3). Izdrobljeni materijal dalje odlazi u prvi stepen separacije (magnetni separator, poz.4), iz kog se kao proizvod dobija gvožđe (6). Ostatak odlazi na drugi stepen separacije (električni separator, poz. 5), gdje se vrši odvajanje nemetala (7) od ostatka obojenih metala (8). Dalje je moguće nemetale i obojene metale razvrstati u jednorodne materijale. To se može postići kombinacijom gravitacijskih i specijalnih (magnetne, električne i optičke) metoda separacije.

Na slici 5. prikazan je postupak kombinovane separacije putničkih automobila.



Sl. 5. Shematski prikaz dijela postrojenja kombinovane metode separacije [2]

4. PROCES RECIKLAŽE U ŠREDER POSTROJENJU

Postrojenje Šreder u fizičkom smislu čini postrojenje sastavljeno od uređaja i instalacija u kojima se vrši usitnjavanje specijalnog komadastog otpada, kao i prateći sadržaj (pomoćni objekti i prostor koji omogućavaju nesmetano funkcionisanje tehnološkog sistema). Oprema i instalacije postrojenja najčešće se postavljaju na otvorenom prostoru. Maksimalna debljina materijala koji se može reciklirati u Šreder postrojenju je 2 mm za metalne limove, 5 mm za čelične limove i 10 mm za okrugle dijelove. Postrojenje Šreder je namijenjeno da u jednom hodu usitnjava:

- spljeskane i nespljeskane kompletne autokaroserije (sa motorom, mjenjačem, osovinama, oprugama, točkovima i tapacirunzima),
- otpad iz domaćinstva (šporeti, peći, mašine za pranje),
- laki sakupljački otpad (maksimalne debljine 3 mm) i
- amortizacioni otpad industrijskog tipa.

Materijal koji se obrađuje u Šreder postrojenju mora biti oslobođen od:

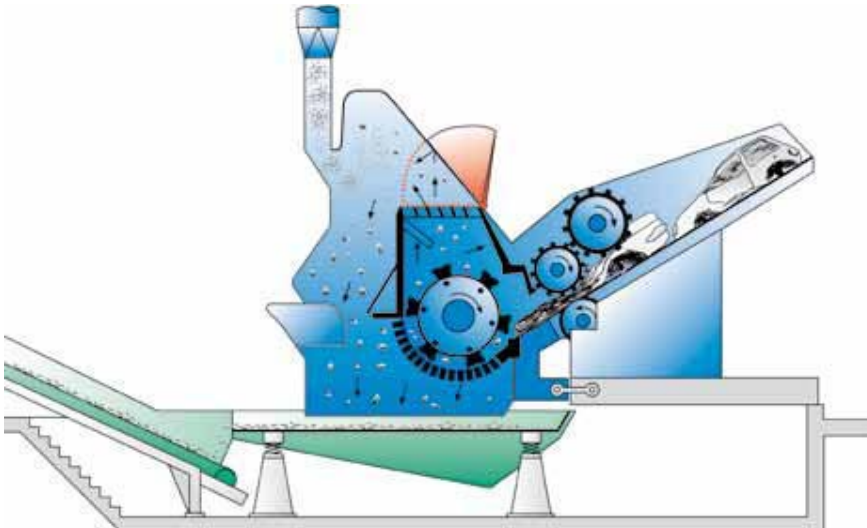
- eksplozivnih,
- zapaljivih,
- otrovnih i
- nagrizajućih tečnosti, gasova i prašina.

Usitnjavanje motornih vozila može se vršiti isključivo kada su iz njih prethodno odstranjeni:

- stakla,
- akumulator,
- elektronika i električni kablovi,
- gume,
- plastični korpusni dijelovi (branici),
- rezervoar za gas,
- klima uređaj i
- otpadna ulja koja se nalaze u sljedećim sklopovima automobila (mjenjač, amortizeri, kočnice, motor vozila i servo uređaj) [3].

Nakon toga se automobili obrađuju u Šreder postrojenju, bilo da se prethodno sabijaju na manju zapreminu ili u originalnoj veličini i obliku.

Na slici 6. je dat shematski prikaz Šreder postrojenja.



Sl. 6. Shematski prikaz Šreder postrojenja [3]

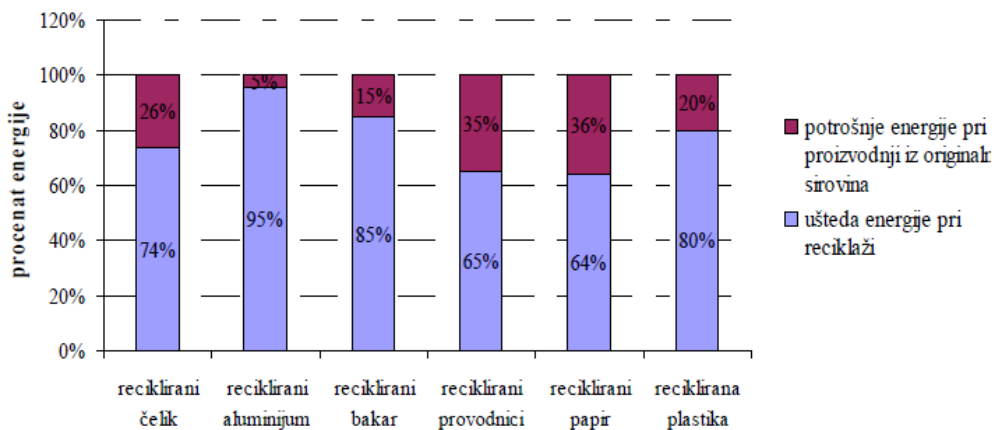
5. EKONOMSKA STUDIJA I UŠTEDA ENERGIJE U PROCESU RECIKLAŽE

Automobilski otpad, pored elektronskog otpada, spada u najkompleksnije otpade, i to zbog svog sastava u koji ulazi veliki broj različitih materijala kao što su: metali, plastika, guma, staklo, itd. Samim tim je za njegovu reciklažu potrebno primijeniti kompleksnu shemu u cilju separacije ovih različitih materijala. Prema dostupnim podacima, u Americi se odbaci 15 miliona automobila i kamiona svake godine. Dobro je to što se 75% materijala iz ovih vozila reciklira, ali ipak ostaje 25 % materijala koji se odbacuje.

Prosječan putnički automobil sadrži oko 250 kg čelika, 140 kg aluminijuma, 15 kg bakra i oko 80 kg plastike.

Za dobijanje 1 kg čelika iz rude gvožđa treba angažovati 40.000 kJ energije, a za čelik iz reciklaže 18.100 kJ što je više nego dva puta manje. Za dobijanje 1 kg aluminijuma iz rude treba angažovati 190.000 kJ, a iz reciklaže 26.700 kJ što je oko 7 puta manje.

Na slici 7. dat je prikaz poređenja uštede u energiji dobijene reciklažom i energije koja se potroši u primarnoj proizvodnji. Ukoliko se vrši poređenje sa sačuvanom energijom u odnosu na primarnu proizvodnju, dobijaju se sljedeći rezultati, odnosno efekti uštede reciklažom sljedećih komponenata: čelik 74%, aluminijum 95%, bakar 85%, provodnici 65%, papir 64% i plastika 80%.



Sl. 7 Grafički prikaz poređenja uštede u energiji dobijene reciklažom i energije koja se potroši u primarnoj proizvodnji [1]

Podaci dovode do zaključka da sekundarna proizvodnja emituje manje zagađenja nego primarna, što je od izuzetnog značaja posmatrano sa ekološkog aspekta. Kada se radi o gvožđu i aluminijumu, reciklaža dijelova od ovih materijala ima ogroman značaj u uštedi sirovina vrednijih metala u koje se ubrajaju čelik, nerđajući čelik, bakar, aluminijum, provodnici, stroncijum, cink, ali i najskuplje supstance kao što su zlato i platina, koje se inače izdvajaju specijalizovanom preradom elektronske opreme, uključujući kompjutersku opremu u automobilima.

Zahvaljujući primjeni reciklaže u automobilskoj industriji, smanjuje se zavisnost svjetskog tržišta od stvarnih rezervi metala.

6. ZAKLJUČAK

Automobilska industrija je doživjela veliku ekspanziju krajem prošlog i početkom ovog vijeka. Jedan od glavnih nosilaca privrednog razvoja svake zemlje je automobilska industrija. Pri projektovanju i izradi novih automobila, pored tehničko-tehnoloških parametara, mora se obratiti pažnja i na aspekte koji se odnose na zaštitu životne sredine. Posebna pažnja se poklanja smanjenju emisije izduvnih gasova, tipizaciji pojedinih elemenata motornog vozila u cilju jednostavnije montaže i demontaže za potrebe reciklaže, odnosno ponovne upotrebe pojedinih dijelova.

U cilju eliminisanja negativnih uticaja motornih vozila, prije svega na životnu sredinu, potrebno je sprovesti postupke navedene u radu za reciklažu motornih vozila na kraju životnog ciklusa. Postupci podrazumijevaju reciklažu svih komponenata koje nastaju duž cjelokupnog životnog ciklusa motornog vozila. Primjena tih postupaka višestruko unapređuje mnoge indikatore životne sredine, nauke i tehnologije, ekonomije, a time i unapređuje kvalitet cjelokupnog života ljudi. Na ovaj način se stvaraju realni uslovi za visok kvalitet života budućih generacija i to kroz očuvanje prirodnih resursa i unapređenje životne sredine na regionalnom i globalnom nivou.

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RAZVOJ I PERSPEKTIVE NOVIH HIDROENERGETSKIH SISTEMA U REPUBLICI SRPSKOJ

Vladimir Gojković¹, Ranka Gojković²

Rezime: Zbog prirodnih karakteristika Republika Srpska se svrstava u oblasti bogatije hidroenergetskim potencijalom. Procijenjeni hidroenergetski potencijal u Republici Srpskoj iznosi oko 10 000 GWh godišnje od čega je neiskorišćeno gotovo 70 %. RS u postojećim objektima proizvodi od 5200 do 5500 GWh godišnje od čega u hidroelektranama proizvodi oko 45 %. U RS se planira izgradnja velikog broja hidroelektrana i njihovom izgradnjom RS bi trajno stabilizovala svoj energetska sistem i postala bi značajan faktor u regionu. U ovom radu je izvršen pregled hidroenergetskog potencijala Republike Srpske i dati su podaci o postojećim i planiranim hidroelektranama.

Ključne riječi: hidroenergija, hidroenergetski potencijal, Republika Srpska i nove hidroelektrane.

DEVELOPMENT AND PROSPECT OF NEW HYDROPOWER SYSTEM IN THE REPUBLIC OF SRPSKA

Abstract: Due to the natural characteristics, Republic of Srpska is among the wealthier areas hydropower potential. The estimated hydropower potential of the Republic of Srpska is about 10 000 GWh per year of which almost 70 % unused. RS produces in existing buildings by 5200 to 5500 GWh per year, of which hydroelectric plants produce in about 45 %. Republic of Srpska is planning to build a large number of plants and their construction would permanently stabilize their own energy system and would become an important factor in region. In this paper you have been given an overview of hydropower potential and information of existing and planned hydroelectric plants.

Keywords: hydro energy, hydropower potential, Republic of Srpska, new hydroelectric plants.

1. UVOD

Hidroenergija je jedan od najznačajnijih izvora energije prije svega zbog toga što je ona jedini obnovljivi izvor energije kod kojeg se transformacija u korisniji oblik vrši konvencionalnim elektranama. Eksploatacijom hidroenergije dobija se jeftina i ekološki čista električna energija. Hidroelektrane kumulativno gledano emituju manje od svih elektrana štetne gasove u atmosferu (13,5-60 grama CO₂ po kilovatu), imaju

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najveći stepen transformacije energije (95%) i period energetske amortizacije je relativno kratak (oko godinu dana). Mana im je nestalno snabdijevanje (zavisi od padavina) ali to se može ublažiti izgradnjom akumulacija. [1]

Republika Srpska je bogata hidroenergijom i njen potencijal je uglavnom neiskorišćen. U planu je realizacija velikog broja hidroelektrana za koje su već izrađene projektne dokumentacije. Energija dobijena iz ovih planiranih hidroelektrana biće namjenjena izvozu i u toj činjenici leži ogroman investicioni potencijal.

2. HIDROENERGETSKI POTENCIJAL REPUBLIKE SRPSKE

Prema strategiji razvoja elektroprivrede Republike Srpske tehnički iskoristiv potencijal iznosi (tabela 1):

- Ukupan tehnički iskoristiv potencijal koji pripada RS-oj sa graničnim rjekama iznosi 13 505 GWh/god.,
- Tehnički iskoristiv potencijal koji pripada RS-oj iznosi 10 027 GWh/god.,
- Iskorišćeni hidropotencijal RS je 2985,8 GWh/god.,
- Preostali neiskorišćeni hidropotencijal je 7041, 2 GWh/god. [2]

Tabela 1: Prikaz tehnički iskoristivog hidropotencijala koji pripada Republici Srpskoj [2]

Sliv	Instalisana snaga			Prosječna godišnja proizvodnja		
	>10 MW	<10MW	Ukupno (MW)	>10 MW	<10MW	GWh
Drina	1087,12	154,18	1241,3	3971,86	688,14	4660
Vrbas	303,01	86,1	389,11	1386,62	338,27	1724,9
Trebišnjica	725,4	8	733,4	2535,7	14,6	2550,3
Una i Sana	48,96	7	55,96	224,24	45	269,24
Neretva	38,08	-	38,08	94,16	-	94,16
Bosna	113,84	42,18	156,02	529,08	199,8	728,88
UKUPNO	2316,41	297,46	2613,87	8741,66	1285,81	10027,5

Kao što se vidi sa tabele najveći dio neiskorišćenog potencijala (92%) pripada planiranim hidroenergetskim objektima sa instalisanom snagom većom od 10 MW a taj odnos kod iskorišćenog potencijala je veći od 97 %.

Najveći dio hidroenergetskog potencijala se nalazi u slivu rijeke Drine (4600 GWh/god), zatim u slivu rijeke Vrbas (1725 GWh/god) i u slivu rijeke Trebišnjice (2550 GWh/god).

Karakteristično je da nijedan od šest slivova ne pripada u cjelosti Republici Srpskoj. Srednja i Donja Drina sem Republici Srpskoj pripadaju i Srbiji, a u hidrosistemu Trebišnjica koriste se vode sliva Neretve koji najvećim dijelom pripada Federaciji BiH. Slivovi rjeka Vrbas i Bosne pripadaju RS i FBiH a sliv Une i Sane

pripada RS i Hrvatskoj. Ova činjenica znatno otežava realizaciju hidroenergetskog rješenja na ovim slivovima.

3. POSTOJEĆI HIDROENERGETSKI SISTEMI U REPUBLICI SRPSKOJ

Najveći dio proizvodnje ostvaruje se u hidroelektranama na Trebišnjici i u hidroelektrani Višegrad. Ovi sistemi proizvode do 90 % ukupne električne energije dobijene iz hidroelektrana a ostatak se proizvodi u HE Bočac i u malim hidroelektranama. Podaci o postojećim hidroelektranama dati su u tabeli 2.

Tabela 2: Postojeće HE u Republici Srpskoj i HE koje koriste vode hidrosistema na Trebišnjici [1].

HE	Rijeka	Tip elektrane	Korisna zaprem. mil/m ³	Max. bruto pad m.	Srednji protok m ³ /s	Sred. god. proizvod. GWh	Instal. snaga elekt. MW
Trebinje I	Trebišnjica	akum.	1082,3	104,15	71	480	3 x 60
Trebinje II	Trebišnjica	akum.	9,3	22	82,9	12,5	8
Dubrovnik	Trebišnjica	akum.	9,3	295	82,9	1391,1	2 x 108
Čapljina	Trebišnjica	reverz.	6,5	227	28,9	451	2 x 220
Višegrad	Drina	pribr.	101	48,16	342	1038	3 x 105
Bočac	Vrbas	pribr.	42,9	54,13	78,4	307,5	2 x 55
Vlasenica	Jadar	protočna	0.10	165.7	0.7	6.9	2 x 0.45
Bogatići	Željeznica	protočna	0.45	165	5.5	33.0	2 x 4
Mesići	Prača	protočna	0.05	53	8.0	16	2 x 1.54
Tišća	Tišća	protočna	-	165	0,75	6,3	2 x 1.06
Štrpci		Protočna	-	98	-	0.25	1x0.06

Prema sporazumu sa HEP-om 78% proizvedene električne energije u HE Trebinje i HE Dubrovnik pripada ERS a 22% HEP-u, a za RHE Čapljina nije definisana raspodjela. [3]

4. RAZVOJ NOVIH HIDROENERGETSKIH SISTEMA U REPUBLICI SRPSKOJ

U Republici Srpskoj se planira izgradnja velikog broja hidroelektrana za koje su u većoj ili manjoj mjeri razrađeni idejni projekti i pripremljene dokumentacije. Projekti većine planiranih hidroelektrana su izrađeni 70-ih i 80-ih godina prošlog vijeka i ovi projekti su zbog više razloga više puta revidirani, naprimjer hidroelektrana Buk Bijela je po starom projektu bila predviđena kao hidroelektrana sa instalisanom snagom od 450 MW i godišnje proizvodnje u iznosu 1150 GWh/god, ali zbog odbijanja Crne Gore da učestvuje na ovom projektu, projekat je izmijenjen i po njemu se predviđa izgradnja hidroelektrane sa instalisanom snagom od 114,16 MW i godišnje proizvodnje od 370 GWh/god. [1].

Od svih prijekata posebno se ističu hidroenergetski sistem Drina koji se sastoji od tri podsistema: Donja, Srednja i Gornja Drina i hidroenergetski sistem Trebišnjica koji se sastoji od dva podsistema: Gornji i Donji Horizonti. U podsystemu Donji

Horizonti preostala je samo realizacija hidroelektrane Dubrovnik II.

U tabeli 3 dat je prikaz planiranih većih hidroelektrana i sistema na rijekama Republike Srpske.

Tabela 3: Prikaz planiranih većih hidroelektrana i sistema na rijekama RS [2]

Red. br.	HE	Rijeka	Tip postr.	Instal. protok	Kota normal. Uspora	Instal. snaga.	God. proizv. Energije
1.	Buk Bijela	Drina	prib.	450,00	433,6	114,6	369,4
2.	Foča	Drina	prib.	450,00	402,0	51,7	183,62
3.	Sutjeska	Sutjeska	deriv.	50,00	527,0	35,0	90,19
4.	Paunci	Drina	prib.	450,00	384,0	36,6	154,12
5.	Rogačica*	Drina	prib.	800,00	224,0	140,0	538,1
6.	Srednje Tergare*	Drina	prib.	800,00	200,0	126,0	475,0
7.	Mala Dubravica*	Drina	prib.	800,00	175,0	122,0	434,0
8.	Kozluk*	Drina	protoč.	800,00	135,0	93,4	396,5
9.	Drina I*	Drina	protoč.	800,00	121,0	93,4	396,5
10.	Drina II*	Drina	protoč.	800,00	107,0	93,4	396,5
11.	Drina III*	Drina	protoč.	800,00	93,0	93,4	396,5
12.	Mrsovo	Lim	prib.	220,00	358	43,8	165,1
13.	Vikoč	Čehotina	prib.	45,00	574,0	33,0	121,4
14.	Sistem Cijevna	Bosna	prib.	-	-	90,4	438,2
15.	Krupa	Vrbas	prib.	240,00	228,0	48,5	140,1
16.	Banja Luka niska	Vrbas	prib.	150,00	204,0	37,2	186,94
17.	Novoselija	Vrbas	prib.	155,00	174,6	16,4	69,98
18.	Trn	Vrbas	prib.	160,00	146,0	24,01	139,9
19.	Laktaši	Vrbas	prib.	160,00	133,0	16,18	95,2
20.	Kosjerevo	Vrbas	prib.	160,00	120,0	13,3	102,00
21.	Razboj	Vrbas	prib.	160,00	107,0	16,87	102,10
22.	Nevesinje	Trebišnjica	deriv.	55,0	970,0	60,0	100,6
23.	Dabar	Trebišnjica	deriv.	55,0	836,0	160,0	270,6
24.	Bileća	Trebišnjica	deriv.	60,0	465,6	36,0	117,0
25.	Dubrovnik II*	Trebišnjica	deriv.	90,0	295,0	304,0	318,4
26.	HE Kostajnica*	Una	prib.	300,00	116,0	20	110,4
27.	HE Ključ**	Sana	deriv.	64,0	323,5	48,7	114,3
28.	HE Nedavić/Ulog	Neretva	deriv.	35,0	641,0	32,8	75,0

*Republici Srpskoj pripada 50%.

**Republici Srpskoj pripada 80 %.

Male hidroelektrane u Republici Srpskoj

Male HE su hidroelektrane sa instalisanom snagom do 25 MW, a u većini zemalja ta granica je 10 MW. Male HE proizvode oko 2 % električne energije u svijetu (najviše od svih tzv. novih obnovljivih). [4]

U Republici Srpskoj postoji značajan hidropotencijal za male hidroelektrane, ali zbog nedovoljne istraženosti teško je dati tačnu procjenu potencijala malih hidroelektrana. Prema istraživanjima koja su sprovedena 80-ih godina definisano je oko 120 lokacija za izgradnju malih hidroelektrana ukupne instalisane snage 340 MW i prosječne godišnje proizvodnje 1500 GWh. Vlada Republike Srpske je do 2009 g. dala koncesije za izgradnju 107 malih hidroelektrana ukupne instalisane snage 280 MW i prosječne godišnje proizvodnje 1400 GWh. Koncesije su dodjeljene na svim slivovima a najviše na slivu rjeke Drine (52 MHE), zatim na Vrbasu (38 MHE), pa na slivu Bosne (11 MHE). Uzimajući u obzir snagu od ukupnog broja dodjeljenih koncesija: [5]

- 35 su male hidroelektrane snage do 1 MW
- 24 su snage od 1 do 2 MW,
- 36 su snage od 2 do 5 MW,
- 5 su snage od 5 do 10 MW i
- 6 malih hidroelektrana je snage veće od 10 MW.

Na slici 1. prikazani su planirani i postojeći HE sistemi na prostoru RS.



Sl. 1 Planirani i postojeći HE sistemi na području Republike Srpske [2].

5. ANALIZA RAZVOJA NOVIH HIDROENERGETSKIH SISTEMA U REPUBLICI SRPSKOJ

Iz prethodnih poglavlja se vidi da Republika Srpska posjeduje ogroman hidroenergetski potencijal koji je u najvećoj mjeri neiskorišćen. Za iskorišćavanje ovog potencijala planiran je veliki broj malih i velikih hidroelektrana za koje su u većoj i manjoj mjeri razrađeni idejni projekti. Dobijena električna energija iz ovih hidroelektrana bi bila namjenjena izvozu. Razvijene zemlje svijeta teže ka tome da smanje emisiju štetnih gasova tj. da povećaju udio obnovljivih izvora energije u cjelokupnoj potrošnji. U ovim činjenicama leži ogroman investicioni potencijal u nove hidroenergetske sisteme u RS. Naprimjer, njemački konzorcijum RWE će obezbijediti novac za izgradnju hidroelektrana na Gornjoj Drini a zauzvrat će dobijati 60 % proizvedene električne energije [6]. Na ovaj način mogu se realizovati i ostali hidroenergetski sistemi.

Treba naglasiti da će u skorijoj budućnosti veliki broj trenutno ekonomski neisplativih hidroelektrana postati rentabilan, prije svega zbog toga što u posljednje vrijeme sve više tehnički iskoristivog hidropotencijala prelazi u ekonomski isplativ hidropotencijal, čak se može reći da će doći do izjednačavanja ova dva pojma.

Analiza razvoja velikih hidroelektrana na području Republike Srpske

Do sada su razrađeni idejni projekti za oko tridesetak srednjih i velikih hidroelektrana (tabela 3) i u većini tih projekata, pošto su izrađeni 70-ih i 80-ih godina prošlog vijeka, nisu uzimani u obzir sociološki i ekološki parametri i ti dodatni faktori uveliko utiču na rentabilnost tih hidroelektrana.

Od svih HE najrentabilnije su hidroelektrane na slivu Drine (tabela 3) zbog sljedećih činjenica:

- potencijalna godišnja proizvodnja ovih HE bi bila oko 4000 GWh od čega bi oko 2500 GWh pripalo Republici Srpskoj,
- uticaj ovih HE na okolinu je zanemarljiv i područje koje bi bilo potopljeno je pretežno nenaseljeno pa je eksproprijacija jeftina i jednostavna,
- ove HE se nalaze na slabo razvijenom području gdje postoji velika potreba za novim radnim mjestima,
- za realizaciju hidroelektrana na Srednjoj i Gornjoj Drini već su pronađeni strateški partneri.

Zbog ovih činjenica očekuje se njihova izgradnja u skorijoj budućnosti.

U slivu rijeke Trebišnjice planira se izgradnja četiri hidroelektrane i to HE Dabar, HE Nevesinje, HE Bileća i HE Dubrovnik II (tabela 3). Izgradnja ovih hidroelektrana je isplativa ne samo zbog dobijanja jeftine električne energije već i zbog toga što bi se njihovom izgradnjom riješio problem vodosnabdijevanja Hercegovine i omogućilo bi se snabdijevanje kraških polja i time bi se pospješio razvoj poljoprivrede. Ovaj sistem je zbog svoje multifunkcionalnosti ima veliki značaj za južni dio RS i zbog toga mora imati apsolutni prioritet u strategijama razvoja.

Realizacija hidroelektrana na slivu Vrbasa je dosta komplikovanija prije svega zbog toga što je ovo područje gusto naseljeno pa je eksproprijacija relativno skupa. U centru ove regije nalazi se grad Banja Luka i veliki broj manjih naselja oko ovog grada i zbog toga hidroelektrane koje su nizvodno od ovog grada (HE Trn, HE Laktaši, HE

Kosjerevo i HE Razboj) su ekonomski neisplative za razliku od hidroelektrana uzvodno od ovog grada.

Hidroelektrane na ostalim slivovima u Republici Srpskoj (Una, Sana, Neretva i Bosna), su rentabilne ali ne očekuje se njihova realizacija u skorije vrijeme sem HE Ulog prije svega što sad prioritet imaju hidrositemi na Drini i na Trebišnjici. Pošto su u pitanju srednje velike hidroelektrane, one nemaju negativan uticaj na okolinu.

Dakle, ako se nastavi ovakvim tempom razvoja u skorijoj budućnosti će se realizovati veliki broj većih hidroelektrana i to:

- HE Buk Bijela i HE Foča (Gornja Drina)
- HE Nevesinje, HE Dabar i HE Bileća (Gornji Horizonti-Trebišnjica)
- HE Ulog (Neretva)

Ovi objekti po planu će biti završeni do 2020 godine.

U periodu do 2030 godine trebalo bi da će u pogon biti puštene sljedeće HE:

- HE Sutjeska i HE Paunci (Gornja Drina)
- HE na Srednjoj i Donjoj Drini
- HE Mrsovo (Lim)
- HE Krupa i HE Banja Luka niska (Vrbas)
- HE Dubrovnik II

Izgradnjom ovih hidroelektrana Republika Srpska bi bila značajan energetska faktor u regionu i bila bi među rijetkim zemljama u svijetu koje većinu električne energije dobijaju iz hidroelektrana.

Analiza razvoja malih hidroelektrana na području Republike Srpske

Iako je do Vlada Republike Srpske dala veliki broj koncesija za izgradnju malih hidroelektrana, do sada je realizovano samo nekoliko malih hidroelektrana prije svega zbog: neadekvatnih hidroloških podataka i tehničkih rješenja, nepostojanja prostorno planske dokumentacije i adekvatne prenosne mreže i male cijene električne energije. Ali uprkos tome realno je očekivati realizaciju većeg broja tih hidroelektrana do 2020 godine što će u najvećoj mjeri zavisiti od restrikcija koje će se postaviti sa stanovišta zaštite okoline ali od toga koliko će brzo i efikasno nadležne institucije izdavati potrebne dozvole i saglasnosti. U smislu poboljšanja situacije u vezi sa zakonskim procedurama za male hidroelektrane a i time za olakšano investiranje u takve projekte potreban je viši nivo podrške Vlade RS. Da bi došlo do realizacije malih hidroelektrana neophodno je uvesti i set podsticajnih mjera za investiranje u takve projekte kao naprimjer neophodno je garantovati otkupnu cijenu dobijene električne energije od malih hidroelektrana s kojom će njihova realizacija biti ekonomski isplativa.

Ako se uklone navedene barijere i pod uslovom aktivnog učešća Vlade RS do 2020 Republika Srpska će iz malih hidroelektrana dobijati oko 1200 GWh ekološki čiste električne energije.

Na kraju treba naglasiti da energetska potencijal za snage ispod 0,5 MW (mikro i mini hidroelektrane) još nije istražen na području Republike Srpske, pa dakle postoji i dodatni potencijal za mikro i mini hidroelektrane čiji ukupni iznos u ovom trenutku nije moguće procijeniti.

6. ZAKLJUČAK

Republika Srpska je zahvaljujući svojim prirodnim karakteristikama bogata hidroenergijom. Bruto tehnički iskoristiv hidropotencijal koji pripada RS-uj iznosi 10 000 GWh godišnje od čega je iskorišćeno manje od 30 %. Zahvaljujući tome elektroenergetski sektor RS ima blistavu perspektivu i on će predstavljati ključni oslonac njenog razvoja. Posebna prednost je to što se većina planiranih hidroelektrana nalazi na demografski ugroženim i privredno nerazvijenim ruralnim dijelu RS gdje su investicije preko potrebne. Realizacijom planiranih hidroenergetskih rješenja u narednom periodu ostvariće se tehnološki razvoj, jačanje domaćih kompanija, porast ulaganja i povećanje konkurentnosti privrede Republike Srpske. Do 2030 godine biće pušten u pogon veliki broj hidroelektrana i umjesto sadašnjih 2500 proizvođiće preko 7000 GWh. Kada bi Republika Srpska iskoristila sav tehnički iskoristiv potencijal proizvođila bi toliko energije da bi i bez termoelektrana mogla da namiri potrebe domaćeg konzuma i da postane značajan energetski faktor u regionu.

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SISTEM ZA PROIZVODNJU VJEŠTAČKOG SNIJEGA NA JAHORINI

Vladimir Gluhović¹, Marko Šolaja²

Rezime: Globalne promjene klime donijele su velike probleme u zimske turističke centre. Osnovni problem je veliki nedostatak snijega na stazama. Da bi se uspješno dočekala skijaška sezona, neophodno je imati sisteme za proizvodnju vještačkog snijega. Sistem vještačkog osnježavanja koji posjeduje OC "Jahorina" je proizvod italijanske firme Snowstar, i postavljen je na stazi "Skočine", zbog položaja staze, i najmanje nadmorske visine, pa je uvijek bio prisutan nedostatak snijega, prije instalacije sistema. U ovom radu je predstavljen sistem vještačkog osnježavanja, koji je umnogome poboljšao uslove za skijanje na planini

Ključne riječi: Vještački snijeg, kompresori, pumpe, akumulacija, senzori

SNOWMAKING SYSTEM ON MOUNTINE JAHORINA

Abstract: Global climate changes have brought major problems in the winter tourist centers. The main problem is a lack of snow on the ski-track. To successfully met the ski season, it is necessary to have systems for the production of artificial snow. System of artificial snow that has OC "Jahorina" is a product of the Italian company Snowstar, and is set to the track "Skočine", due to its path, and at least above sea level, and has always been a lack of snow, before installing the system. In this work a system of artificial snowmaking, which has greatly improved conditions for skiing on the mountain

1. UVOD

Sistem vještačkog osnježavanja na Jahorini je proizvod italijanske firme Snowstar, U ovom radu je predstavljen sistem vještačkog osnježavanja, koji je umnogome poboljšao uslove za skijanje na planini. Sistem se sastoji iz dvije crpne stanice, akumulacije vode, potrebne za proizvodnju vještačkog snijega, sistema za razvodjenje vode i vazduha do topova za proizvodnju snijega. U sklopu sistema osnježavanja na Jahorini postoje tri vrste topova za proizvodnju snijega, Street, Taurus i Super Cristal. Bitan element sistema, je i senzorski sistem zahvaljujući kome se dobijaju informacije o trenutnim vremenskim prilikama na svakom pojedinom topu. Da bi sistem funkcionisao potrebno je da se steknu određeni vremenski uslovi. Za kontrolu kompletnog sistema osnježavanja zadužen je sistem automatskog upravljanja, kojim se upravlja preko specijalnog softvera.

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2. DIJELOVI SISTEMA ZA PROIZVODNJU VJEŠTAČKOG SNIJEGA

Sistem za proizvodnju vještačkog snijega u suštini se sastoji od:

- Vodozahvata (akumulacije)
- Dvije pumpne stanice
- Sistema za pravljenje snijega

2.1. Vodozahvat

Uloga vodozahvata ja da isporuči vodu crpnoj stanici. Isporučka vode se vrši korišćenjem gravitacije ili pomoću pumpi. Postoji više vrsta akumulacija iz kojih se voda distribuira pumpnim stanicama:

- Jezero (vještačko ili prirodno)
- Rijeka
- Spremište (tank)

U sistemu vještačkog osnježavanja sistema na Jahorini, postoje dvije vrste vodozahvata: sa potoka i vještačko jezero koje se nalazi u centralnom dijelu staze »Skočine«.



Sl.1 Vještačko jezero sistema osnježavanja na Jahorini [1]

Da bi se spriječilo da se voda zaledi na ekstremno niskim temperaturama koje vladaju na planini u zimskom periodu, postoji sistem za pravljenje mjehurića vazduha u jezeru, koji sprečavaju da se voda zaledi.



Sl.2 Cijevi za ispuštanje mjehurića [1]



Sl.3 Kompresor za proizvodnju mjehurića [1]

2.2. Pumpne stanice

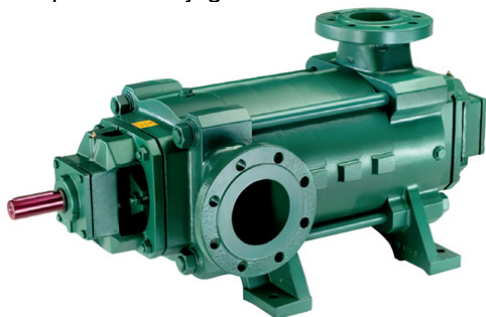
Pumpne stanice predstavljaju srce sistema za proizvodnju vještačkog snijega. U crpnim stanicama su instalirani kompresori za vazduh, pumpe koje pumpaju vodu kroz sistem do topova za proizvodnju snijega, i sistem automatskog upravljanja. Sistem osnježavanja na Jahorini ima dvije crpne stanice.



Sl.4 Kompresor BOGE S serija kompresora [1]

Kompresori u pumpnoj stanici šalju vazduh pod pritiskom kroz pneumatske vodove do topova za snijeg. BOGE kompresori su vijčani kompresori. Sustavljeni su od tri jasno određena sekcije. Elektronski dio, motora sekcija, sekcija za servisiranje kompresora i autonomni ventilator / hladnjak sekcija.

U svakoj pumpnoj stanici postoje po dvije vijčane pumpe koje pogoni elektromotor, koje pumpaju vodu iz vodozahvata i hidrauličnim vodovima je dostavljaju do topova za snijeg.



Sl.5 Vijčana pumpa [1]



Sl. 6 Sklop vijčane pumpe i elektromotora [1]

U pumpnim stanicama se nalazi i kompletna elektro oprema koja služi za napajanje sistema kao i komponente upravljačkog sistema.



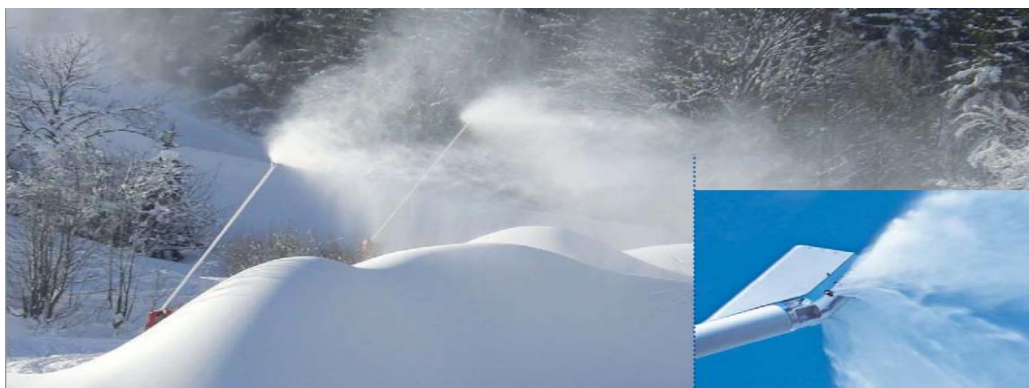
Sl.7 Elektro ormar sa opremom za napajanje sistema i upravljačkom opremom [1]

2.3. Topovi za snijeg

Zadnju stanicu sistema za proizvodnju vještačkog snijega čine topovi za snijeg. U sistemu za osnježavanje na jahorini postoje 3 vrste topova za snijeg, zavisno od mjesta na koje se postavljaju: Street, Taurus i Super Cristal topovi. Street i taurus topovi su sličnih karakteristika, i postavljaju se u redu ni stazu. Super Cristal topovi su namjenjeni za pokrivanje snijegom većeg otvorenog prostora. Za razliku od Street i Taurus topova Super Cristal posjeduju svoj sopstveni motor i imaju sopstveni kompresor i ventilator koji im omogućuje da rade nezavisno od ostatka instalacije osim sto im je potreban dovod vode. Super Cristal topovi imaju i sopstveni PLC kontroler preko koga je manuelno moguće podešavati parametre kvaliteta snijega.



Sl.8 Street topovi za snijeg [2]



Sl. 9 Taurus topovi za snijeg [2]



Sl.10 Super Cristal topovi za snijeg [2]

2.4. Senzorski sistemi na topovima

Senzorski sistemi na topovima predstavljaju senzori koji mjere vremenske uslove, brzinu vjetrova, temperaturu i pritisak vazduha. Da bi se proizvodio vještački snijeg potreban uslov je temperatura niža od -5°C . Senzori mjere zadate uslove i prosledjuju ih upravljačkom sistemu koji signalizira rukovaocu sistema, da neki dijelovi sistema nemaju potrebne uslove za proizvodnju snijega

3. ZAKLJUČAK

Zahvaljujući sistemu vještačkog osnježavanja, osigurano je da će i u slučaju manjka snježnih padavina, skijanje biti osigurano i Jahorina će biti spremna da primi sve skijaše koji žele da svoj zimski odmor provedu na planini.

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PRIMJENA ENERGIJE SUNCA I VJETRA ZA POTREBE NAVODNJAVANJA POLJOPRIVREDNIH POVRŠINA

Ranka Gojković¹, Vladimir Gojković²

Rezime: Solarna energija i energija vjetra kao i većina obnovljivih izvora energije su ekološki prihvatljivi i neograničeni ali ovi izvori su gledano s ekonomskog aspekta nekonkurentni neobnovljivim izvorima energije. Zbog toga su solarna energija i energija vjetra zasad pogodni samo za male sisteme. U ovom radu je opisan jedan takav sistem. Riječ je o primjeni solarne energije i energije vjetra za potrebe navodnjavanja poljoprivrednih površina. Na kraju rada obrađen je jedan primjer proračuna energetske mogućnosti korišćenja vjetra i sunca koji pokazuje da je ovaj sistem veoma isplativ. Ključne riječi: solarna energija, vjetar, navodnjavanje, pumpa.

IMPLEMENTATION SOLAR AND WIND ENERGY FOR IRRIGATION OF AGRICULTURAL LAND

Abstract: Solar and wind energy as well as most renewable energy sources are environmentally friendly and unlimited but these sources are viewed from an economic point of view uncompetitive non-renewable sources of energy. Therefore, solar energy and wind energy for the time being are suitable only for small systems. In this paper is described such a system. It is the application of solar energy and wind energy for irrigation of agricultural land. Finally prepare is an example calculation possibilities of using wind energy and solar, which shows that the system is very cost effective.

Keywords: solar, wind, irrigation, pump.

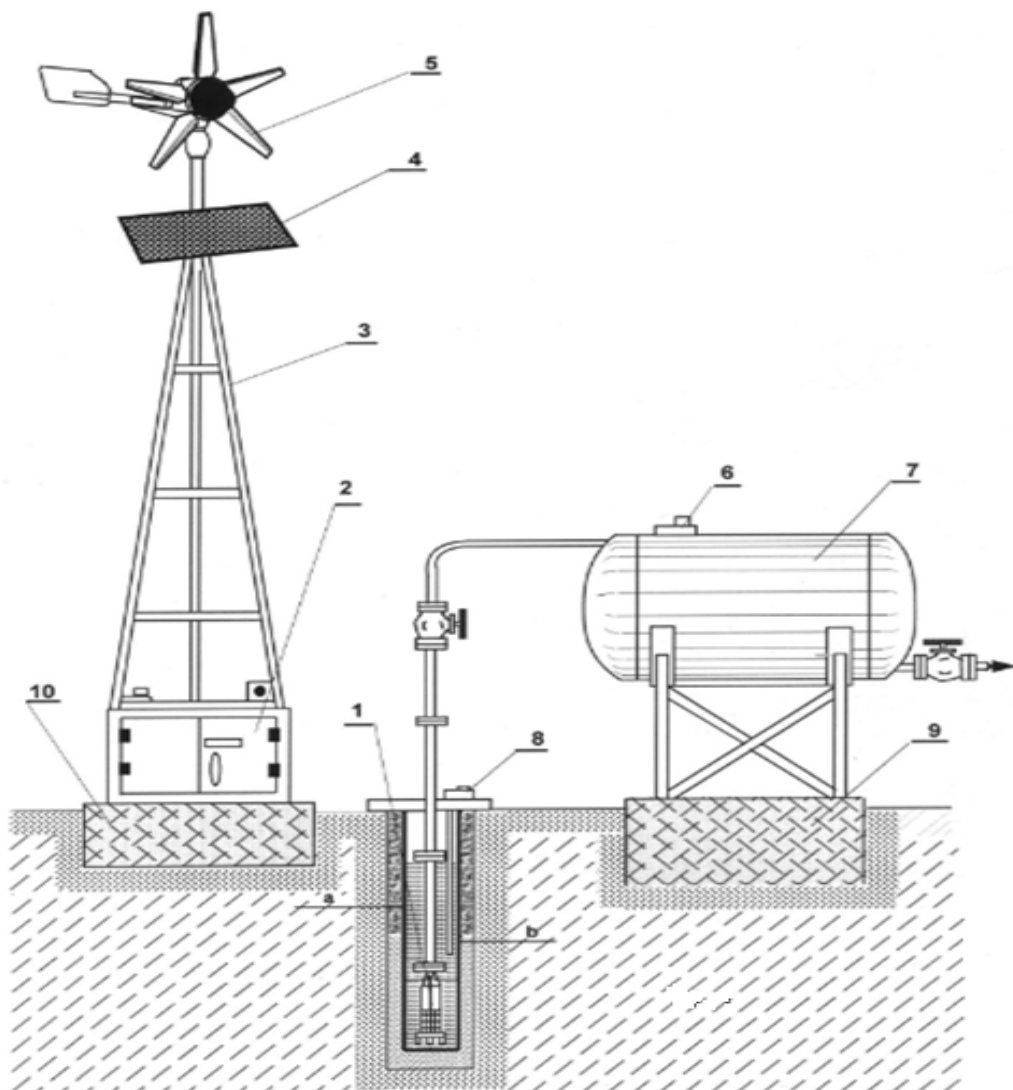
1. UVOD

U praksi se primjenjuju razni sistemi navodnjavanja što zavisi od vodenog bilansa tj. od vrste sadnih kultura, količine potrebne vode, godišnjeg doba, vrste tla, geografskog položaja i drugog. U primjeni bilo kojeg sistema, najvažniji je ipak izvor i nabavka potrebne količine vode. Vode mogu biti površinske i podzemne, a površinske vode nalaze se u rijekama, potocima, kanalima, jezerima, močvarama i izvorima. Za ispušavanje bilo kojih spomenutih voda potrebno je uložiti energiju za pogon pumpi. Najčešće se za tu svrhu koriste pumpe pogonjene dizel ili benzinskim motorom ili agregati koji pogone elektromotorne pumpe. Pumpe u oba slučaja podižu vodu u rezervoar, koji se nalazi na višem nivou radi potrebnog pritiska i neposredno prskaju vodu u okolinu što zavisi od vode koja se ispušava. Ako se rijeke ili jezera koriste za

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ispumpavanje vode, tada se navodnjavanje vrši neposredno prskalicama naokolo ili odvodi dugim cjevovodima do mjesta navodnjavanja. Ako se koristi podzemna voda, tada je neophodno vodu dovesti najprije u rezervoar, koji se nalazi na višem visinskom nivou radi potrebnog pritiska. Podzemne vode mogu se koristiti i za prskanje, ali je zato potreban pritisni sistem za ispumpavanje vode. Agregati ili motorne pumpe koje se za tu svrhu koriste su najčešće na naftu, a nerijetko benzin ili plin, a ako je u blizini električna mreža, koriste se elektromotori. U nekim zemljama navodnjavanje se vrši iskapanjem mreže kanala u koje se povremeno propušta voda iz riječnog korita. U tom slučaju za dovod vode je potrebna dodatna energija.



Slika 1. Primjena energije sunca i vjeta za potrebe navodnjavanja poljoprivrednih površina [1]

U ranijim vremenima, dok se još nisu poznavali učinci nafte, a niti se poznavala električna energija koristila se vrlo uspješna energija vjetra i to tako, da je vjetrenjača pogonila mehaničke pumpe. Rado se prisjećamo kaubojskih filmova u kojima su često bile viđene takove vjetrenjače. To su bile višekrilne i sporohodne vjetrenjače koje su bile poznatije pod nazivom „vjetrene turbine“, a koristile su se za navodnjavanje podzemnim vodama. U tom slučaju, voda se morala najprije dovesti do većeg rezervoara i na veću visinsku razliku kako bi se ostvario dovoljan pritisak. Nedostatak takvog načina ispumpavanja vode je u nemogućnosti vršenja kontrole punjenja rezervoara bez prisustva čovjeka pa se često događalo, da se rezervoar prepunio. Taj nedostatak prati i ispumpavanje vode pomoću agregata ili motorne pumpe jer je agregate ili motorne pumpe teško prilagoditi automatskom radu bez nadzora. [4] Nedostatak agregata i motornih pumpi je još u tome, što troši dodatnu energiju, stvara buku i zagađuje okolinu.

Korišćenje kinetičke energije vjetra i toplotne energija sunca na način, kako je prikazano na slici (sl. 1), za ispumpavanje vode za navodnjavanje, je svima dostupan, lako izvodljiv, bez zagađenja okoline i sa mogućnošću automatskog nadzora i što je najvažnije da se koristi „domaći um“ i domaća oprema. [1]

Ovakav sistem se može brzo primijeniti bez velikog finansijskog ulaganja i utroška vremena. Ovaj sistem se za početak odnosi na najjednostavniju varijantu ispumpavanja podzemnih voda i dovoda u rezervoar. To je niskopritisna varijanta i vrlo je pogodna za navodnjavanje manjih površina, a naročito za postupak „kap po kap“.

2. OPIS SISTEMA

Sistem se sastoji od potopne pumpe za vodu (1), kućišta za aku-baterije (2), obrtnog stuba (3), fotonaponskog modula (4), aerogeneratora-vjetrenjače (5), presostata rezervoara za vodu (6), rezervoara za vodu (7), presostata za potopnu pumpu (8), osnove rezervora (9) i osnove stuba (10). [1] Vjetrenjača i fotonaponski modul pune aku-bateriju električnom energijom napona 12 V.

Potopna pumpa za vodu priključena je na napon aku-baterije preko oba presostata. Kada se rezervoar napuni vodom, presostat rezervoara (6) isključi pumpu i ponovo uključi kad nivo vode u rezervoaru padne na određenu visinu. Presostat za potopnu pumpu takođe ukopčava i iskopčava pumpu kada se nivo vode u bušotini (bunaru) spusti ispod dozvoljenog nivoa. Time je osigurana automatska kontrola količine vode u rezervoaru i bušotini bez ikakvog nadzora čovjeka. Prema tome, pumpa je uključena samo ako su uključena oba presostata. Vizualna kontrola nivoa vode u bušotini i rezervoaru vrši se preko svijetlećih dioda smještenih u kućištu za aku-baterije.

Energiju potrebnu za pogon pumpe dobije se putem fotonaponskog modula i vjetrenjače i to tako, da se aku-baterija stalno nadopunjuje. Ako napon baterije padne ispod dozvoljenog, ugrađeni zaštitni uređaj isključi pumpu tako dugo, dok napon aku-baterije ne dostigne nazivni napon tj. dok se aku-baterija ponovo ne napuni električnom energijom putem vjetrenjače i fotonaponskog modula. Time je osigurana i aku-baterija od dubokog pražnjenja.

Stub je izveden tako, da se može lako okrenuti, postaviti vjetrenjaču i fotonaponski modul te ponovo podignuti i vijkom zategnuti.

Izvedba projektovanih pozicija:

- Potopna pumpa ima električni pogon nazivnog napona 12 V, i prečnika za cijev 1, ¼ cola. Snaga pumpe bira se prema dobavi količine vode i visinskoj razlici odnosno prema potrebnom pritisku: - domaće proizvodnje.
- Kućište za aku-bateriju izrađeno je iz Če profila i lima, dvoslojno lakirano: - domaće proizvodnje ili u samogradnji
- Aku-baterija u „Solarnoj“ izvedbi: - domaće proizvodnje
- Nagibni stub je dvoslojno lakiran, visine 4-6 m: - domaće proizvodnje ili u samogradnji
- Fotonaponski modul određene snage: - domaće proizvodnje
- Aerogenerator- vjetrenjača određene snage: - domaće proizvodnje
- Presostati su sa električnim kontaktima i zaštićeni od kapajuće i prskajuće vode: - u maloprodaji
- Rezervoar za vodu do 3 m³ izrađen iz armiranog poliestera: - domaće proizvodnje
- Nosač rezervoara vode izrađeno je iz Če profila, dvoslojno lakirano i prilagođeno rezervoaru: - domaće proizvodnje ili u samogradnji
- Osnova stuba i rezervoara za vodu su betonski MB 200 – moguća samogradnja
- Bušotinu izvode domaće kompanije.

Iz ovog je vidljivo, da su sve pozicije domaće proizvodnje i lako ih je moguće nabaviti.

Postupak i način izvođenja projekta:

Nakon odabira predložene lokacije potrebno je najprije odrediti dubinu, količinu i kakvoću podzemnih voda, pa na osnovu toga odrediti najpovoljnije sadne kulture za uzgoj na toj lokaciji. Takođe je potrebno odrediti broj sunčanih dana i vjetovitost zavisno o godišnjim dobima na toj lokaciji. Nakon izvršenih spomenutih ispitivanja i dogovora sa korisnikom, može se pristupiti izradi konačnog projekta. Projekat tada mora sadržati dubinu bušotine, snagu pumpe u [W] i tip s obzirom na dubinu i potrebnu količinu vode. Projekat dalje mora sadržati potrebnu snagu fotonaponskih modula i vjetrenjače kako bi energetski bilans bio uravnotežen sa potrošnjom. Zatim se određuje kapacitet aku-baterije u [Ah], visina i jačina stuba, veličina rezervoara za vodu i veličina za smještaj rezervoara.

Najprije je potrebno urediti bušotinu, a zatim izraditi temelje za stub i rezervoar. Stub je izveden tako, da se može lako nagnuti i predhodno na njega učvrstiti vjetrenjaču i fotonaponski modul. Zatim se izvrše svi priključci cijevi, postavi aku-baterija u svoje kućište i izvrši električni priključak pumpe za vodu prema električnoj šemi. Kada su svi radovi završeni, slijedi probno puštanje sistema u rad, prilikom koga je potrebno podesiti presostate i to tako, da isključuju i uključuju pumpu kada voda u bušotini i rezervoaru dostigne veći, odnosno manji potrebni nivo. Na izlazu vode iz rezervoara može se tada priključiti sistem za navodnjavanje „kap po kap“ ili bilo koji drugi sistem.

3. PRIMJER PRORAČUNA ENERGETSKE MOGUĆNOSTI KORIŠĆENJA ENERGIJE SUNCA I VJETRA ZA NAVODNJAVANJE POLJOPRIVREDNIH POVRŠINA

Radi boljeg razumijevanja i uočavanja stvarne mogućnosti primjene ovog projekta, u nastavku će biti obrađen jedan primjer proračuna energetske mogućnosti korišćenja energije vjetra i sunca za navodnjavanje poljoprivrednih površina.

Primjer:

Na nekoj predloženoj lokaciji potrebno je osigurati dnevno 3 m³ vode za navodnjavanje manje poljoprivrednih površine, a na raspolaganju je dovoljno izdašna podzemna voda odnosno bunar. Energiju za pogon elektromotorne pumpe treba osigurati kroz energiju vjetra i sunca. Voda se mora dopremiti u rezervoar zapremine 3 m³, koji se nalazi na visini 2 m, a nivo vode u rezervoaru na visini 3 m.

Odrediti: Električnu snagu pumpe, potrebnu električnu energiju za pogon pumpe, snagu vjetrenjače i fotonaponskog modula i kapacitet aku-baterije.

Rješenje: Ispitivanjem je utvrđeno, da se voda nalazi na dubini 10 m i da je podobna za navodnjavanje više vrsti sadnih kultura.

- Radi gubitaka u cijevi i spojnica (Fitinzima), računati treba sa 15% većom visinom – odnosno:

$$H_u = \frac{13 \text{ m} \cdot 15\%}{100} + 13 \text{ m} = 14,95 = 15 \text{ m} \quad (2)$$

- Teor ka snaga pumpe prema tome iznosi:

$$N_z = \frac{Q \cdot H_u}{24 \cdot 3600} \cdot 1000 \cdot g = \frac{3 \cdot 15}{24 \cdot 3600} \cdot 1000 \cdot 9,81 = 5,1 \text{ W} \quad (3)$$

Q - m³, H_u – m, 1 litra vode ≈ 1 kg

Obzirom na gubitke u motoru i samoj pumpi, a koji su prosječno 60%, stvarna snaga pumpe mora iznositi:

$$N_s = \frac{5,1 \cdot 60}{100} + 5,1 = 8,2 \text{ W} \quad (4)$$

Ako je zadana dnevna količina vode Q= 3 m³ = 3.000 litara, pumpa mora biti uključena 24 sata ili manje, ali tada pumpa mora biti veće snage.

Za osiguranje rada pumpe snage 8,2 W i to 24 sata, potrebno je osigurati dnevno 8,2 X 24 = 196,8 Wh električne energije odnosno 200 Wh.

Prema tabelama 1 i 2 za prosječno moguću dobijenu električnu energiju putem fotonaponskih modula i vjetrenjače za kontinentalno područje u ljetnim mjesecima proizlazi, da će 166 Wh električne energije dnevno osigurati i jedan modul snage 60 W i najmanje 120 Wh vjetrenjača snage 120 W. Ukupno je prema tome moguće dnevno prosječno osigurati oko 280 Wh električne energije, što je više nego dovoljno za ovaj primjer. U proljetnim i jesenskim mjesecima, vjetrenjača će osiguravati više električne energije od fotonaponskog modula što je također vidljivo iz tabela 1 i 2. [2]

Iz ovog se primjera može zaključiti, da će vjetrenjača i fotonaponski modul zadovoljiti potrebe navodnjavanja punih 6-8 mjeseci, a to je razoblje vegetacije i dozrijevanja gotovo svih sadnih kultura, odnosno „iscrpiti“ 540-720 m³ vode. [3]

Tabela 1. Tablica približno prosječno dobijene električne energije fotonaponskih modula po danu u Wh [1]

Snaga modula	10W	20W	30W	60W	80W
	Kopno				
Ljeto	30	60	90	180	240
Jesen, proljeće	17	35	52	110	145
Zima	7	14	22	44	60
	Jadran				
Ljeto	37	74	115	230	310
Jesen, proljeće	20	40	60	120	160
Zima	9	18	27	55	75

Tabela 2. Tablica približno prosječno dobivene električne energije vjetrenjače po danu u Wh [1]

Snaga (W)	30	60	120
Tip vjetrenjače	VT - 30	VT - 60	VT - 120
	Nizinski krajevi		
Ljeto	15 – 30	60 – 90	120 – 150
Jesen, proljeće	30 – 45	90 – 105	150 – 200
Zima	45 – 60	105 – 120	200 – 240
	Gorski krajevi		
Ljeto	30 – 45	90 – 105	150 – 200
Jesen, proljeće	45 – 60	105 – 120	200 – 240
Zima	60 – 75	120 – 150	240 – 300
	Jadran		
Ljeto	45 – 60	105 – 120	200 – 240
Jesen, proljeće	60 – 75	120 – 150	240 – 300
Zima	75 – 90 i više	150 – 240 i više	360 i više

Izbor aku-baterije:

Prema gore izračunatoj potrebnoj električnoj energiji treba odrediti kapacitet i vrstu aku-baterije. Kapacitet se lako odredi tako, da se izračunata potrebna električna energija podijeli sa 12 V tj. u ovom primjeru:

$$\frac{280 \text{ Wh}}{12 \text{ V}} = 23,33 \text{ Ah} \quad (1)$$

To je teoretski kapacitet u koji nisu uračunati gubici pri punjenju i pražnjenju. Za aku-baterije, koje se mogu nabaviti u našim trgovinama, računati treba sa gubicima 15 do čak 40 % što zavisi o vrsti baterije. Aku-baterije sa najvećim gubicima su starterske baterije, koje se koriste u automobilima i drugim vozilima pa su stoga i najjeftinije. Osim toga, takve baterije gube kapacitet na niskim temperaturama i prilikom stajanja, ne podnose duboko pražnjenje, gube vodu, kratkog su vijeka trajanja i otvorene su izvedbe. Za prikupljanje električne energije putem vjetra i sunca treba koristiti tzv. „Solarne“ aku-baterije, koje imaju znatno manje gubitke, zatvorene su izvedbe, ne gube vodu, a vijek trajanja je višestruko duži. Osim spomenutih aku-baterija, na našem se tržištu mogu nabaviti i mnogo bolje, koje uz karakteristike „solarne“ baterije podnose još i duboka pražnjenja, ne gube kapacitet na niskim temperaturama i vrlo malo prilikom stajanja. To su aku-baterije pod nazivom „optima“, a na tržištu se pojavljuju samo kapaciteta 55 Ah, a cijena im je dvostruko veća od „Solarnih“ za isti kapacitet. Sve spomenute aku-baterije su olovne baterije, ali mogu se koristiti i druge puno bolje i skuplje vrste. Prema izračunatom kapacitetu preporučljivo je vidjeti „Solarnu“ bateriju kapaciteta 60 Ah, što je gotovo trostruko više od izračunatog kapaciteta. To nije samo zbog gubitaka već i zbog rezervnog kapaciteta, koji je potreban u slučaju dužeg oblačnog vremena ili vremena bez vjetra. Koristiti se može i veća aku-baterija po kapacitetu za gornji primjer, ali ne veća od 90Ah, jer su u ovom primjeru predviđeni dobavljači električne energije-vjetrenjača i fotonaponski modul premalih snaga da bi bateriju potpuno napunili u kraćem vremenu.

U ovom primjeru se može koristiti pumpa veće snage od izračunate, u tom slučaju će pumpa samo zadanu količinu vode dopreмати u puno kraćem vremenu za istu dnevno dobijenu električnu energiju. U koliko je potrebno dobiti veću količinu vode, tada se mora predvidjeti veći fotonaponski modul.

Iz ovoga primjera je takođe vidljivo, da je potrebno da je potrebno zahtjeve tačno definisati i izračunati potrebnu električnu energiju kako bi sistem bio što jeftiniji.

Ako je potrebna veća dobava količine vode i veća visinska razlika t.j. veći pritisak, tada je potrebna pumpa veće snage, a time veći po snazi fotonaponski modul i aku-baterija većeg kapaciteta.

4. ZAKLJUČAK

Do sada solarna energija i energija vjetra nisu našle primjenu u velikim energetske sistemima, prije svega zbog njihove rasutosti i velikih troškova gradnje solarnih i vjetroelektrana, ali ovi izvori energije su pogodni za male energetske sisteme. U našoj zemlji i u regionu postoje velike potrebe za navodnjavanje poljoprivrednih površina, a te površine su uglavnom rascjepkane i mali sistemi navodnjavanja bi imali veliku primjenu. Sistem koji je opisan u ovom radu bi bio kod nas veoma konkurentan, zato što na većini poljoprivrednih površina ne postoji potrebna infrastruktura za postavljanje klasičnih sistema za navodnjavanje. Prednost

ovog sistema je njegova jednostavnost i to što se svi njegovi potrebni dijelovi mogu proizvesti u domaćim fabrikama. Pošto su u pitanju obnovljivi izvori energije mogu se očekivati subvencije od države.

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PRIMJENA INDUSTRIJSKOG ROBOTA "LIMAT RT 280-6" U PROCESNOJ OPERACIJI ZAVARIVANJA

Marina Kondić¹

Rezime: Ovaj rad se odnosi na analizu karakteristika i primjenu industrijskog robota "LIMAT RT 280-6" koji je za svoje potrebe nabavila firma "Energoinvest" RAOP a.d. iz Istočno Sarajeva 1992. godine. Kao i drugi zavarivački roboti, i ovaj robot ima visoku krutost, kreće se jednoliko i ima minimalne veličine statičkog trenja. Moguće greške koje se javljaju u programu, mogu uticati na tačnost zavarivanja. Ovi zahtjevi proizilaze iz specifičnih uslova upravljanja zavarivačkim robotima koji moraju kontinualno pomjerati gorionik duž linije vara, bez trzaja i vibracija pri velikim i malim brzinama. Za prenos snage, u sistemu zakretnih osa koriste se pužni prenosnici, koji su prethodno stegnuti pomoću opruga i koji zahvaljujući svojim dimenzijama i primjeni ojačanih i izbrušenih malih zupčanika, tj. ozupčanih vijenaca, obezbjeđuje izuzetno miran rad i dug vijek trajanja bez prethodnog ili naknadnog podešavanja. Naročita prednost ove konstrukcije sastoji se u tome što se oprugama, pri normalnom radu, anuliraju svi zazoru u oba pužna vratila i u malim zupčanicima.

Ključne riječi: roboti, industrijski roboti, zavarivanje, analiza

APPLICATION OF INDUSTRIAL ROBOT „LIMAT RT 280-6“ IN THE PROCESS OF WELDING

Abstract: This article concerns the analysis of the characteristics and application of industrial robots "LIMAT RT 280-6" who for their own purposes acquired firm "Energoinvest" RAOP ad. East of Sarajevo 1992nd year. Like other welding robots, this robot is equipped stiffness, moving evenly and has a minimum size of static friction. Possible errors that occur in the program, may affect the accuracy of welding. These requirements stem from specific management conditions welding robots which must continually move the torch along the weld line, without jerks and vibrations at high and low speeds. For the power transmission system in the swivel axis used worm propagation, which previously clamped by spring, and thanks to its size and application of reinforced faceted and small gears, provides extremely quiet operation and a long service life without prior or subsequent adjustments. A particular advantage of this construction lies in the fact that the springs, under normal operation, annuled all the gaps in both shafts and small gears.

Keywords: robots, industrial robots, welding, analysis

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1. UVOD U ROBOTSKE SISTEME

Riječ "robot", upotrijebio je prvi put 1921.godine češki pisac Karel Čapek u naučno-fantastičnoj drami "R.U.R. Rosumovi univerzalni roboti. Riječ robot na češkom jeziku znači težak rad, pa je tim imenom Čapek nazvao mašinu u obliku čovjeka namjenjenu za obavljanje teških poslova. Definicija robota prema standardima ISO/TR 88373 i EN 775 : "Industrijski robot je automatski upravljami, reprogramibilni, višenamjenski manipulacioni sistem sa više stepeni slobode kretanja za industrijsku primjenu, sa mogućnošću rada na fiksnom ili pokretnom postolju." Razvoj robota započeo je 1954. godine, prvi robot proizveden je 1960., a već 1985. u Sjedinjenim Američkim Državama radilo je oko 16.000 industrijskih robota. Danas skoro da ne postoji djelatnost industrijske proizvodnje u kojoj bar nije pokušana primena industrijskih robota, tako da možemo konstatovati da su roboti postali nerazdvojni dio savremene industrijske automatizacije.

Zavarivanje je jedan od najčešće upotrebljivanih procesa u montaži mašina i drži dominantnu poziciju u teškoj industriji, brodogradnji, auto industriji i automatizovanoj industriji. Danas, glavni tip elektrolučnog procesa zavarivanja je elektrolučno (elektrošavno) zavarivanje metalnom topivom elektrodom pod zaštitom inertnim gasom, tačnije poznato kao MIG tehnika (metal-inertni gas) i elektrotačkasto (tačkasto) zavarivanje. Galvni razlog za automatizaciju ovog procesa je uklanjanje ljudi iz sredine koja je pod uticajem luka i koja je opasna po život čovjeka, povećanje produktivnosti i poboljšanje kvaliteta vara.

Uvođenje robota u industriju možemo posmatrati na dva načina. S jedne strane, roboti se pojavljuju kao neophodni sastavni element novih proizvodnih linija koje se projektuju kao visoko automatizovane i često sa osobinama fleksibilnosti. Oni su tada bitan dio proizvodnog pogona i zajedno sa ostalom proizvodnom opremom čine neraskidivu cjelinu. S druge strane, roboti se često uključuju u postojeće proizvodne pogone. U tim slučajevima roboti bitno povećavaju učinak postojeće opreme. Tako "stare" mašine postaju ekonomičnije, što smanjuje potrebu za novim, većim investicijama. Svakako, i nabavka robota je investicija, ali se pokazalo da je ona znatno ekonomičnija od nabavke novih mašina.

Polja industrijske primjene robota možemo svrstati u četiri kategorije:

- Prenos (transfer) materijala i opsluživanje mašina,
- Procesne operacije
- Poslovi montaže (asembliranje)
- Poslovi kontrole proizvoda (inspekcija)

2. PRIMJENA INDUSTRIJSKIH ROBOTA U ZAVARIVANJU

2.1. Primjena industrijskih robota u elektrotačkastom zavarivanju

Tačkasto zavarivanje je jedna od tehnika za spajanje limova, pogotovo čeličnih. Ova tehnika naziva se i elektrootpornim zavarivanjem. Uređaj za zavarivanje sastoji se od dvije elektrode koje formiraju zavarivačka klješta. Limovi se postavljaju jedan uz drugi, a zatim stegnu klještima tokom približno jedne sekunde. Sila stezanja zavisi od debljine limova. Kroz elektrode i kroz limove propušta se struja velikog intenziteta (do 1500 A). Budući da je električna otpornost najveća na spoju dva lima, to će pri proticanju struje na tom mestu razviti najveća toplota. Ova toplota je

dovoljna da otopi metal na mjestu spoja i tako se stvara čvrsta veza. Spajanje limova vrši se, po pravilu, nizom tačkastih varova.

Roboti za elektrotlačasto zavarivanje autokaroserija u današnjoj upotrebi su na hidraulički i, u posljednje vrijeme sve brojnije na elektromotorni pogon. Oni imaju znatnu nosivost do 100 kg, zbog težine klješta za zavarivanje sa kablovima od oko 40-60 kg. Međutim, nije samo statička nosivost ono što određuje snagu pogona. Robot mora biti sposoban da pomjera zavarivački uređaj kratkim brzim pokretima (brzine kretanja su do 1,6 m/s), pri čemu se javljaju velika ubrzanja, pa otuda i inercijalna opterećenja.

Ovi roboti se odlikuju visokom tačnošću pozicioniranja i ponovljivosti unutar vrijednosti od 1 mm, dohvat "ruke" im je obično 2,5 do 3,5 m, a praktično svi imaju šest aktivnih stepeni slobode: tri u osnovnoj konfiguraciji i tri u pogonu hvataljke u cilju njene pune orijentacije u prostoru.

2.2. Primjena industrijskih robota u elektrolučnom zavarivanju

Elektrolučno zavarivanje koristi se za spajanje metalnih dijelova tako da se ostvari neprekidna veza na određenoj dužini. Kod ovog postupka spajanja metalnih, najčešće čeličnih ili aluminijumskih dijelova, održava se stalni električni luk između centralne elektrode od volframa (TIG-postupak) ili žice od istog materijala (WIG-postupak) koja se nalazi u mlaznici za zavarivanje i šava i to na tačno određenom rastojanju. Budući da je temperatura luka veoma visoka, doći će do topljenja metala koji se zavaruje. Kako je i elektroda izrađena od istog metala ona će se takođe topiti, a njen materijal kroz luk dolaziti na mjesto spoja i pomagati u popunjavanju vara. Hlađenjem ovakvog spoja ostvaruje se čvrsta veza.

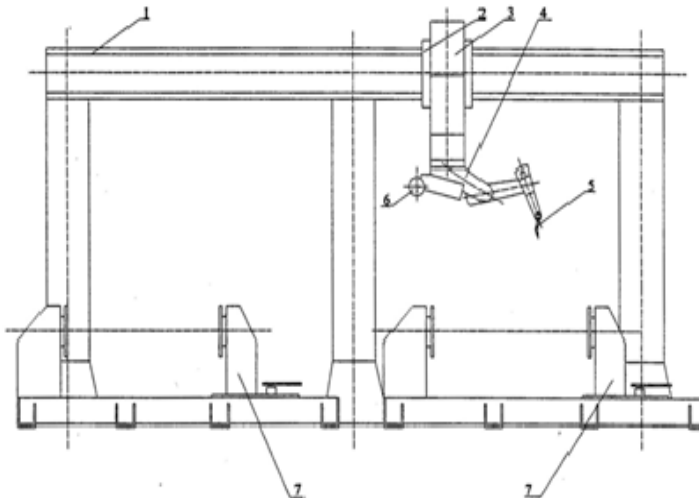
Mlaznica, koja služi i za dovođenje zaštitnog gasa (helijum ili ugljen-dioksid), da bi se spriječila oksidacija vrelom šava odmah posle svarivanja, kreće se duž šava potpuno ravnomjerno i mirno, jer bi inače šav bio neravnomjerne debljine, oblika i kvaliteta. Treba istaći još neke specifičnosti koje se javljaju u nekim slučajevima elektrolučnog zavarivanja. Naime, pri zavarivanju krupnih dijelova često nije moguće u jednom prolazu popuniti cijeli var. Tada se var prolazi više puta ali uz mali pomjeraj u stranu pri svakom prolazu. Druga mogućnost je da se uređaj za zavarivanje vodi oscilatornom (cik-cak) putanjom duž zadate linije vara (šava).

Potrebno je potpuno mirno kretanje relativno malom brzinom od nekoliko desetina cm/min duž tačno praćenih teritorija. Od robota se traži visoka tačnost i ponovljivost. Sa stanovišta geometrije, roboti namjenjeni elektrolučnom zavarivanju moraju imati 5 ili 6 stepeni slobode, mada je dovoljno ukupno 5 stepeni slobode, od kojih je za orijentaciju mlaznice dovoljno dva, jer je mlaznica simetrična u odnosu na sopstvenu uzdužnu osu, pa ovaj stepen slobode praktično nije potreban.

Programiranje robota obično se vrši vođenjem. Tada robot pamti putanju koju će pri zavarivanju ponavljati. Ukoliko je šav pravolinijski, tada se zadaju polazna i krajnja tačka i od robota zahtjeva odgovarajuća interpolacija. Na opisani način robot će se osposobiti za uspješno zavarivanje delova koji su uvek pravilnog oblika i uvek pravilno postavljeni. Problemi nastaju onda kada položaj budućeg vara nije dovoljno preciziran tj. ili su delovi nedovoljno pravilni ili nedovoljno tačno postavljeni. Ovo je, međutim, čest slučaj. Očigledno je da za ovakve primjene robot mora biti opskrbljen nekom vrstom spoljašnjeg senzora koji će mu omogućiti da raspozna traženu putanju i da tako prati željenu liniju zavarivanja.

3. ANALIZA KARAKTERISTIKA INDUSTRIJSKOG ROBOTA “ LIMAT RT 280- 6” ZA ZAVARIVANJE

Preko elektronski dirigovanog sistema klizača KLA 700/KHA 100 (produžna putanja robota), elektrolučni robot za zavarivanje LIMAT RT 280-6, može se kretati aksijalno upravljani. U radnom prostoru (području rada) robota, odgovarajuće se uređuje i priprema periferije obradnih predmeta. Ovdje se radi o dva reverzibilna uređaja (dva noseća sistema) obradnih dijelova RP 550 A, kombinovana sa dva konjića RF 500, koji su montirani na traverzi dugoj 2 m. Pomoću ove traverze moguće je prihvatanje obradnih dijelova. Dvije stanice su projektovane radi smanjenja praznog hoda na minimum i radi postizanja optimalnog iskorišćenja robota. Sve je to prikazano na slici.



Sl.1 Osnovni izgled robota

- | | |
|---------------------------|--|
| 1. Staza uzdužnog klizača | 5. Gorionik |
| 2. Uzdužni klizač | 6. Kutija za smještaj žice |
| 3. Vertikalni klizač | 7. Radne stanice za prihvatanje predmeta zavarivanja |
| 4. Osnovni robot | |

3.1. Noseći sistemi radnih predmeta

Radne stanice za prihvatanje predmeta zavarivanja se sastoje od nosača šiljka (RF) i pogonskih blokova (RPA). Uređaji služe za programsko-sinhrono obrtanje radnih predmeta za vrijeme procesa zavarivanja. Oni mogu da se upravljaju za umetanje dijelova, ali i ručno, ako robot za zavarivanje izvodi svoj program u nekoj drugoj stanici. Pogonski blokovi (RPA) i nosači šiljaka (RF) sastoje se od mašinskog postolja u gruboj, zavarenoj čeličnoj konstrukciji, na kojoj je uležištena ravna ploča. Kod pogonskih blokova RPA, ravnu ploču motora jednosmjerne struje sa montiranim

sistemom induktora puta. Za vrijeme montaže radnih dijelova, pomjeranje nosača šiljka po traverzi, može se vršiti nakon popuštanja steznih zavrtnjeva pomoću ručno aktiviranog radnog pogona preko manjeg zupčanika i zupčaste letve. Svi potrebni upravljački dijelova za obrtne uređaje ugrađeni su u razvodni ormar robota.

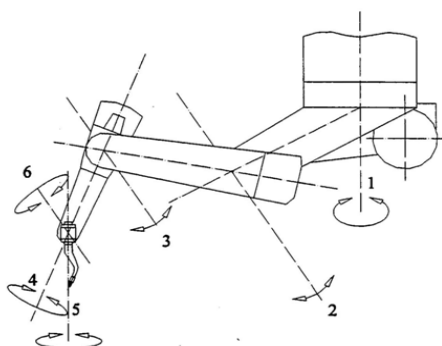
Tabela 1. Upoređivanje karakteristika različitih tipova pogonskih obrtnih blokova (u ovom slučaju instalisan je RPA 500)

Tip	Dozvoljeno opterećenje sa/bez nosača šiljaka (daN)	Maksimalno odstojanje težišta (mm)	Moment okretanja (Nm)	Primljena snaga (Kw)
RPA 300	600/300	200	700	1
RPA 500	1000/500	200	1100	1
RPA 1000	2000/1000	200	2200	2
RPA 1500	3000/1500	200	2700	2

3.2. Sistem zakretnih osa

Precizni roboti LIMAT RT 280 imaju 5 do 6 osa kretanja sa obrtnim zglobovima smještenim u krutoj konstrukciji od livenog aluminijuma. Zahvaljujući ovoj vrsti konstrukcije, i pored kratkih krakova, moguće je obezbijediti područje rada koje je znatno šire od radnog područja nekih drugih uporednih sistema.

Glavna rotaciona osa (1) je izvedena kao koljenasto, konzolno podnožje robota, koje drži dvije zakretne poluge (2 i 3), montirane jedna na drugu. U prvom, krajnjem dijelu druge poluge ugrađen je specijalni zglob sa šupljim vratilom (4). Kroz zglob, preko spojnice brzog djelovanja, montiran je gorionik za zavarivanje koji može da se kreće (vrti) oko dvije nove ose (5 i 6). Kod izvedbe RT 280-6, prednji krak se može rotirati i oko svoje podužne ose (4). I pored velikih mogućnosti rotacije odnosno kretanja, kod ovog sistema ne može doći do preplitanja paketa cijevi gorionika.



Sl.2 Glavne ose robota

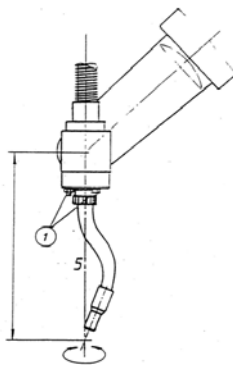
Robot je pogodan za stojeću i viseću montažu i odlikuje se posebno robusnim i krutim načinom gradnje konstrukcije i upotrebom potpuno novih reduktora bez zazora, koji garantuje veliku tačnost i dug vijek trajanja.

Precizno upravljanje kretanja zatom putanjom obezbjeđuje multiprocesor, čiji je softver orijentisan na primjenu, omogućuje brzu izradu i optimiranje radnih programa za sve zadatke i poslove elektrolučnog zavarivanja. Zahvaljujući novoj koncepciji pulta za upravljanje, odnosno komandne table, rukovanje je pojednostavljeno do te mjere da je upotreba robota ekonomična i kod izrade malih serija. Pored toga, na raspolaganju stoji i obiman i bogat program dodatnih i perifernih aparata, koji mogu da se upotrijebe za proširenje uređaja.

3.3. Završni sklop industrijskog robota za zavarivanje

Specijalni zglob za okretanje i zakretanje zavarivačkog gorionika, koji je ugrađen u prednjem kraju drugog kraka poluge, raspolaže šupljim vratilom za provođenje paketa priključnih cijevi (crijeva). U šupljem vratilu nalazi se ugrađena prirubnica sa spojnicom sa brzim dejstvom zavrtnja, za montažu gorionika. Ova prirubnica smještena je na nosećoj podlozi sferičnog oblika. Tako da se može zakretati i premještati radi podešavanja vrha žice. Pomoću uređaja za uklapanje, u priključku gorionika omogućava se slobodno upravljanje pogonima prilikom naginjanja zavarivačkog gorionika. Kod gorionika je veoma bitno istaći da vrh žice za zavarivanje mora da pada na osu okretanja gorionika (osa 5) i da se ne pomjera kada se gorionik okrene. To se najbolje vidi na slici 3.

Pogonski motori za obje osovine smješteni su u zadnjem dijelu drugog kraka, gdje istovremeno imaju funkciju protiv teža. Prenos sile za nagibnu osovinu pištolja vrši se preko kugličnog, rotacionog vretena sa maticom bez zazora, koje, preko prethodno zategnutog kratkog zupčastog lanca pokreće zglob uz pomoć lančanika. Veliki stepen učinka ovog pogona, kod kojeg apsolutno nema nikakvog zazora i koji čini izlišnim bilo kakava podešavanja, omogućuje izbor motora male težine za prednji krak. Rotaciona osovina gorionika pokreće se preko dvostepenog prenosnika s koničnim zupčanicima, koji je sa motorom povezan preko kardanskog vratila. Apsolutno nepostojanje zazora ovdje više nije potrebno, pošto sada nisu moguća odstupanja od pozicije, zahvaljujući postavljanju vrha elektrode u sredinu osovine.



Sl.3 Položaj žice za zavarivanje u odnosu na osu gorionika

Kutija u kojoj se smješta namotoj žice za zavarivanje nalazi se na zadnjoj strani prve poluge. Sistemom cijevi, žica se dovodi do zavarivačkog gorionika. Agregat za pogon elektrode opremljen je motorom istosmjerne struje, sa ugrađenim digitalnim tahometrom. Montiran je zajedno sa kućištem, direktno na glavnu osu robota. Opremljen je priključnom spojnicom brzog dejstva za paket spojnih cijevi. Ovaj agregat obezbeđuje optimalno pomicanje elektrode u svim položajima zavarivačkog gorionika.

Kao izvor struje za zavarivanje za MIG/MAG postupak, primjenjuje se tranzistorski pretvarač sa kompenzacijom mrežnog napona, koji, pretvaranjem frekvencije na maksimalno 25 kHz postižu se visoke performanse za upravljanje i regulaciju.

Kod MIG/MAG postupka zavarivanja moguće je programirati i širinu frekvencije i širinu impulsa, čime se u velikoj mjeri mogu izbjeći prskanja pri zavarivanju. Zahvaljujući izrazito velikoj pogonskoj sigurnosti, ovaj izvor struje je naročito pogodan za primjenu automatizovanog zavarivanja.

Svi električni aparati za napajanje i upravljanje robotom, montirani su u jednom centralnom upravljačkom ormaru sa okretnim ramom.

Prenosna jedinica za upravljanje robotom i njegovo programiranje, nalazi se uz upravljači ormar i služi za unošenje komandi robotu na licu mjesta. Sve instrukcije za rad robota se zadaju pritiskanjem određenih tipki koje se nalaze na toj konzoli. Na konzoli su tipkama predstavljene i mogućnosti pomjeranja glavnih osa robota, tako da i to olakšava posao poslužiocu. Pored osnovnih instrukcija zadavanja programa, na konzoli se nalazi mali monitor radi lakšeg praćenja tačnosti unesenih instrukcija kao i praćenje pojavljivanja eventualne greške.

4. ZAKLJUČAK

Preovladujuća uloga tehnike zavarivanja u robotizaciji proizvodnje može se vidjeti iz primjene robota u Velikoj Britaniji, Francuskoj i Njemačkoj, i to ukupni broj instaliranih robota do kraja 1989. godine, te broj instaliranih robota u 1989. godini. Bez obzira na aktuelnost i uporednu tačnost podataka, ta istraživanja pokazuju da je najveći broj robota uveden u postupcima zavarivanja, zahvaljujući prije svega robotizaciji automobilske industrije. Sumirajući moguće pravce narednih istraživanja, moguće je konstatovati da su dosadašnja istraživanja otvorila niz pitanja i dilema koje je neophodno osvijetliti i razrješiti. To se naročito odnosi na određenu problematiku vezanu za manipulacione, obradne i mjerno-kontrolne sisteme, ali i na kompletne NU fleksibilne strukture. Neophodno je istaći i potrebu da se na početku naredne faze ponovo analiziraju dostignuća i tendencije razvoja robotskih sistema, posebno onih koji služe za procesne operacije, u svijetu i u skladu s tim postavi detaljna koncepcija narednih istraživanja. Pri tome ne treba zaboraviti i na neophodnost da se rezultati dosadašnjih istraživanja po pojedinim segmentima posebno analiziraju sa stanovišta potreba i zahjeva do kojih se došlo kroz istraživanja u drugim segmentima i u tom svjetlu aktuelizuju.

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INDEX OF AUTORS

INDEX OF AUTORS

A

Abagiu Sorin	487
Adamovic Zivoslav	435
Alexandrov Sergei	109
An elkovi Boban	303
Antunovi Ranko	43, 607
Arsi Jovana	525
Arsovski Slavko	533
Arsovski Zora	533

B

Babi živko	331
Baji Nikola	141
Bajmak ¥efik	423
Bajri Rusmir	187, 195
Bani Milan	53, 359
Batini željko	607, 663
Beloica Nikola	235
Blagojevi Milan	251, 601
Blagojevic Mirko	133, 243, 315, 331, 339, 367
Boji Milorad	409
Boji Nada	347
Bo0i kovi Zdravko	145, 383
Burazer Jela	431
Busarac Nenad	255, 355
Buzatu Gabriel Cosmin	415

Č

abrilu Dragan	623
---------------	-----

C

Cvejic Radoje	435
---------------	-----

D

Desnica Eleonora	141
Dimi Zoran	125
Dinu Radu Cristian	415
Dobraz Dragoslav	145
Dobrnjac Mirko	431
Du ak Ljubica	567

Đ

or evi Zorica	133, 339, 367, 409
urica Maja	577
urica Nina	577
urovi D.	503
ur evi Slavoljub	557

Dž	
D0aleta Marija	525
E	
Enache Sanda Diana	487
G	
Geramitchioski Tale	171, 179, 399
Glavonji Miloz	125
Gluhovi Vladimir	641, 701
Gojkovi Ranka	693, 707
Gojkovi Vladimir	693, 707
Golubovi Duzan	383
Gr e Slavoljub	91
Gvero Petar	465
H	
Had0ikaduni Fuad	229
Hlebanja Gorazd	9
I	
Ili Andreja	235, 243, 593
Isailovi Biserka	213
Ivanizevi Aljoza	109
Ivankovi Rade	541
Ivanovi Lozica	235, 243, 593
J	
Janozevi Dragoslav	309
Janozevi Miloz	355
Jeremi Dejan	75, 161
Jocanovi Mitar	447, 631
Josifovi Danica	235, 243, 593
Jovanovi Saza	133, 409
K	
Ka mar ik Igor	109
Kalabi Dragana	431
Kanovi željko	269
Karanovi Velibor	447, 631
Kiss Imre	435
Kne0evi Darko	447, 631
Kondi Marina	715
Kosti Nenad	133, 213, 339
Kozarac Aleksandar	117
Kova Omer	479
Kraiznik Milija	99, 447, 631
Krivokapi Zdravko	91, 541
Krsti Dejan	375, 495
Ku inar ur ica	541
Kuzmanovi Siniza	269

L

Lazi Vuki	593
Lutovska Monika	399

M

Ma ki Tihomir	331
Man i Marko	457
Mari Bogdan	557, 587
Mari Miha	577
Marinovi Budimirka	83,
Marjanovic Nenad	213, 339, 367
Marjanovic Vesna	133, 213, 339, 367
Markovi Biljana	53, 359, 391, 549
Markovi Marijana	153
Markovi Svetislav	153
Medakovi Vlado	465, 557, 587
Mihai C t lin	487
Mihai Paul Mircea	415, 487
Mijajlovi Miroslav	277, 303
Mijakovski Vladimir	399
Miladinovi Slobodan	277,
Mil i Dragan	277, 303, 347, 457
Mil i Miodrag	303
Mileti Ivan	315
Mileti Marko	315
Mili Davor	465
Mili Jelena	153
Milovanovi Ljubiza	153
Milovanovi Vladimir	221, 251
Miltenovi Aleksandar	53
Miltenovi Vojislav	53
Milutinovi Dragan	125
Milutinovi Miroslav	221, 251, 323
Mitrevski Vangelce	179, 399
Moljevi Slaviza	557, 587
Movrin Dejan	109

N

Nikoli Aleksandar	251, 601
Nikoli Saza	205
Nikoli Vesna	309
Nikzi Petar	607

O

Ognjanovi Milosav	31, 263, 323
Orazanin Goran	647

P

Panaitescu Fanel-Viorel	511, 517
Panaitescu Ileana Irina	517
Panaitescu Mariana	511, 517
Panaitescu Vlad-Adria	517
Pavlovi Jovan	309

Pekez Jasmina	141
Petrovi Nikola	309
Petrovi žarko	99
Plan ak Miroslav	109
Plavzi Milan	383
Poljazevi Milorad	145
Popovi Marija	153
Prodanovi Saza	117
Prorok Nemanja	663

R

Rackov Milan	269,
Radi Mina	525
Radi Nebojza	75, 161
Radovi Zoran	607, 663
Rajkovi Dragan	557
Raki Boris	235
Raki Dragan	221
Risti Miloz	263
Roganovi D.	503

S

Savi Miljan	391
Savi Slobodan	409
Simi Stojan	471, 479
Slavkovi Nikola	125
Spai Obrad	83, 91
Spre i Denijal	187
Stan Ivan Felicia Elena	487
Stan Liviu Constantin	511
Stefanovi Miladin	533
Stefanovic Slobodan	435
Stepanovi Biljana	409
Stevovi Svetlana	525
Stojadinovi Slobodan	141
Stojanovi Bla0a	243, 367

Š

Ši anin Leposava	99
Šolaja Marko	641, 701

T

Tabakovic Slobodan	63,
Tanasijevi Rajko	655
Tanovi Ljubodrag	37
Tomovi Radoslav	293, 615
Topalovi Marko	255, 355
Trajcevski Ljupco	171, 179
Trifkovi Spasoje	323

V

Vaskovi Sr an	465, 587, 663
Veg Aleksandar	21, 43

Veg Emil	21
Veli kovi Dragoljub	153
Verez Miroslav	269
Viloti Dragiza	99, 109
Vlazki Dalibor	647
Vu eti Nikola	673, 683
Vujanac Rodoljub	367
Vuji Snje0ana	479
Vuji i Mihajlo	615
Vukeli or e	631
Vukojevi Nedeljko	229
Vukoti Vojin	623
Vulovi Sne0ana	221, 255, 315, 355

W

Wagner Stefan	1
---------------	---

Z

Zeljкови Milan	63, 117
Zivkovic Aleksandar	63,
Zuber Ninoslav	187, 195

Ž

živanovi Saza	125
živkovi Dragoljub	277, 457
živkovi Miroslav	221, 251, 255, 355, 601
živkovi Predrag	285

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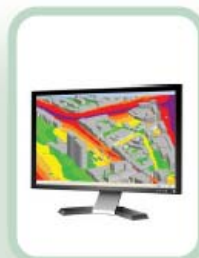
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- Galvansko-hemijska zaštita dijelova;
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PRODUCTION



REMONT
OVERHAUL

Vazduhoplovni programi

- Remont, opravke i održavanje prema stanju turbomlaznih motora i njihovih komponenti i sklopova: Rolls-Royce VIPER svih serija, Tumanski R13-300, R25-300, R95Sh i Klimov RD-33 II serije;
- Proizvodnja dijelova i alata prema specifikaciji naručioca.

Specijalne tehnologije i procesi



LABORATORIJE
LABORATORIES

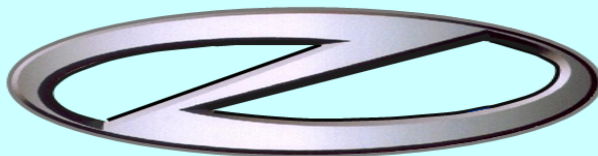


ORAO A.D. raspolaže širokim spektrom tehnoloških mogućnosti: mašinska obrada na CNC i univerzalnim mašinama, elektroeroziona obrada (EDM), obrada plastičnom deformacijom, termička obrada, zavarivanje TIG, zavarivanje snopom elektrona (EBW), galvano-hemijska zaštita dijelova u potpuno novom i savremeno opremljenom pogonu, metode ispitivanja sa i bez razaranja (NDT), plazma i HVOF prevlake, tvrde i temozaštitne prevlake postupkom jonskog napanjanja (PVD), dinamičko i statičko balansiranje rotora, površinsko ojačavanje dijelova (shotpeening). Laboratorije raspolažu modernom opremom: primarni etalon dužina – interferometar; laserski mjerni sistem za etaloniranje; uređaj i etalon za hrapavost; precizni etalon za generisanje i mjerenje ugla; oprema za etaloniranje uređaja za mehanička ispitivanja materijala; oprema za generisanje i mjerenje pritiska; mjerna oprema i etaloni za generisanje i mjerenje momenta sile; oprema i etaloni za mjerenje protoka tečnih fluida; oprema za mjerenje temperature i ispitivanje homogenosti temperaturnog polja, atomsko apsorpcioni spektrofotometar, elektronski mikroskop, kitalice i ostala oprema za metalografska ispitivanja i ispitivanja mehaničkih osobina i hemijskog sastava materijala.

Sertifikati sistema kvaliteta

- NF EN ISO 9001:2008 (BVC, Pariz);
- AS EN JISQ 9100:2009 (BVC, Pariz);
- BAS EN ISO/IEC 17025:2006 (BATA, Sarajevo);
- Part 145 (BHDCA, Sarajevo);
- SRPS ISO 9001:2008 (VKK MOD Srbije);
- SORS 9000/05 (VKK MOD Srbije).

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