Univerzitet u Novom Sadu
FAKULTET TEHNIČKIH NAUKA
DEPARTMAN ZA PROIZVODNO MAŠINSTVO
Novi Sad, Srbija

MEĐUNARODNA NAUČNA KONFERENCIJA

INTERNATIONAL SCIENTIFIC CONFERENCE

ETIKUM 2021

ZBORNIK RADOVA
PROCEEDINGS

NOVI SAD DECEMBAR/DECEMBER 2021

University of Novi Sad
Faculty of Technical Sciences
Department of Production Engineering

ETIKUM 2021

PROCEEDINGS

Novi Sad, 02-04 December 2021

PROCEEDINGS OF THE INTERNATIONAL SCIENTIFIC CONFERENCE

ETIKUM 2021

Novi Sad 2021

Publisher: **UNIVERSITY OF NOVI SAD, FACULTY OF TECHNICAL SCIENCES**
DEPARTMENT OF PRODUCTION ENGINEERING
CHAIR OF METROLOGY, QUALITY, FIXTURES, TOOLS AND ECOLOGICAL ENGINEERING ASPECTS
21000 NOVI SAD, Trg Dositeja Obradovica 6, SERBIA

Organization of this Conference was approved by Educational-scientific Council of Faculty of Technical Sciences in Novi Sad

Technical treatment and design: Milana ILIĆ MIĆUNOVIĆ
Branko ŠTRBAC,
Miodrag HADŽISTEVIĆ

CIP classification:

CIP - Каталогизација у публикацији
Библиотеке Матице српске, Нови Сад

62:006.91(082)(0.034.2)
62:658.562(082)(0.034.2)

INTERNATIONAL Scientific Conference ETIKUM (13 ; 2021 ; Novi Sad)
Proceedings [Elektronski izvor] / [Scientific Conference with International Participation] ETIKUM 2021, Novi Sad, 02-04 December 2021. - Novi Sad : Faculty of Technical Sciences, Department of Production Engineering, 2021. - ilustr.

Način pristupa (URL): http://www.dpm.ftn.uns.ac.rs/sr/o-departmanu/konferencije/etikum. - Nasl. sa naslovnog ekrana. - Opis zasnovan na stanju na dan 29.11.2021. - Radovi na srp, engl. i hrv. jeziku. - Elektronska publikacija u formatu pdf opsega 266 str. - Bibliografija uz svaki rad.

ISBN 978-86-6022-387-8

а) Инжењерство -- Метрологија -- Зборници б) Инжењерство -- Контрола квалитета -- Зборници

COBISS.SR-ID 52253193

Financing of the Proceedings was sponsored by the Provincial Secretariat for Science and Technological Development of AP Vojvodina.

ETIKUM 2021

INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 02-04, 2021

CONFERENCE ORGANIZER

University of Novi Sad, Faculty of Technical Sciences, Department of Production Engineering
Chair of Metrology, Quality, Fixtures, Tools and Ecological Engineering Aspects

PROGRAMME COMMITTEE

Aco Antić, Univerzitet u Novom Sadu, Srbija
Aleksandar Kiralj, Univerzitet u Novom Sadu, Srbija
Aleš Nagode, Univerzitet u Ljubljani, Slovenija
Amalija Horvatić Novak, Sveučilište u Slavonskom Brodu, Hrvatska
Balazs Miko, Bánki Donát Fakultet za mašinstvo i bezbednost, Budimpesta, Mađarska
Biserka Runje, Sveučilište u Zagrebu, Hrvatska
Bojan Ačko, Univerzitet u Mariboru, Slovenija
Bojana Milekić, Univerzitet u Novom Sadu, Srbija
Boris Agarski, Univerzitet u Novom Sadu, Srbija
Borut Kosec, Univerzitet u Ljubljani, Slovenija
Branka Nakomčić-Smargdakis, Univerzitet u Novom Sadu, Srbija
Branka Trifković, Univerzitet u Beogradu, Srbija
Branko Škorić, Univerzitet u Novom Sadu, Srbija
Branko Tadić, Univerzitet u Kragujevcu, Srbija
Branko Štrbac, Univerzitet u Novom Sadu, Srdija
Daniela Korolija-Crkvenjakov, Galerija matice Srpske, Srbija
Danimir Jevremović, Univerzitet Privredna akademija, Srbija
Dejan Lukić, Univerzitet u Novom Sadu, Srbija
Dejan Ubavin, Univerzitet u Novom Sadu, Srbija
Dominic Eggbeer, Univerzitet u Kardifu, Velika Britanija
Dragana Štrbac, Univerzitet u Novom Sadu, Srbija
Dražan Kozak, Sveučilište u Slavonskom Brodu, Hrvatska
Drégelyi-Kiss Ágota, Bánki Donát Fakultet za mašinstvo i bezbednost, Budimpesta, Mađarska
Dubravka Marković, Univerzitet u Novom Sadu, Srbija
Duško Pavletić, Sveučilište u Rijeci, Hrvatska
Đorđe Vukelić, Univerzitet u Novom Sadu, Srbija,
Ferenc Kiss, Univerzitet u Novom Sadu, Srbija
Funda Cansu Ertem, Univerzitet u Groningenu, Holandija
Goran Šimunović, Sveučilište u Slavonskom Brodu, Hrvatska
Goran Stojanović, Univerzitet u Novom Sadu, Srbija
Goran Vujić, Univerzitet u Novom Sadu, Srbija
Igor Budak, Univerzitet u Novom Sadu, Srbija
Igor Drstvenšek, Univerzitet u Mariboru, Slovenija
Ilija Ćosić, Univerzitet u Novom Sadu, Srbija
Ivan Kuric, Univerzitet u Žilini, Slovačka
Jozef Živčak, Tehnički univerzitet u Košicama, Slovačka
Juraj Šebo, Tehnički univerzitet u Košicama, Slovačka
Lidija Krstanović, Univerzitet u Novom Sadu, Srbija
Marian Borzan, Tehnički univerzitet u Kluž-Napoka, Ruminija
Mario Šokac, Univerzitet u Novom Sadu, Srbija
Miladin Stefanović, Univerzitet u Kragujevcu, Srbija
Milan Martinov, Univerzitet u Novom Sadu, Srbija
Milana Ilić Mićunović, Univerzitet u Novom Sadu, Srbija
Miljana Prica, Univerzitet u Novom Sadu, Srbija
Milovan Lazarević, Univerzitet u Novom Sadu, Srbija
Mijodrag Milošević, Univerzitet u Novom Sadu, Srbija
Miodrag Hadžistević, Univerzitet u Novom Sadu, Srbija, predsednik
Miodrag Manić, Univerzitet u Nišu, Srbija
Mirko Gojić, Univerzitet u Zagrebu, Hrvatska
Mirko Soković, Univerzitet u Novom Mestu, Slovenija
Miroslav Badida, Tehnički univerzitet u Košicama, Slovačka
Miroslav Trajanović, Univerzitet u Nišu, Srbija
Mladen Šercer, Univerzitet u Zagrebu, Hrvatska
Nenad Simeunović, Univerzitet u Novom Sadu, Srbija
Nermina Zaimović-Uzunović, Univerzitet u Zenici, Bosna i Hercegovina
Nikola Jorgovanović, Univerzitet u Novom Sadu, Srbija
Numan Durakbasa, Tehnički univerzitet u Beču, Austrija
Nusret Imamović, Univerzitet u Zenici, Bosna i Hercegovina
Petar Petrović, Univerzitet u Beogradu, Srbija
Peter Monka, Tehnički univerzitet u Košicama, Slovačka
Robert Čep, Tehnički univerzitet u Ostravi, Češka
Rok Klobučar, Bojan Ačko, Univerzitet u Mariboru, Slovenija
Sabahudin Jašarević, Univerzitet u Zenici, Bosna i Hercegovina
Samir Lemeš, Univerzitet u Zenici, Bosna i Hercegovina
Siniša Mirković, Univerzitet u Novom Sadu, Srbija
Stanislaw Legutko, Tehnički univerzitet u Poznanu, Poljska
Slobodan Mitrović, Univerzitet u Kragujevcu, Srbija
Šefket Goletić, Univerzitet u Zenici, Bosna i Hercegovina
Tatjana Puškar, Univerzitet u Novom Sadu, Srbija
Tomaž Brajlih, Univerzitet u Mariboru, Slovenija
Vesna Stojaković, Univerzitet u Novom Sadu, Srbija
Viktor Till, Univerzitet u Novom Sadu, Srbija
Vladimir Koči, Tehničko-hemijski univerzitet u Pragu, Češka
Zbigniew Klos, Tehnički univerzitet u Poznanu, Poljska
Zdravko Krivokapić, Univerzitet Crne Gore, Crna Gora
Živana Jakovljević, Univerzitet u Beogradu, Srbija
Zorana Tanasić, Univerzitet u Banja Luci, Bosna i Hercegovina

ORGANIZING COMMITTEE

Boris Agarski, Univerzitet u Novom Sadu, Srbija,
Branko Štrbac, Univerzitet u Novom Sadu, Srbija, predsednik
Daniela Đurovic Koprivica, Univerzitet u Novom Sadu, Srbija
Đorđe Vukelić, Univerzitet u Novom Sadu, Srbija
Igor Budak, Univerzitet u Novom Sadu, Srbija
Ivan Matin, Univerzitet u Novom Sadu, Srbija
Mario Šokac, Univerzitet u Novom Sadu, Srbija
Milana Ilić Mićunović, Univerzitet u Novom Sadu, Srbija, sekretar
Milica Jeremić Knežević, Univerzitet u Novom Sadu, Srbija
Miloš Ranisavljev, Univerzitet u Novom Sadu
Miodrag Hadžistević, Univerzitet u Novom Sadu, Srbija
Zorana Lanc, Univerzitet u Novom Sadu, Srbija
Željko Santoši, Univerzitet u Novom Sadu, Srbija

ACKNOWLEDGEMENT

Organisation of International Scientific Conference ETIKUM 2021 was made possible with understanding and financial help of following sponsors:

- **PROVINCIAL SECRETARIAT FOR HIGHER EDUCATION AND SCIENTIFIC RESEARCH OF AP VOJVODINA** – Novi Sad
- **FACULTY OF TECHNICAL SCIENCES -** Novi Sad
- **DEPARTMENT FOR PRODUCTION ENGINEERING AT THE FACULTY OF TECHNICAL SCIENCES -** Novi Sad

Predgovor

Međunarodna naučno stručna konferencija ETIKUM 2021 se održava tradicionalno već trinaesti put. U vreme kada je koncipirana, 2006. godine, konferencija je osmišljena kao informativno-edukativna i naučno-stručna. Informativno-edukativna dimenzija se oslikava kroz učešće predavača iz redova stručnih predstavnika eminentnih proizvođača opreme koja se koristi u edukativnim i istraživačkim procesima na našem Fakultetu. Pri tome je akcenat na diseminaciji informacija i edukaciji u vezi sa tehnološkim novitetima u oblasti hardverskih i softverskih komponenti. Naučno-stručna dimenzija konferencije se ostvaruje kroz predstavljanje naučnih i stručnih rezultata, pre svega, iz oblasti koje obuhvata Katedra za metrologiju, kvalitet, pribore, alate i ekološko inženjerske aspekte. Pored toga, zahvaljujući razvoju interdisciplinarne saradnje, konferencija je i ove godine obuhvatila i srodne naučno stručne oblasti, u okviru kojih članovi Katedre realizuju naučno-istraživačke i stručne projekte.

Od 2016. godine, uvedena je nagrada za najbolji rad mladog istraživača u znak sećanja na Prof. dr Janka Hodoliča. Programski odbor ETIKUM konferencije je i 2021. godine nagradio najbolji rad mladog istraživača ETIKUM konferencije sa Prof. dr Janko Hodolič nagradom.

Konferencija ETIKUM 2021 je strukturirana u tri tematske celine:

1. *Metrologija i kontrola kvaliteta u proizvodnom inženjerstvu;*
2. *Metrologija i kontrola kvaliteta u biomedicinskom inženjerstvu;*
3. *Metrologija i kvalitet u zaštiti životne sredine i zaštite na radu;*

Prva tematska oblast je, pored klasičnih aspekata metrologije i kvaliteta u oblasti proizvodnog mašinstva, obuhvatila i precizno inženjerstvo, odnosno nano metrologiju i srodne tehnologije.

U okviru druge tematske oblasti su ove godine - pored rezultata istraživanja na nacionalnom projektu u oblasti tehnološkog razvoja „Istraživanje i razvoj metoda modeliranja i postupaka izrade dentalnih nadoknada primenom savremenih tehnologija i računarom podržanih sistema“ - rezultate svojih aktivnosti u oblasti biomedicinskog inženjerstva predstavili istraživači sa drugih departmana FTN-a.

Treća tematska oblast privukla je istraživače iz različitih oblasti zaštite životne i radne sredine. U okviru treće tematske oblasti predstavljena su istraživanja vezana za merenja i analize zagađujućih materija emitovanih u vazduh, vodu, zemljište, merenje i monitoring fizičkih aspekata životne sredine kao što su buka, zračenje i vibracije, kao i ocenjivanje životnog ciklusa proizvoda i procesa.

Na konferenciji ETIKUM 2021 je prezentovano ukupno 63 naučnih i stručnih radova, dok je u radu konferencije učestvovalo preko 80 predavača i slušalaca iz akademskih institucija i privrede iz više evropskih zemalja. Prethodno pomenute činjenice predstavljaju, sa jedne strane, potvrdu koncepcije konferencije, a sa druge strane, garanciju da će konferencija ETIKUM i narednih godina predstavljati značajan informativno-edukativni i naučno-stručni događaj na ovim geografskim prostorima.

Novi Sad, Decembar 2021 *PROGRAMSKI I ORGANIZACIONI* ODBOR

Foreword

International Scientific-Expert Conference ETIKUM 2021 will be held for the thirteenth time and it has become a traditional. When established in 2006, the conference is designed as informative-educational and scientific-expert. Informative and educational dimension is reflected through the participation of lecturers from among expert representatives of the eminent manufacturers of equipment connected to educational and research processes at the Faculty. Moreover, the emphasis are on the dissemination of information as well as on education in relation to technological innovations related to both - hardware and software components. Scientific and expert, i.e., professional dimensions of conference are achieved through the presentation of scientific and expert results, primarily from the field of the Chair of metrology, quality, fixtures, tools and ecological engineering aspects. In addition, thanks to the development of interdisciplinary cooperation, the conference this year included the related scientific and technical fields, in which members of the Chair implement research and professional projects.

From the 2016, in memoriam of Prof. dr Janko Hodolic award for the best paper of the young researcher was introduced. The best paper of the young researcher from ETIKUM 2021 conference was rewarded with the Prof dr Janko Hodolic award on behalf of the ETIKUM conference programme committee.

In the context of this conception, the conference was divided into three thematic sections:

1. *Metrology and quality control in the production engineering;*
2. *Metrology and quality control in the biomedical engineering;*
3. *Metrology and quality in the field of environmental protection and occupational safety.*

The first thematic area, in addition to the classical aspects of metrology and quality in the field of production engineering, included subjects related to precision engineering and nano metrology and related technologies.

The second thematic area was focused on presenting the research results obtained in the framework of a national project from the program of technological development "Research and development of modelling methods and processes of manufacturing of dental restorations using modern technology and computer aided system". In addition, this year this section is enriched with submissions of researchers from other Faculty's departmens dealing with biomedical engineering.

The third thematic area this year attracted researchers from various areas of environmental protection and occupational safety. Research in field of measurement and analysis of pollutants to air, water, and soil, measurement and monitoring of physical aspects of environment such as noise, radiation and vibrations, as well as life cycle assessment of products and processes is presented in third thematic area.

At ETIKUM 2021 conference 63 scientific-expert papers were presented, while the conference was attended by over 80 speakers and listeners from academia and business from several European countries. The previously mentioned facts are, on the one hand, the confirmation of the conference's concept, and on the other hand, a guarantee that the ETIKUM conference will be considered as important informative and educational, scientific and professional event in these region.

Novi Sad, December 2021

PROGRAMME AND ORGANIZING COMMITTEE

ETIKUM 2021

INTERNATIONAL SCIENTIFIC CONFERENCE
NOVI SAD, SERBIA, DECEMBER 02-04, 2021

CONTENTS

SESSION 1: METROLOGY AND QUALITY CONTROL IN THE PRODUCTION ENGINEERING

Klobučar, R., Šafarič, J., Ačko, B. : SET-UP FOR GRID PLATES CALIBRATION 1

Bošnjaković, A., Runje, B., Džemić, Z.: APPLYING THE BAYESIAN METHOD FOR EVALUATING UNCERTAINTY IN MASS CALIBRATION 5

Urekar, M., Gazivoda, N., Župunski I.: LABORATORIJA ZA METROLOGIJU: IZJAVA O USAGLAŠENOSTI I PRAVILO ODLUČIVANJA PREMA SRPS ISO/IEC 17025:2017.....9

Urekar, M., Gazivoda, N.: LABORATORIJA ZA METROLOGIJU: UVERENJE O ETALONIRANJU PREMA SRPS ISO/IEC 17025:2017.....13

Razumić, A., Horvatić Novak, A., Štrbac, B., Runje B.: INFLUENCE OF SCAN PARAMETERS ON SURFACE TOPOGRAPHY OBTAINED VIA AFM.....17

Tóth, T., Varga, P., Hudák, R.: DETERMINATION OF POLYMERS DENSITY USING INDUSTRIAL COMPUTED TOMOGRAPHY.....21

Ranisavljev, M., Štrbac, B., Hadžistević, M., Matin, I.: OPTIMIZACIJA MERENJA RAVNOSTI NA KOORDINATNOJ MERNOJ MAŠINI PRIMENOM TAGUČI DIZAJNA EKSPERIMENTA 25

Đokić, Nj., Moljević, S., Medaković, V., Gojković, R.: OCJENA DOBAVLJAČA U AUTOMOBILSKOJ INDUSTRIJI.....29

Bijelić, M., Bijelić, Z., Bijelić, Ž., Milanović, B.: SISTEMSKO UPRAVLJANJE TEHNOLOŠKIM RAZVOJEM KOMPANIJA KOJE PROIZVODE PROIZVODE VISOKOG STEPENA POUZDANOSTI.....33

Rašković Depalov, V., Pavlović, K.: TYPES OF INNOVATION AND DEGREE OF INNOVATION: MORE OR THE SAME? 37

Đorđević, V., Dašić, P., Pravdić, P.: OCENA SPOSOBNOSTI PROCESA NA PRIMERU POGONSKOG ZUPČANIKA 41

Zahar Đorđević, M., Puškarić, H.: SOFTWARE SOLUTION FOR THE EVALUATION OF THE BUSINESS PROCESS PERORMANCE IN MANUFACTURING SMEs BASED ON TIFNs 45

Žižakov, M., Vasić, S., Delić, M., Vulanović, S.: UTICAJ MENADŽMENTA KVALITETOM NA PERFORMANSE ORGANIZACIJE: PREGLED LITERATURE I KLJUČNIH STAVOVA U OBLASTI 49

Vasić, S. Žižakov, M., Delić, M., Vulanović, S.: RELATIONSHIP BETWEEN QUALITY 4.0, QUALITY MANAGEMENT PRACTICES AND INDUSTRY 4.0: THE VITAL ROLE OF IMPLEMENTATION BARRIERS.....53

Walter, I., Tanasković, M.: OBJECT RECOGNITION IN THE DARK WITH IMAGE SEGMENTATION ..57

Havrlišan, S., Šimunović, K., Šarić, T., Šimunović, G., Lujić, R., Svalina, I., Turinski, D., Klarić, Š.: REGRESIJSKO MODELIRANJE GUBITKA VOLUMENA PRI DULJEM TROŠENJU PLINSKI NAŠTRCANIH PREVLAKA 61

Nedeljković, D., Stanojević, S., Puzović, R., Jakovljević, Ž.: INTEGRACIJA PROIZVODNIH RESURSA U SISTEM ZA IZVRŠAVANJE PROIZVODNJE KORIŠĆENJEM OPC-UA 65

Košarac, A., Mlađenović, C., Zeljković, M.: PREDICTION OF SURFACE ROUGHNESS IN END MILLING USING ARTIFICIAL NEURAL NETWORK 69

Kovač, P., Savković, B., Ješić, D., Dudić, B.: ODREĐIVANJE FUNKCIJE ODZIVA U ZAVISNOSTI OD VIŠE PROMENLJIVIH NA OSNOVU JEDNOFAKTORNOG EKSPERIMENTA 75

Krstanović, L., Antić, A., Janev, M., Popović, B.: SISTEM ZA NADGLEDANJE STANJA ALATA PRIMENOM OBELEŽJA TEKSTURE SPEKTROGRAMA 81

Đurđev, M., Desnica, E., Novaković, B., Đorđević, L., Palinkaš, I.: ANALIZA STANJA I PRIMENE METAHEURISTIČKIH ALGORITAMA ZA REŠAVANJE PROBLEMA INŽENJERSKE OPTIMIZACIJE .85

Aleksić, A., Rodić, D., Gostimirović, M., Sekulić, M., Savković, B., Kulundžić, N.: MODELOVANJE HRAPAVOSTI OBRAĐENE POVRŠINE PRI SEČENJU PLAZMOM 89

Bojanić Šejat, M., Knežević, I., Živković, A., Rackov, M., Ilić,V.: MODELOVANJE STATIČKOG PONAŠANJA RADIJALNIH LEŽAJA 93

Karabegović, I., Husak,E., Karabegović, E., Mahmić, M.: IMPLEMENTATION OF INDUSTRY 4.0 - ROBOTIC TECHNOLOGY IN PRODUCTION PROCESSES: A REVIEW OF WELDING PROCESSES IN THE WORLD 97

Kosec, P.D., Bernetič, J., Kosec, G., Burzić, Z., Nagode, A. Soković, M., Kosec, B.: HEAT TREATMENT AND CHARACTERIZATION OF ARMOUR STEEL OF NEW GENERATION 105

Žmak, I., Kuljanac, J., Culjaga, I., Hren, S.: PREVENTING CASTING DEFECTS IN FIRE PUMP SYSTEMS WHEN USING RECYCLED ALUMINIUM ALLOYS 109

Goluža, B.: GREŠKE ALATA I KOREKCIJA ALATA U EKSTRUZIJI ALUMINIJA 113

Némedi, I., Sánta R., Simon, J.: KONSTRUKCIJA PROTOTIPA MEŠALICE ZA HOMOGENU SMEŠU GLAZURE 117

Topčić, A. Nurkić, A. Cerjaković, E. Lovrić , S. Herić, M.: APPLICATION OF "SOFT" THREE-DIMENSIONAL PRINTING TOOLS IN INJECTION MOULDING OF PLASTIC PARTS 121

Živković; M., Beloica, N.: HOW TO MAKE HYDRAULIC SYSTEMS MORE ENERGY EFFICIENT? 125

Bobić, Z., Kovačević, L., Škorić, B., Čapo, I., Bulajić, D., Drljača, J., Csik, A., Terek, P.: INFLUENCE OF AFM SCANNING PARAMETERS ON CHARACTERIZATION OF FIBROBLAST CELLS ON COATED SURFFACES 131

Brdar, A., Ilić, K., Spasojević, S., Labus Zlatanović, D., Dramićanin, M., Pećanac, M., Janjatović, P., Šiđanin, L., Rajnović, D., Baloš, S.: UTICAJ GEOMETRIJE ALATA I PARAMETARA ZAVARIVANJA TRENJEM SA MEŠANJEM NA OSOBINE SPOJEVA OD AL 5052 135

Ilić, K., Brdar, A., Spasojević, S., Dramićanin, M., Pećanac, M., Janjatović, P., Labus Zlatanović, D., Rajnović, D., Baloš, S., Šidjanin, L.: NAVARIVANJE LEGURA STELITA SA INFILTRIRANIM NANOČESTICAMA 139

Matin, I., Štrbac, B., Vukelić, Đ., Kulundžić, N., Hadžistević, M.: THE ADVANCED MOLD DESIGN METHOD 143

Spasojević, S., Ilić, K., Brdar, A., Dramićanin, M., Labus Zlatanović, D., Pećanac, M., Janjatovi, P., Rajnović, D., Baloš, S., Šiđanin, L.: UTICAJ NANOČESTICA METALNIH OKSIDA NA MEHANIČKE OSOBINE AUSTENITNOG NERĐAJUĆEG ČELIKA ZAVARENOG A-TIG POSTUPKOM 147

Terek, V., Miletić, A., Kovačević, L., Škorić, B., Bobić, Z., Panjan, P., Terek, P.: AFM ANALYSIS OF SURFACE TOPOGRAPHY AND GRAIN MORPHOLOGY OF NANOSTRUCTURED TiAlSiN COATING 151

Živković, T., Movrin, D., Milutinović, M., Ranđelović, S., Stefanović, Lj.: ISPITIVANJE DEFORMACIJA TANKIH DELOVA IZRAĐENIH SLA TEHNOLOGIJOM 155

SESSION 2: METROLOGY AND QUALITY IN THE FIELD OF BIOMEDICAL ENGINEERING

Bednarčíková, L., Michaliková, M., Staško, R., Živčák, J.: EFFECT OF BRACE THERAPY ON SCOLIOSIS TREATMENT 159

Michaliková, M. Ondrejová, B., Štefanovič, B., Barcalová, M., Živčák, J.: DESIGN OF A VARIABLE ANATOMICAL MODEL OF THE HEAD FOR EDUCATIONAL PURPOSES 163

Milić, L., Qureshi, S., Vejin, M., Stanojević, K., Kojić, S., Petrović, B., Stojanović, G.: AUTOMATION OF MEASUREMENT OF WETTING ANGLE OF HUMAN ENAMEL WITH ANTISEPTIC SOLUTIONS USING MATLAB.....167

Ondrejová, B., Štefanovič, B., Bednarčíková, L., Hudák, R., Živčák, J.: CUSTOM PROSTHETIC SOCKET PRODUCTION USING ADDITIVE TECHNOLOGY.....171

Plavac, N., Vejin, M., Spajić, K., Kalamković, J., Petrović, B., Kojić, S., Stojanović, G.: STABILITY OF SALIVARY PH AFTER USE OF ORAL ANTISEPTICS AND CARBONATED BEVERAGES 175

Potran, M.: POREĐENJE KONVENCIONALNOG I DIGITALNOG PROTOKOLA IZRADE INDIREKTNIH ZUBNIH NADOKNADA- UTICAJ NA RUBNO ZAPTIVANJE 179

Stanojević, K., Kalamković, J., Milić, L., Stavrakis, A., Kojić, S., Plavac, N., Stojanović, G.: APPLICATION OF SEM AND CONVENTIONAL MICROSCOPY IN THE ANALYSIS OF DENTAL FLOSS WEAR AND BREAK.....185

Šokac, M., Đurović Koprivica, D., Kuzmanović, M., Santoši, Ž., Vukelić, Đ., Radumilo, D., Budak, I.: PRELIMINARNA STUDIJA ODREĐIVANJA POZICIJE BAZE IMPLANTATA SA CILJEM NJIHOVE ANALIZE I MERENJA.....189

Kuzmanović, M., Đurović Koprivica, D., Puškar, T,. Jeremić-Knežević, M, Ilić Mićunović, M.: CAD/CAM TEHNOLOGIJA - INOVATIVAN METOD U RESTORATIVNOJ STOMATOLOGIJI 193

Đurović Koprivica, D., Puškar. T., Jeremić Knežević. M., Milekić, B., Maletin, A, Kuzmanović, M.: PRIMENA OPTIČKIH LUPA U STOMATOLOGIJI 197

Jeremic Knezevic M, Knezevic A, Djurovic Koprivica D, Milekic B, Maletin A, Puskar T: CAD SYSTEMS IN DENTAL MEDICINE 201

Maletin, A., Ristić, I., Puškar, T., Jeremić-Knežević, M., Đurović-Koprivica, D., Veljović, T., Ramić, B., Milekić, B.: PRIMENA PUSH-OUT TESTA U DENTALNIM ADHEZIVNIM ISTRAŽIVANJIMA 205

SESSION 3: METROLOGY AND QUALITY IN THE FIELD OF ENVIRONMENTAL PROTECTION AND OCCUPATIONAL SAFETY

Benčina, A., Udir, T., Karpe, B., Kosec, B.: CALORIFIC VALUE OF WOOD AND WOOD PELLETS.....209

Lemeš, S. Prcanović, H., Duraković, M.: VERIFIKACIJA REZULTATA MJERENJA EMISIJA U ZRAK IZ INDUSTRIJSKIH POSTROJENJA.....213

Imamović, N., Birdahić, V., Kadušić, E.: IZRADA MODELA KARTE BUKE NA PRIMERU INDUSTRIJSKE ZONE 217

Pravdić, P., Đorđević, V.: CAR FUELS CONSUMPTION OPTIONS AND THEIR IMPACT ON ENVIRONMENT 221

Savković, M., Đapan, M., Mačužić, I., Vukićević, A., Jovičić, M.: MODEL FOR THE OCCUPATIONAL SAFETY AND HEALTH IMPROVEMENT IN SMALL AND MEDIUM ENTERPRISES IN SERBIA 225

Savković, M., Jovičić, M., Vukićević, A., Mačužić, I., Todorović, P.: RESEARCH ON THE POSSIBILITY OF IMPROVING THE SAFETY AND HEALTH AND EFFECTIVENESS OF WORKERS WHO PERFORM MANUAL WORK ACTIVITIES USING EXOSKELETONS 229

Cveticanin, L., Ninkov, I.: BENEFITS AND LACKS OF THE SELF-DRIVING CARS INCLUDING THE

ASPECT OF ENVIRONMENTAL PROTECTION.....233

Dakić, N., Reljić, V., Dudić, S., Milenković, I., Komar, N.: SMANJENJE NEGATIVNIH UTICAJA SISTEMA VAZDUHA POD PRITISKOM NA ŽIVOTNU SREDINU OPTIMIZACIJOM DUŽINE PNEUMATSKIH CREVA.....237

Adamović, S., Rajs, V., Adamović, D., Pinćjer, I., Tomić, I., Mihailović, A., Dramićanin, M.: ELEKTROKOAGULACIONO UKLANJANJE HAZARDNIH ANJONSKIH SURFAKTANATA IZ OFSET EFLUENTA.....241

Tot, R.: INFRACRVENA SPEKTROSKOPIJA U GEOTERMALNIM ISTRAŽIVANJIMA 245

Mirosavljević, Z., Knežević, V., Batinić, B., Ilić Mićunović, M.: RECIKLAŽA I PRERADA NEOPASNOG INDUSTRIJSKOG OTPADA OD POLIMERNIH MATERIJALA – PRAKTIČNI PRIME**R** 249

Kovačić, I., Kanović, Ž., Rajs, V., Rakarić, Z.: O METASTRUKTURAMA SA UGRAĐENIM HOMOGENIM APSORBERIMA 255

Agarski, B., Ilić Mićunović, M., Budak, I., Vukelić, Đ.: IZBOR ODGOVARAJUĆIH AKTIVNOSTI IZ BAZE PODATAKA KOD ANALIZE INVENTARA ŽIVOTNOG CIKLUSA.....259

Lanc, Z., Zeljković, M., Hadžistević, M., Štrbac, B., Živković, A.: GRANIČNI USLOVI ZA NASTANAK KONTAKTNIH TERMIČKIH OPEKOTINA IZAZVANIH VRUĆIM METALNIM POVRŠINAMA 263

INTERNATIONAL SCIENTIFIC CONFERENCE ETIKUM 2021

PROCEEDINGS

Session 1:

METROLOGY AND QUALITY CONTROL IN THE PRODUCTION ENGINEERING

Novi Sad, 02 – 04 December 2021

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE**
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Klobučar, R., Šafarič, J., Ačko, B.

SET-UP FOR GRID PLATES CALIBRATION

Abstract: *In this paper, a calibration method for two-dimensional grid plate intersection is described using numerical controlled multi-axes granite stage, laser interferometer, and digital microscope. The increasing use of optical coordinate devices demonstrates the need to calibrate 2D standards. Profile projectors, microscopes and vision measuring equipment's are mainly based on measuring two-dimensional reference grid plates. The design for the numerically controlled multi-axis granite stage is based on a custom design by Laboratory for Production Measurement (LTM) at the University of Maribor. The basic components of the manufacturer Newport Micro-Controle Spectra-Physics are used. Two-dimensional grid plates are calibrated by a completely automated high precision measuring machine which uses a computer vision system to detect and locate the grid intersections.*
Key words: *grid plates, dimensional measurements, optical coordinate metrology, calibration, laser interferometry*

1. INTRODUCTION

The increasing use of optical coordinate devices demonstrates the need to calibrate 2D standards [1], line standards, stage micrometres, linewidth standards, and standards with different special patterns.

Very high accuracy level for the calibration of line scales is widely achievable [2-14], but only a few laboratories in the world are able to calibrate grid plates with sufficient precision. A preliminary survey on the calibration services from various national metrology institutes (NMLs) shows that only 6 institutes in the World can calibrate grid plates [3].

This measurement set-up can calibrate grid plates with an area up to dimensions 300 mm x 200 mm with an expanded uncertainties at k=2 below 1 µm.

2. MEASUREMENT EQUIPMNET

There are three main parts. The two dimensional numerically controlled stage, the laser interferometer with reference mirror, and the digital microscope.

The two dimensional numerically controlled stage consists of a high-precision air bearing X-Y motion stage for positioning a grid plate, a Z-Tip-Tilt (ZTT) theta stage for adjusting the grid plate in the measurement direction and a motorized Z-axis stage to which a digital video microscope system is mounted for localizing measurement features on grid plates. The measurement range of the system is 1000 mm x 350 mm (Fig. 1). The measurement procedure, together with the system control code and data processing algorithms have been created by LTM. For fast economical calibration of industrial grid plates with dimensions up to 300 mm x 200 mm, measurements are performed by using the instrument's three built-in incremental Heidenhain LIDA 403 linear encoders which each have a 5 nm resolution. However, linear error mapping in the X and Y axis, as well as angular correction between the axes has to be performed prior to using this instrument to calibrate reference grid plate standards.

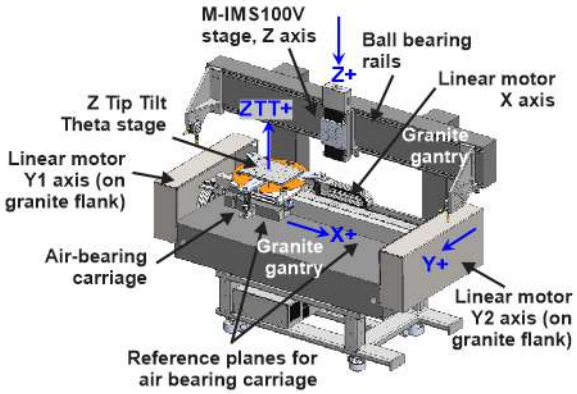


Fig. 1. The two dimensional numerically controlled stage

The design for the numerically controlled multi-axis granite stage is based on a custom design by Laboratory for Production Measurement (LTM) at the University of Maribor for calibrating line scales and grid plates, as well as one-dimensional metrology artefacts such as rings, precise probes, plugs and step gauges.

Because the y-axis of the ball-bearing guide ways did not meet our requirements, it was decided to employ a linear laser interferometer in combination with a plane mirror. We used a 600 mm long Zerodur plane mirror and mounted it on the machine's table. Straightness and alignment deviations of the mirror were measured before each calibration and thus eliminated from the calibration results. The laser interferometer with reference mirror is shown in Fig. 2.

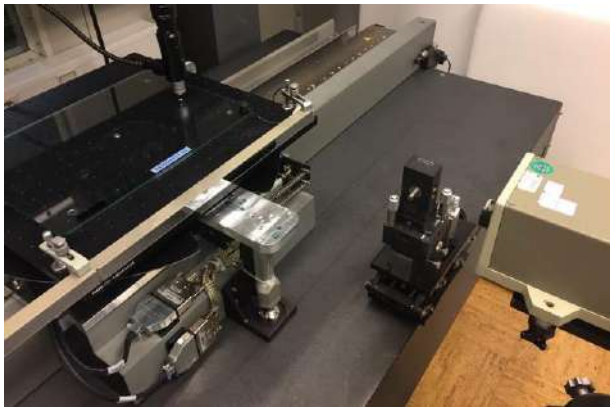


Fig. 2. The two dimensional numerically controlled stage

A digital video microscope for detecting the position of intersection of two lines was used. The software was developed in LabVIEW. The software analyses the images and determinates the middle of the target in the measurement window. This procedure is described in previous work [2]. The operator defines the region of interests in the image. The digital camera takes monochrome images in resolution of 5 Megapixels. The software calculates the distance in pixels and transforms it to micrometers [15].

2. CALIBRATION PROCEDURE

The calibration is performed in the following steps:

- Defining the origin point T_0 (x_0,y_0) and the measurement points T_i (x_i,y_i) on the grid,
- Defining the grid co-ordinate system (x-axis through the origin and an additional point),
- Adjusting laser interferometer and measuring mirror alignment and straightness,
- Establishing measurement programme (in a LabView application),
- Executing measurement programme (number of repetitions),
- Transferring measured co-ordinates into a MS Excel application for error correction (correcting for mirror alignment and straightness, deviation of the orthogonality between the x and y-axis of the machine's guide ways, calibrated deviations of the x-axis measurement system),
- Calculating final calibration results (Excel application) and measurement uncertainty, creating calibration certificate.

2.1 Defining the origin point T_0 (0,0) and the measurement points T_i (x_i,y_i) on the grid

The origin of the calibration is defined in accordance with the customer's requirements or with the marks on the grid to be calibrated. It can be set in the grid centre (Fig. 3) or in the grid corner (Fig. 4).

The measurement points are defined in agreement with client. The maximum number of points is not limited in the calibration procedure.

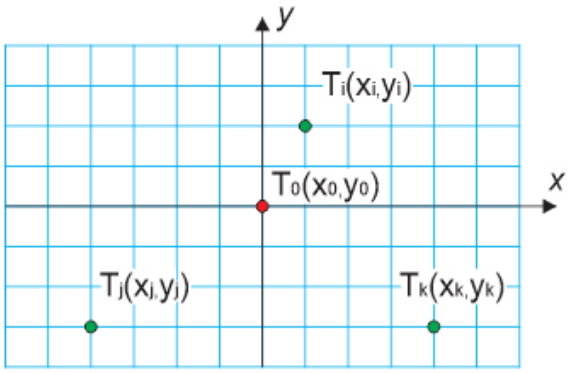


Fig. 3. Defining the origin point T_0 (0,0) in the grid centre

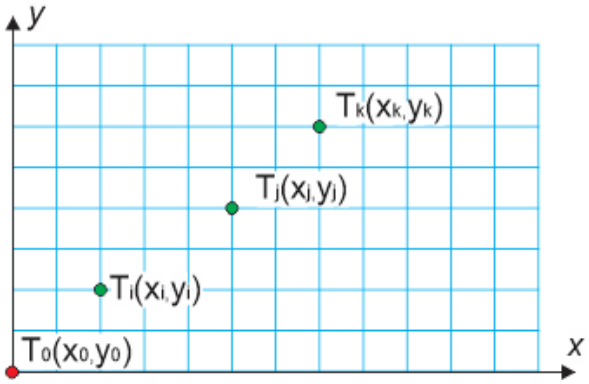


Fig. 4. Defining the origin point T_0 (0,0) in the grid corner

2.2 Defining the grid co-ordinate system

The x-axis of the grid coordinate system is defined through the origin point and through the point at the maximum positive distance from the origin along x-axis. The grid is physically aligned with the x-axis movement of the stage carrying the table. This alignment is executed by precise turning of the table carrying the grid. The grid is rotated as long as y coordinates in both points (measured with the video-positioning system) are equal to 0. It is assumed that the defined x-axis for

the measurement is perfectly overlapping the actual x-axis of the grid. This uncertainty contribution is taken into account.

2.3 Adjusting laser interferometer and measuring mirror alignment and straightness

The plane mirror is fixed on the machine table and is aligned with the grid plate edge. After this alignment is done, the laser beam is aligned perpendicular to the plane mirror. Because of imperfect parallelism between the x-axis and the edge of the grid, as well as straightness deviation of the plane mirror. It is important to emphasis that the reference for evaluating mirror straightness is the x-guide of the comparator. The straightness of the guide was evaluated in relation to a grid line by applying reversal method. This straightness is compensated in the measurement algorithm.

2.4 Establishing and executing the measurement programme

The measurement application has been created in the LabView environment. Before each calibration, it is necessary to enter the grid origin and coordinates (x,y) of the defined calibration points. Number of repetitions in each point are entered, as well. The application then calculates all necessary movements of the machine table in X and Y coordinates and executes the measurements.

2.5 Transferring measured co-ordinates into an Excel application and error corrections

The raw measurement results are transferred from the LabView application into the prepared Excel sheet, which performs the corrections of mirror alignment and straightness, deviation of the orthogonality between the x and y-axis of the machine's guide ways, and calibrated deviations of the x-axis measurement system. The calibration values (deviations) of the x-axis measurement system are entered into this file after each calibration, while the orthogonality between the x and y-axis of the machine's guide ways is checked twice a year and entered in the Excel file. The mirror deviations are entered before each calibration for actual measurement positions along the x-axis.

The orthogonality between the x and y-axis of the machine's guide ways is being evaluated by experiment, in which a grid plate 300 mm x 200 mm is measured in 3 extreme positions (-150 mm, 0 mm, 150 mm) by applying a reverse method. In the initial experiment, an average angle of 18,6 µm/200 mm (93 µm/m) was calculated and is currently used for correcting the calibration result. The dispersion of the results was within an interval ±0,2 µm/200 mm (1 µm/m). The influence of the uncertainty of this angle on determining x coordinate (error in y coordinate is negligible) of a single line cross section (calibrated values) is illustrated in Figure 5.

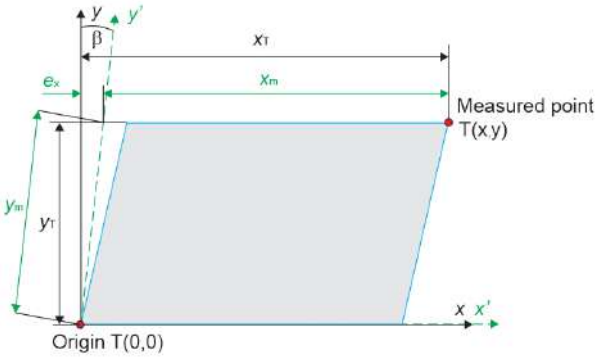


Fig. 5. Coordinates of the measured point in the "ideal" and in the "deformed" coordinate systems

Quantities in Figure 5 are:

- x - y - grid coordinate system
- x' - y' - determined coordinate system (through 2 points on the x-axis)
- x - nominal coordinate x of the measured point
- y - nominal coordinate y of the measured point
- X_T - true coordinate x of the measured point
- Y_T - true coordinate y of the measured point
- X_m - measured coordinate x of the measured point
- Y_m - measured coordinate y of the measured point

The error interval ($\pm e_x$) in x coordinate is:

$$e_x = Y_m \cdot \sin\beta \quad (1)$$

where:

- Y_m - measured coordinate y of the measured point
- β - angle between the machine x and y-axes

This error is calculated and eliminated from the measurement result as follows:

$$X_{i\text{-}corr} = X_{i\text{-}m} - y_i \cdot \sin\beta \quad (2)$$

where:

- $X_{i\text{-}corr}$ - corrected coordinate x of the measured point $T(x_i, y_i)$
- $X_{i\text{-}m}$ - measured coordinate x of the measured point $T(x_i, y_i)$
- y_i - nominal coordinate y of the measured point $T(x_i, y_i)$

3. MEASURMENT UNCERTAINTY FOR BOTH AXISES

In corner points of a grid plate having a maximum dimension (300 mm x 200 mm) a

standard measurement uncertainty $u(x)$=372 nm for x-axis and $u(y)$=217 nm for y-axis where achieved. Uncertainty budget is in detailed presented in previous work [2]. In this calculation, it is assumed that the coordinate origin is in the centre of the plate. Expanded uncertainties at k=2 are well below 1 µm.

3. CONCLUSION

Our goal was to offer the customer an economical calibration at an acceptable accuracy level which is less than 1 µm over the whole measurement range.

This measurement set-up offers a fully automated calibration and enables a very fast and reliable calibration of 2D standards with intersections lines. Experimental tests have shown that the measurement of 100 targets with 3 repetitions at each target can be achieved within one hour. A total calibration time for a grid plate 300 mm x 200 mm with a raster of 10 mm x 10 mm is around 5 hours.

The analysis has shown that the majority of time is spent on set-up preparation, for example aligning the grid pate in the machine, determining best focus, adjusting the laser interferometer and its plane mirror. By applying additional improvements such as Zerodur block with mirrors and two laser interferometers we could improve the measurement uncertainty and time for the calibration.

4. REFERENCES

[1] Mariko, K., Tsukasa, W., Makoto, A., Toshiyuki, T.: *Calibrator for 2D Grid Plate Using Imaging Coordinate Measuring Machine with Laser Interferometers*, International Journal of Automation Technology 9, p.p. 541-545, 2015.

[2] Klobucar, R., McCarthy, M., Acko, B.: Metrological set-up for calibrating 2-dimensional grid plates with sub-micrometre precision, Measurement, Volume 132, p.p 60-67, January 2019.

[3] Web site https://www.bipm.org/kcdb/cmc/ (accessed September 22, 2021)

[4] Koops, R., Mares, A., Nieuwenkamp, J.: *A new standard for line-scale calibrations in the Netherlands*, Mikroniek - Professional Journal on Precision Engineering 30, 2010.

[5] Klobucar, R., Acko, B.: *Experimental evaluation of ball bar standard thermal properties by simulating real shop floor conditions*, International journal of simulation modelling, Volume 15, p.p. 511-521, 2016.

[6] Lassila, A.: *Fibre-coupled differential dynamic line scale interferometer*, Measurement Science and Technology 23, MIKES, 2012.

[7] Flügge, J., Köning, R., Weichert, Ch., Vertu, S., Wiegmann, A., Stavridis, M., Elster, C., Schulz, M., Bosse, H.: *The PTB Nanometer Comparator for metrology on length graduations and incremental length encoder systems*, Physikalisch-Technische Bundesanstalt, Germany, 2009.

[8] Dai, G., Hahm, K., Bosse, H., Dixson, R. G.: *Comparison of line width calibration using critical dimension atomic force microscopes between PTB and NIST*, Meas. Sci. Technol. 28 065010, 2017.

[9] Fujima, I., Fujimoto, Y., Sasaki, K., Yoshimori, H., Iwasaki, S., Telada, S., Matsumoto, H.: *Laser interferometer for calibration of a line scale module with analog output*, Proc. of SPIE 5190 102-110, 2003.

[10] Bosse, H., Hassler-Grohne, W., Flügge, J., Köning, R.: *Final report on CCL-S3 supplementary line scale comparison*, Nano3 40 04002, 2003.

[11] Acko, B.: *Final report on EUROMET Key Comparison EUROMET.L-K7: Calibration of line scales*, Metrologia 49 04006, 2021.

[12] Haitjema, H.: *Iterative solution of least-squares problems applied to flatness and grid measurements*, Advanced mathematical tools in metrology II, p.p. 161-171, 1996.

[13] Haitjema, H.: *Calibration of a 2-D grid using 1-D length measurements*, Proceeding of the XIII IMEKO world congress Italy Torino, p.p. 1652-1657, 1994.

[14] Köning, R., Weichert, Ch., Przebierala, B., Flügge, J., Haessler-Grohne, W., Bosse, H.: *Implementing registration measurements on photomasks at the Nanometer Comparator*, Meas. Sci. Technol. 23 094010, 2021.

[15] Družovec, M., Ačko, B., Godina, A., Welzer, T.: *Robust algorithm for determining line centre in video position measuring system*, Optics and Lasers in Engineering 47, p.p. 1131-1138, 2009.

Authors: **Doc. dr Rok Klobučar, mag Jakob Šafarič, Prof. dr Bojan Ačko,** University of Maribor, Faculty of Mechanical Engineering, Smetanova ulica 17, 2000 Maribor, Slovenia, Phone.: +386 2 220 7608, Fax: +386 2 220 7586.
E-mail: rok.klobucar@um.si
jakob.safaric@um.si
bojan.acko@um.si

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE**
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Bošnjaković, A., Runje, B., Džemić, Z.

APPLYING THE BAYESIAN METHOD FOR EVALUATING UNCERTAINTY IN MASS CALIBRATION

Abstract: *The procedure for evaluating measurement uncertainty by applying the Bayesian method is described in the paper. The Bayesian method differs from the MCS method and GUM method for evaluating the measurement uncertainty. The Bayesian method combines prior knowledge about the measurand with the data collected during the calibration process. The best estimate and coverage interval for the measurand can be calculated from the joint posterior probability distribution obtained from the combination mentioned above. In addition to this, the GUM method, MCS method, and Bayesian method for evaluating the measurement uncertainty are compared for the mass calibration model. It proved that all three methods give the similar results when the Bayesian method is conducted under the noninformative prior distribution.*

Key words: *Uncertainty propagation, Bayesian method, prior distribution, posterior distribution, MC method, GUM method*

1. INTRODUCTION

The primary goal in metrology is how to estimate the measurement uncertainty of measurement results. Thus, in 1993, the think-tank group from the international organizations from the metrological area (ISO, IEC, BIPM, OIML, IUPAP, IUPAC, IFCC) made the Guide to the Expression of Uncertainty in Measurement (GUM). Accepting the international convention for expressing the measurement uncertainty makes it possible to express doubtless and compare the measurement results obtained by different laboratories. In line with the GUM framework [1], the measurement uncertainty is defined as "a parameter associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand". Although an enormous priority is given to the GUM method because it provides the conceptual framework that allows the consistent approach for measurement uncertainty evaluation, it is noticed in short time that the GUM method requirements in some cases cannot be fulfilled, and its application leads to unacceptable results. The Bayesian method for the measurement uncertainty evaluation for the mass calibration model is presented as an alternative to the GUM method in the paper.

2. MEASURAND SPECIFICATION

The paper considers the mass calibration procedure [2] of a weight T of mass density ρ_{T} against a reference weight R of mass density ρ_{R} with the same nominal mass by using a balance operating in air of mass density ρ_a. The conventional weight mass is weight mass calibrated in the ambient condition, and true weight mass is weight mass calibrated in the vacuum. Considering that ρ_{T} and ρ_{R} have different mass density values, it is necessary to account for buoyancy effect. Applying the Archimedes principle, the mass calibration model can be written as it follows:

$$m_{\mathrm{T}}\left(1-\frac{\rho_{\mathrm{a}}}{\rho_{\mathrm{T}}}\right)=(m_{\mathrm{R}}+\delta m_{\mathrm{R}})\left(1-\frac{\rho_{\mathrm{a}}}{\rho_{\mathrm{T}}}\right) \quad (1)$$

where δm_{R} is the mass of small weight of density ρ_{R} added to R to balance it with T.

The conventional weight mass m_{Tc} of the test weight T is the weight mass of density mass $\rho_0 = 8000$ kg/m^3 which balances the reference weight of density mass $\rho_{\mathrm{a0}} = 1.2$ kg/m^3 and it can be written as it follows:

$$m_{\mathrm{T}}\left(1-\frac{\rho_{\mathrm{a}}}{\rho_{\mathrm{T}}}\right)=(m_{\mathrm{R}}+\delta m_{\mathrm{R}})\left(1-\frac{\rho_{\mathrm{a0}}}{\rho_{0}}\right). \quad (2)$$

In terms of the conventional masses m_{Tc}, m_{Rc} and δm_{Rc}, the mass calibration model can be written is it follows:

$$m_{\mathrm{T,c}}\left(1-\frac{\rho_{\mathrm{a}}}{\rho_{\mathrm{T}}}\right)\left(1-\frac{\rho_{\mathrm{a0}}}{\rho_{\mathrm{T}}}\right)^{-1}=\left(m_{\mathrm{R,c}}+\delta m_{\mathrm{R,c}}\right)\left(1-\frac{\rho_{\mathrm{a}}}{\rho_{\mathrm{R}}}\right)\left(1-\frac{\rho_{\mathrm{a0}}}{\rho_{\mathrm{R}}}\right)^{-1}. \quad (3)$$

The above expression can be approximated as it follows:

$$m_{\mathrm{T,c}}=\left(m_{\mathrm{R,c}}+\delta m_{\mathrm{R,c}}\right)\left[1+(\rho_{\mathrm{a}}-\rho_{\mathrm{a0}})\left(\frac{1}{\rho_{\mathrm{T}}}-\frac{1}{\rho_{\mathrm{R}}}\right)\right]. \quad (4)$$

Deviation of $m_{\mathrm{T,c}}$ of the test weight T from the nominal weight mass can be written as it follows:

$$\delta m = m_{\mathrm{T,c}} - m_{\mathrm{nom}}. \quad (5)$$

The mass calibration model used for weight mass calibration is given by the following equations:

$$\delta m = \left(m_{\mathrm{R,c}} + \delta m_{\mathrm{R,c}}\right)\left[1 + (\rho_{\mathrm{a}} - \rho_{\mathrm{a0}})\left(\frac{1}{\rho_{\mathrm{T}}} - \frac{1}{\rho_{\mathrm{R}}}\right)\right] - m_{\mathrm{nom}}. \quad (6)$$

The input quantities $m_{\mathrm{R,c}}$ and $\delta m_{\mathrm{R,c}}$ are represented by the Gaussian (normal) distributions. The input quantities ρ_{a}, ρ_{T} and ρ_{R} are represented by the uniform distributions. The input quantity ρ_{a0} is assigned value 1.2 kg/m^3 with no measurement uncertainty. The input quantities with the assigned distributions are given in Table 1.

Table 1. The input quantities and the PDFs

Quantity	Distribution	Parameters			
		Expectation	Standard Dev.	Expectation	Semi-Width
		mg	mg	kg/m^3	kg/m^3
$m_{\mathrm{R,c}}$	N (μ, σ^2)	100000.000	0.050		
$\delta m_{\mathrm{R,c}}$	N (μ, σ^2)	1.234	0.020		
ρ_{a}	R (a, b)			1.20	0.10
ρ_{T}	R (a, b)			8000	1000
ρ_{R}	R (a, b)			8000	50

3. BAYESIAN ANALYSIS

The Bayesian method for the uncertainty evaluation is implemented in the following way, the measurement model is transformed to the observation one [3,4]:

$$\delta m_{\mathrm{R,c}} = (\delta m + m_{\mathrm{nom}})/[1 + (\rho_{\mathrm{a}} - \rho_{\mathrm{a0}})(1/\rho_{\mathrm{T}} - 1/\rho_{\mathrm{R}})] - m_{R,c}, \quad (7)$$

where the indication $\xi \equiv \delta m_{R,c}$ is expressed by the output quantity $\eta \equiv \delta m$ and other input quantities $\theta \equiv \left(m_{R,c}, \rho_{\mathrm{a}}, \rho_{\mathrm{T}}, \rho_{\mathrm{R}}\right)^{\mathrm{T}}$.

In line with that, the observation model can be written as it follows:

$$\xi = g(\eta, \theta).$$

In line with the Bayesian method, the measurement uncertainty evaluation is done by step-by-step procedure:

(1) The measurand is defined as a parameter $\eta \equiv \delta m$;

(2) The input quantities are identified:
   a. The input quantity is identified for Type A information $\xi \equiv \delta m_{R,c}$;
   b. The input quantity is identified for Type B information $\theta \equiv \left(m_{R,c}, \rho_{\mathrm{a}}, \rho_{\mathrm{T}}, \rho_{\mathrm{R}}\right)^{\mathrm{T}}$.

(3) The measurement values $d_1, \ldots, d_{\mathrm{n}}$ are taken as Type A information for the input quantity ξ.

Table 2. Type A information

ξ	N	$\overline{d}_{\mathrm{N}}$	s_{N}
$\delta m_{\mathrm{R,c}}$	5	1.2345 mg	0.0201 mg

The observation values are: $\delta m_{\mathrm{R,c}}$= [1.205092; 1.222; 1.248; 1.251429; 1.245862]

(4) The measurement model is transformed to the statistical one:

$$D_1, \ldots, D_N \mid \eta, \theta, \sigma \sim N\,(\xi, \sigma^2).$$

(5) The priory distributions are assigned for $\pi(\eta, \theta, \sigma^2)$:

$$\pi(\eta, \theta, \sigma) \propto \pi(\eta)\pi(\theta)\pi(\sigma).$$

(6) The Bayesian method is applied:

$$\pi\left(\eta, \theta, \sigma \middle| \overline{d}_{\mathrm{N}}, s_{\mathrm{N}}\right) \propto \left(\overline{d}_{\mathrm{N}}, s_{\mathrm{N}} \middle| \eta, \theta, \sigma\right)\pi(\eta)\pi(\theta)\pi(\sigma),$$

where

$$l\left(\overline{d}_{\mathrm{N}}, s_{\mathrm{N}} \middle| \eta, \theta, \sigma\right) \propto \frac{1}{\sigma^{\mathrm{N}}} \times \exp\left\{\frac{1}{2}\frac{\left(\xi - \overline{d}_{\mathrm{N}}\right)^2}{\sigma^2/\mathrm{N}} - \frac{1}{2}\frac{{s_{\mathrm{N}}}^2}{\sigma^2/(\mathrm{N}-1)}\right\},$$

represents probability.

(7) The marginal posterior distribution for η is determined by applying the MCMC method:

$$\pi\left(\eta \middle| \overline{d}_{\mathrm{N}}, s_{\mathrm{N}}\right) \propto \int \frac{\pi(\eta)\pi(\theta)\pi(\sigma)}{\sigma^{\mathrm{N}}} \times \exp\left\{\frac{1}{2}\frac{\left(\xi - \overline{d}_{\mathrm{N}}\right)^2}{\sigma^2/\mathrm{N}} - \frac{1}{2}\frac{{s_{\mathrm{N}}}^2}{\sigma^2/(\mathrm{N}-1)}\right\} d\theta d\sigma,$$

where $\overline{d}_{\mathrm{N}}$ denotes the average value and s_{N} standard deviation for data $d_1, \ldots, d_{\mathrm{N}}$.

(8) The expected value and standard deviation are estimated uncertainty by applying MCMC method [4]:

$$\hat{\eta} = E\left[\eta \middle| \overline{d}_{\mathrm{N}}, s_{\mathrm{N}}\right] = \int \eta\pi\left(\eta \middle| \overline{d}_{\mathrm{N}}, s_{\mathrm{N}}\right) d\eta,$$

$$u(\hat{\eta}) = \left(V\left[\eta \middle| \overline{d}_{\mathrm{N}}, s_{\mathrm{N}}\right]\right)^{1/2} = \left(\int (\eta - \hat{\eta})^2 \pi\left(\eta \middle| \overline{d}_{\mathrm{N}}, s_{\mathrm{N}}\right) d\eta\right)^{1/2}.$$

In the Bayesian paradigm, prior knowledge is described by a prior distribution. For example, a way to express the prior beliefs that the measurand is closed to the specified value is to use prior Gaussian distributions. If the expected value is significantly larger than the standard deviation value and the value of relative uncertainty is small, respectively, we have the informative Bayesian distribution. Otherwise, if the expected value is significantly smaller than the standard deviation value and the value of relative uncertainty is small, respectively, we have the less informative Bayesian distribution. In addition to this, another way to model the less prior information distribution is to use the so-called noninformative prior distribution [4]. The Bayesian noninformative distribution for the measurand is used to evaluate measurement uncertainty for the mass calibration model. Table 1 is used to set up the prior distributions for the measurement mass calibration model for calibration weights. By applying the Bayesian method, posterior distribution $\pi\left(\eta, \theta, \sigma \middle| \overline{d}_{\mathrm{N}}, s_{\mathrm{N}}\right)$, probability function $l\left(\overline{d}_{\mathrm{N}}, s_{\mathrm{N}} \middle| \eta, \theta, \sigma\right)$, and posterior

distributions $\pi(\eta)\pi(\theta)\pi(\sigma)$ are calculated. For noninformative distribution $\pi(\eta) \propto 1$ and $\pi(\sigma) \propto 1/\sigma$, the Bayesian method can be written as it follows:

$$\pi(\eta, \theta, \sigma|\overline{d}_{\mathrm{N}}, s_{\mathrm{N}}) \propto l(\overline{d}_{\mathrm{N}}, s_{\mathrm{N}}|\eta, \theta, \sigma)\pi(\theta)/$$
$$\pi(\eta, \theta, \sigma|\overline{d}_{\mathrm{N}}, s_{\mathrm{N}}) \propto l(\overline{d}_{\mathrm{N}}, s_{\mathrm{N}}|\eta, \theta, \sigma)\pi(\theta)/\sigma \qquad (7)$$

4. RESULTS

The Bayesian method is conducted for the noninformative posterior distribution in line with formula (7). The obtained results are calculated by using the Python programming language, and they are given in Table 3 for $\widehat{\delta m}$ and $u(\widehat{\delta m})$.

Table 3. Results of the Bayesian method applied to the problem of mass calibration for the symmetric 95% coverage interval

Posterior distribution	$\widehat{\delta m}$ mg	$u(\widehat{\delta m})$ mg	Interval 95%
Bayes NI	1.2346	0.0738	[1,0876; 1,3805]

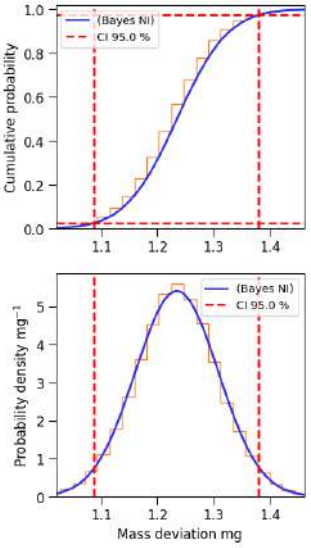


Fig. 1. Approximation to the posterior PDF for the measurand in the observation model (7) obtained by using the Bayesian method for the symmetric 95% coverage interval

In most cases, it is required that the shortest interval be determined. This interval corresponds to the best estimate of the output quantity for the specified coverage level. In line with that, the shortest 95% coverage interval is determined, and it can be represented by the following formula:

$$\delta m_{\widehat{(q^*+0,95\mathrm{M})}} - \delta \widehat{m_{(q^*)}} \leq \delta m_{\widehat{(q+0,95\mathrm{M})}} - \delta \widehat{m_{(q)}}.$$

The obtained results are calculated by using the Python programming language, and they are given in Table 4 for $\widehat{\delta m}$ and $u(\widehat{\delta m})$.

Table 4. Results of the Bayesian method applied to the problem of mass calibration for the shortest 95% coverage interval

Posterior distribution	$\widehat{\delta m}$ mg	$u(\widehat{\delta m})$ mg	Interval 95%
Bayes NI	1.2329	0.0745	[1,0806; 1,3782]

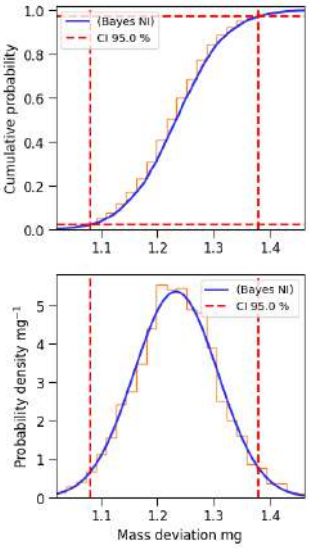


Fig. 2. Approximation to the posterior PDF for the measurand in the observation model (7) obtained by using the Bayesian method for the shortest 95% coverage interval

In figure 4, on the right side are presented the four chains for the parameters from the observed model generated by the MCMC method (200,000 samples), and on the left side are presented distributions of the input quantities.

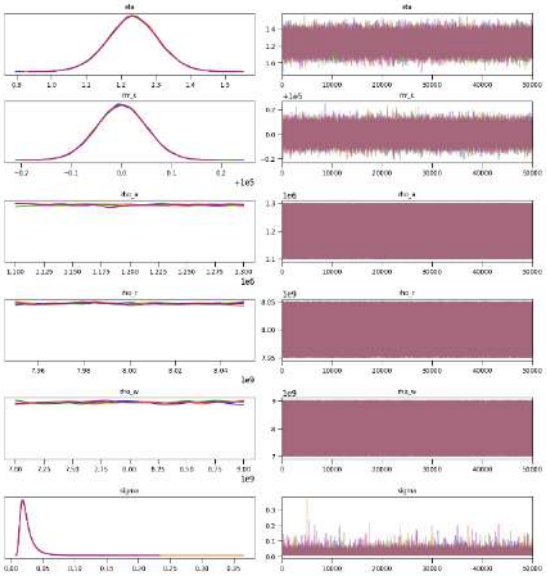


Fig. 3. Trace plot of the mass model parameters

5. CONCLUSION

The result analysis obtained by different

methods for the measurement uncertainty evaluation are presented in this paper. The GUM method [1] is based on summarizing the input quantities by the best estimate with the standard uncertainties, associated with the estimates. The output quantity is characterized by Gaussian or t-distribution. The MCS method [2] samples random from the given probability distribution for each input quantity. This process is repeated several times, for each sample a new value is generated for each input quantities. The Bayesian method combines prior knowledge about the measurand with the data collected during the calibration process. The best estimate and coverage interval for the measurand can be calculated from the joint posterior probability distribution obtained from the combination mentioned above.

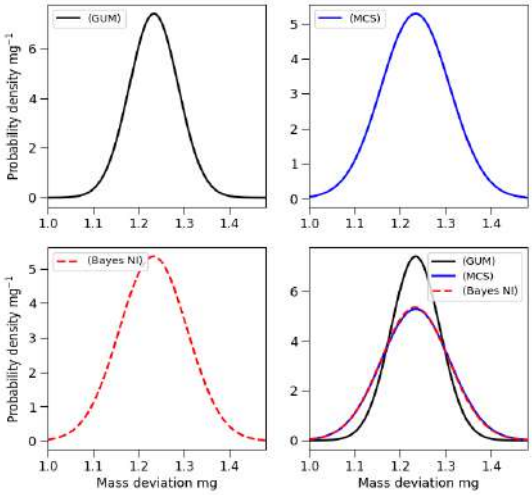


Fig. 4. Comparison of the measurement results obtained by LPU1, MCS and Bayes-NI, the Bayesian analysis conducted with noninformative prior distribution.

Table 5. Comparison of the measurement results obtained by LPU1, MCS and Bayes-NI, the Bayesian analysis conducted with noninformative prior distribution.

Posterior distribution	$\widehat{\delta m}$ mg	$u(\widehat{\delta m})$ mg	Interval 95%
GUM	1.2340	0.0539	[1.1285; 1.3395]
MCS	1.2340	0.0754	[1.0844; 1.3837]
Bayes NI	1.2329	0.0745	[1.0806; 1.3782]

Results for LPU1, MCS are also calculated but they are not presented in the paper. The obtained results showed a good agreement among the methods for the uncertainty evaluation applied to the mass calibration model for the measurand i.e., the best estimate of the output quantity $\widehat{\delta m}$. As for the standard deviation, the methods for the uncertainty evaluation provided significantly different results. The standard deviation value $u(\widehat{\delta m}) = 0.0754$ mg obtained by the MCS method is 40% greater than the standard deviation value $(\widehat{\delta m}) = 0.0539$ mg obtained by the GUM method. In addition to this, the standard deviation value $u(\widehat{\delta m_{\mathrm{BayesNI}}}) = 0.0740$ mg obtained by the Bayesian method is 38% greater than the standard deviation value $u(\widehat{\delta m}) = 0.0539$ mg obtained by the GUM method. The standard deviation value $u(\widehat{\delta m}) = 0.0754$ mg obtained by the MCS method is 1% greater than the standard deviation value $u(\widehat{\delta m_{\mathrm{BayesNI}}}) = 0.0745$ mg obtained by the Bayesian method. It can be concluded that there is a good agreement between these methods for the mass calibration model. The measurement uncertainty can have a significant benefit from the available prior distributions for the measurement model. In that sense, the Bayesian method (inference) is a convenient statistical tool for improving the procedures for the measurement uncertainty evaluation. The Bayesian method in the measurement uncertainty procedure is based on the statistical model, and calculation is done by using the MCMC (Markov chain Monte Carlo) method. In line with that, the Bayesian method requires some statistical skills to establish the statistical model and determine the prior distributions for the input quantities of interest that make the model. In addition to this, it is presented that the Bayesian method for the noninformative distribution provides the same results as the MCS method.

6. REFERENCE

[1] BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP, and OIML 2008 *Guide to the Expression of Uncertainty in Measurement*, JCGM 100:2008, *GUM 1995 with Minor Corrections* (BIPM)

[2] BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP, and OIML 2008 *Supplement 1 to the 'Guide to the Expression of Uncertainty in Measurement' - Propagation of Distributions using a Monte Carlo Method, JCGM 101:2008* (BIPM)

[3] Forbes A and Sousa J 2011 The GUM, Bayesian inference and the observation and measurement equations *Measurement*

[4] Demeyer, S., Fischer, N., & Elster, C. 2020 Guidance on Bayesian uncertainty evaluation for a class of GUM measurement models.

Authors: **Alen Bošnjaković**, Institute of Metrology of Bosnia and Herzegovina, **Biserka Runje,** Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, **Zijad Džemić,** Faculty of Engineering and Natural Sciences, International University Burch Sarajevo, E-mail: alen.bosnjakoivc@met.gov.ba

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Urekar, M., Gazivoda, N., Župunski, I.

LABORATORIJA ZA METROLOGIJU: IZJAVA O USAGLAŠENOSTI I PRAVILO ODLUČIVANJA PREMA SRPS ISO/IEC 17025:2017

Rezime: *Izveštavanje o rezultatima je bitan deo standarda ISO 17025:2017. Nova verzija ovog standarda je uvela pojmove „izjava o usaglašenosti“ i „pravilo odlučivanja“ koji se vezuju za Uverenje o etaloniranju koje izdaju laboratorije za etaloniranje. Kako novi termini i pravila koja se uvode standardom uvek proizvode nedoumice i potencijalne probleme za laboratorije koje su u procesu (re)akreditacije, potrebno je analizirati, rastumačiti i odrediti kako i na koji način ove zahteve implementirati u praksi. Ovaj rad je nastao kao rezultat analize ovih zahteva u Laboratoriji za metrologiju na Fakultetu tehničkih nauka u Novom Sadu.*
Ključne reči: *etaloniranje, metrologija, ISO 17025, izjava o usaglašenosti, pravilo odlučivanja*

1. UVOD

Izveštavanje o rezultatima je važan aspekt nove verzije standarda ISO 17025. Uvedeni su pojmovi *izjava o usaglašenosti* i *pravilo odlučivanja* koji se vezuju za *Uverenje o etaloniranju* koje izdaju laboratorije za etaloniranje. Kako novi termini i pravila koja se uvode nekim standardom uvek proizvode nedoumice i potencijalne probleme za laboratorije koje su u procesu (re)akreditacije, potrebno je analizirati, rastumačiti i odrediti kako i na koji način ove zahteve implementirati u praksi. Ovaj rad je nastao kao rezultat analize ovih zahteva u Laboratoriji za metrologiju (LzM) na Fakultetu tehničkih nauka, kao i na osnovu prethodnih radova [1] i [2].

2. DEFINICIJE

Ovaj standard, pored navođenje zahteva za laboratorije, pojašnjava šta korisnici mogu da očekuju od usluge etaloniranja, daje opis relevantne dokumentacije koju treba da dobiju pri tome. *Uverenje o etaloniranju* koji odgovara principu merne sledljivosti mora biti u skladu sa SRPS ISO/IEC 17025:2017 [3].

Na osnovu rezultata etaloniranja svaki korisnik etaloniranog instrumenta treba da je u stanju da utvrdi da li merni instrument zadovoljava uslove tačnosti koje je deklarisao proizvođač instrumenta, ali, često je praktično da se tokom postupka etaloniranja to i eksplicitno utvrdi i navede u *Uverenju o etaloniranju*. Postoje različiti razlozi za to, pa su i pravila za iskazivanje prilagođena potrebama i veoma različita.

Od kada je predstavljena nova verzija ovog standarda, u stručnoj javnosti traje diskusija vezana za pojmove *izjava o usaglašenosti* i *pravilo odlučivanja*. Da bi znali šta i kako postupamo sa ovim zahtevima, potrebno je krenuti od temelja koji predstavljaju definicije ovih termina, koji su nekima (naizgled) poznati, ali su potpuno novi u ISO 17025 okruženju.

Pravilo odlučivanja je nedvosmisleno definisano na samom početku standarda [3] kao:

3 Termini i definicije

3.7 pravilo odlučivanja

pravilo koje opisuje kako se merna nesigurnost uzima u obzir kada se iskazuje usaglašenost sa specificiranim zahtevom.

(Svi citati iz standarda su dati *kurzivom*.)

Sa terminom *izjava o usaglašenosti* je nešto nejasnija situacija, pošto nije eksplicitno definisan u standardu, iako je to odavno prisutan pojam.

Možda je ISO pretpostavio da je pojam poznat, jasan i samodefinisan delom rečenice iz prethodne definicije: *iskazuje usaglašenost sa specificiranim zahtevom*. Možda je želja bila oslanjanje na eksternu definiciju iz nekog drugog dokumenta, što nije navedeno. Svakako, ovo bi se moglo smatrati propustom i očiglednom nedostatkom u standardu koji bi trebao da bude samostalan dokument, sa potpuno definisanim pojmovima.

Deo istraživačkog posla u LzM je uključio i traženje jasne definicije ovog termina, te pretpostavke na koji dokument bi se trebalo referencirati.

Prva logična destinacija je ISO/IEC serija vodiča za terminologiju. U [4] se navodi:

12 Ocenjivanje usaglašenosti

Primenjuju se termini i definicije date u ISO/IEC 17000.

U dokumentu [5], navode se definicije:

4.1 ocenjivanje usaglašenosti

demonstracija da su specificirani zahtevi (5.1) ispunjeni.

Napomena 1 uz unos: Proces ocenjivanja usaglašenosti kako je opisan u funkcionalnom pristupu u Aneksu A može imati negativan ishod, tj. pokazati da navedeni zahtevi nisu ispunjeni.

Napomena 2 uz unos: Ocenjivanje usaglašenosti obuhvata aktivnosti definisane na drugom mestu u ovom dokumentu, kao što su, ali ne ograničavajući se na testiranje (6.2), inspekcija (6.3), validacija (6.5), verifikacija (6.6), sertifikacija (7.6) i akreditacija (7.7).).

Napomena 3 uz unos: Ocenjivanje usaglašenosti je objašnjeno u Aneksu A kao niz funkcija. Aktivnosti koje doprinose bilo kojoj od ovih funkcija mogu se opisati kao aktivnosti ocenjivanja usaglašenosti.

Napomena 4 uz unos: Ovaj dokument ne sadrži definiciju „usaglašenosti". „Usaglašenost" se ne nalazi u definiciji „ocenjivanja usaglašenosti". Niti se ovaj dokument bavi konceptom usklađenosti.

5.1 specificirani zahtev

potreba ili očekivanje koje je navedeno

Napomena 1 uz unos: Specifikovani zahtevi se mogu navesti u normativnim dokumentima kao što su propisi, standardi i tehničke specifikacije.

Napomena 2 uz unos: Specifikovani zahtevi mogu biti detaljni ili opšti.

Odavde postaje jasno da je originalna ideja bila da se samodefiniše ovaj pojam iz *pravila o odlučivanju*. Ipak, detalji navoda ostavljaju dosta prostora za istraživanje i spekulaciju, pa bi svakako trebalo nedvosmisleno dati definiciju ovog pojma.

3. IZJAVA O USAGLAŠENOSTI (IoU)

IoU je uključena u *Uverenje* kao odgovor na zahteve korisnika merne opreme. Njome se označava da li je merni uređaj u skladu sa nekim konkretnim specifikacijama (npr. proizvođačkim) ustanovljenim etaloniranjem.

Da bi se donela ova odluka, potrebno je utvrditi posebno pravilo – *pravilo odlučivanja*, kako je definisano standardom. Ne postoji egzaktna definicija načina kako se ono ispunjava niti je striktno propisana forma ispunjavanja zahteva. Ovo se može dogovoriti između laboratorije i korisnika instrumenta, pa postoje razni modeli za sporazume koji se mogu postići, propisani normativnim dokumentima, ali i arbitrarni (dogovorni). Na osnovu analize primera iz prakse drugih laboratorija, najčešći oblici su:

- IoU se definiše posebno u svakom posebnom Ugovoru laboratorije, zavisno od dogovora i korisnika.
- Laboratorija unapred definiše pravila o IoU, koja se dostavljaju u ponudi Ugovora, a na korisniku je da odluči da li mu odgovaraju ili ne.
- Laboratorija poseduje Poslovnik/Pravilnik rada gde je ovo pitanje jasno definisano i određeno (često u pravnim okvirima).
- Dogovorom se koriste modifikovana pravila laboratorije ili pravila koja dostavlja korisnik.

Ovde je jasno da se podrazumeva da ukoliko uopšte dolazi do ovakvih ugovornih uslova, korisnik mora unapred imati jasnu svest o tome šta je ova izjava, čemu služi i kako se koristi.

Zahtevi standarda vezano za IoU i *pravilo odlučivanja* su dati kao:

7.8.4 Specifični zahtevi za sertifikate o etaloniranju

7.8.4.1 Pored zahteva koji su navedeni u 7.8.2, sertifikati o etaloniranju moraju da obuhvataju sledeće:

e) kada je relevantno, izjavu o usaglašenosti sa zahtevima ili specifikacijama (videti 7.8.6);

Postavljaju se pitanja: Kada je relevantno za laboratoriju da daje IoU? Ko o tome odlučuje? Da li je potrebno uvek se izjašnjavati o tome, ili samo na zahtev korisnika? Da li je moguće nikada ne davati ovu izjavu? Ovde je jasno da je tumačenje prepušteno sertifikacionom telu i da je potrebno uskladiti tumačenje sa njime.

Tumačenje LzM je sledeće:

IoU nije obavezna – *relevantno* znači „kada su ispunjeni neki uslovi". Ovo znači da je moguće eksplicitno se odreći mogućnosti davanja izjave. Ako se to ne uradi, korisnik može biti doveden u zabunu da se izjava dobija po automatizmu. Ovde je potrebno prepoznati interes laboratorije za davanjem IoU, što je LzM prihvatila kao isplativu opciju.

U skladu sa ovim, potrebno je razmotriti dalje zahteve o izveštavanju o IoU, kojem je pored osnovnih zahteva, posvećen deo posebnog poglavlja dodatnih zahteva standarda:

7.8.6 Izveštavanje u vezi sa izjavom o usaglašenosti

Kada daje izjavu o usaglašenosti sa specifikacijom ili standardom, laboratorija mora da dokumentuje pravilo odlučivanja koje primenjuje, uzimajući u obzir nivo rizika (kao što su lažno prihvatanje i lažno odbijanje i statističke pretpostavke) koji je povezan sa pravilom odlučivanja i da primeni pravilo odlučivanja.

NAPOMENA Kada pravilo odlučivanja propisuju korisnik, propisi ili normativni dokumenti, nije potrebno dalje razmatranje nivoa rizika.

Laboratorija mora da izveštava o izjavi o usaglašenosti tako da se tom izjavom jasno

identifikuje:

a) na koje se rezultate izjava o usaglašenosti primenjuje;

b) koje specifikacije, standardi ili njihovi delovi su ispunjeni ili nisu ispunjeni;

c) koje pravilo odlučivanja se primenjuje (osim ako je ono sadržano u zahtevanoj specifikaciji ili standardu).

NAPOMENA Za više informacija videti ISO/IEC Guide 98-4.

Ono što odavde nije jasno je da li laboratorija mora obavezno da prihvati davanje IoU kada to korisnik zahteva? Zbog toga je potrebno jasno naznačiti stav laboratorije o tome. Ukoliko prihvati takvo izveštavanje, jasno je da mora korisniku unapred omogućiti informaciju o *pravilu odlučivanja*, što je LzM rešila slanjem *pravila* uz tekst ponude ugovora.

LzM je usvojila način izveštavanja saglasno sa standardnim dokumentom [6] i oformila dokument [7], u kojem se navodi:

2 Ocena usaglašenosti sa specifikacijom

Ako Laboratorija ocenjuje usklađenost sa specifikacijom mernog instrumenta, pored niza zahteva koji treba da budu ispunjeni, u skladu sa dokumentom [6] mora se navesti i pravilo po kome se te ocene donose. Ako korisnik ne zahteva drugačije, Laboratorija donosi svoje sopstveno pravilo o donošenju ocene o usaglašenosti sa specifikacijom.

Sledeće pitanje je: Šta ako korisnik zahteva odlučivanje po svom sistemu pravila? Ovo je svakako predmet ugovora dve strane i mora se jasno dogovoriti pre početka posla. Ukoliko korisnik insistira na svojim *pravilima odlučivanja*, tada je jasno da se laboratorija mora ograditi od odgovornosti o takvim rezultatima i to jasno naglasiti, što je predviđeno u [3]:

7.8.2.2 *Laboratorija mora da bude odgovorna za sve informacije koje se daju u izveštaju, osim kada se informacija dobija od korisnika. Podaci dobijeni od korisnika moraju da budu jasno identifikovani. Osim toga, kada se informacija dobija od korisnika i ako ona može da utiče na validnost rezultata, u izveštaju mora da bude navedeno odricanje od odgovornosti.*

4. PRAVILO ODLUČIVANJA (PO)

Praktično objašnjenje i primena PO su dati u dokumentu LzM [7]:

2.1 Pravilo za donošenje ocene

Pravilo za donošenje ocene o usaglašenosti mernog instrumenta sa njegovom specifikacijom koje primenjuje Laboratorija prikazano je na Slici 1. Pravilo (izbor b) je izabrano i preuzeto iz dokumenta [4].

Greška mernog instrumenta, utvrđena etaloniranjem, na slici je predstavljena kružićem kome je pridružena duž što predstavlja proširenu mernu nesigurnost etaloniranja ±U. Greška (zajedno sa nesigurnošću) može da se nađe u jednoj od četiri oblasti na slici:

A. Između donje i gornje granice prihvatanja;

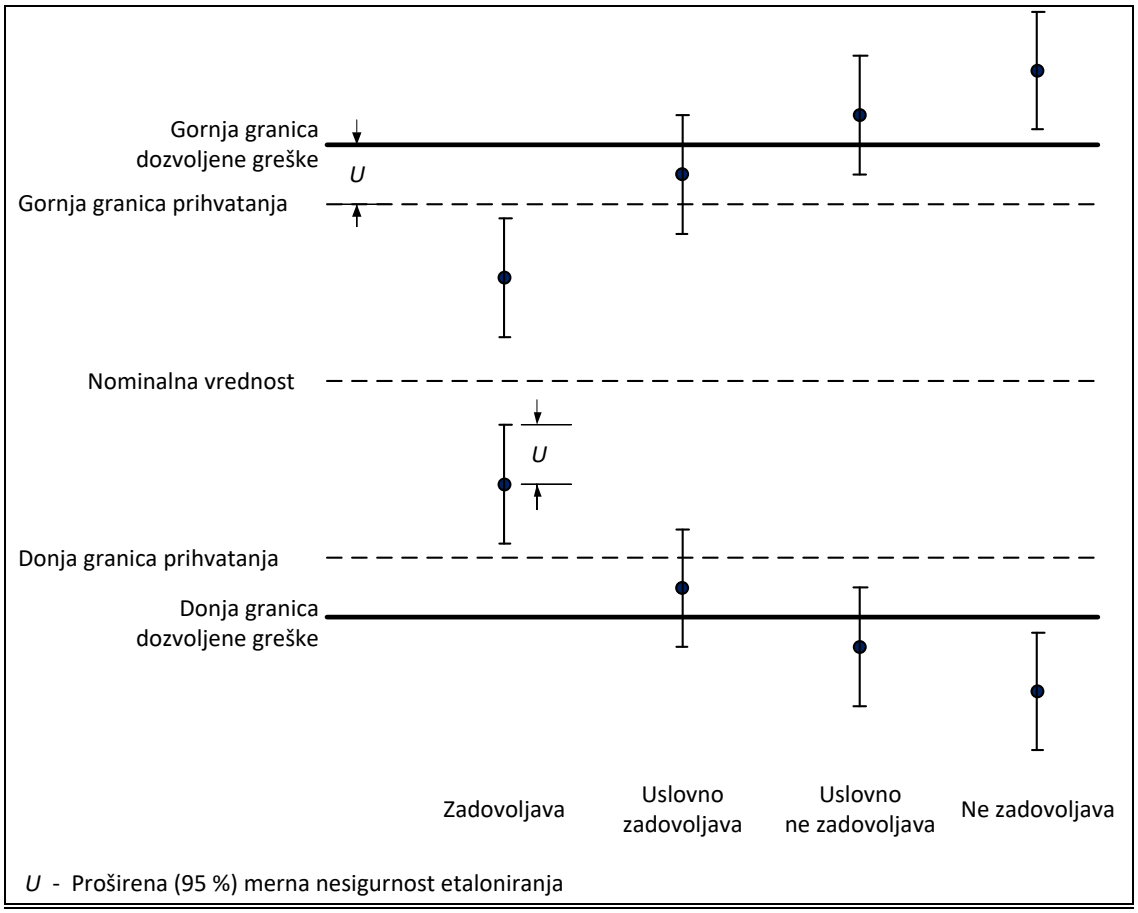
B. Između gornje granice prihvatanja i gornje granice dozvoljene greške, ili, između donje granice prihvatanja i donje granice dozvoljene greške;

C. Iznad gornje granice dozvoljene greške, uz nesigurnost koja zahvata i oblast ispod gornje granice dozvoljene greške, ili, ispod donje granice dozvoljene greške, uz nesigurnost koja zahvata i oblast iznad donje granice dozvoljene greške;

D. Zajedno sa nesigurnošću iznad gornje granice dozvoljene greške, ili, zajedno sa nesigurnošću ispod donje granice dozvoljene greške.

Ocena usaglašenosti sa specifikacijom instrumenta donosi se na osnovu položaja greške na Slici 1.

- *Ako se greška nađe u oblasti A, zaključuje se da za datu tačku etaloniranja instrument zadovoljava uslove u pogledu tačnosti i dodeljuje mu se ocena "Zadovoljava - "Pass". Rizik, (false accept), da se dodeli ocena "Zadovoljava" i u slučaju da instrument ne ispunjava uslove tačnosti, nije veći od 2.5 %.*
- *Ako se greška nađe u oblasti B, zaključuje se da za datu tačku etaloniranja instrument uslovno zadovoljava uslove u pogledu tačnosti i dodeljuje mu se ocena "Uslovno zadovoljava" - "Conditional Pass". Rizik (false accept) da se dodeli ocena "Uslovno zadovoljava" i u slučaju da instrument ne ispunjava uslove tačnosti, nije veći od 50 %.*
- *Ako se greška nađe u oblasti C, zaključuje se da za datu tačku etaloniranja instrument uslovno ne zadovoljava uslove u pogledu tačnosti i dodeljuje mu se ocena "Uslovno ne zadovoljava" - "Conditional Fail". Rizik (false reject) da se dodeli ocena "Uslovno ne zadovoljava" u slučaju da instrument ispunjava uslove tačnosti, nije veći od 50 %.*
- *Ako se greška nađe u oblasti D, zaključuje se da za datu tačku etaloniranja instrument ne zadovoljava uslove u pogledu tačnosti i dodeljuje mu se ocena "Ne zadovoljava" – "Fail". Rizik (false reject) da se dodeli ocena "Ne zadovoljava" u slučaju da instrument ispunjava uslove tačnosti, nije veći od 2.5 %.*



Sl. 1. Grafički prikaz Pravila za ocenu usaglašenosti mernog instrumenta sa njegovom specifikacijom

5. ZAKLJUČAK

Ne postoji obavezujući zahtev za IoU, ali ako je potreban, može se dogovoriti između laboratorije za etaloniranje i korisnika/vlasnika instrumenta. U tom slučaju se mora jasno definisati i dogovoriti PO, dato od strane laboratorije ili korisnika.

6. REFERENCE

[1] Urekar, M.: P*relazak na novu verziju standarda SRPS ISO/IEC 17025:2017 i njegova primena u akreditovanoj Laboratoriji za metrologiju na Fakultetu tehničkih nauka*, 26. skup *Trendovi razvoja*, TREND 2020, Kopaonik, 2020.

[2] Urekar, M.: *Izmene i novi zahtevi u standardu ISO/IEC 17025:2017*, 4. skup *Merno-informacione tehnologije*, FTN, Novi Sad, 2019.

[3] SRPS ISO/IEC 17025:2017 *Opšti zahtevi za kompetentnost laboratorija za ispitivanje i laboratorija za etaloniranje*, Institut za standardizaciju Srbije, 2017.

[4] ISO/IEC Guide 2:2004, *Standardization and related activities, General vocabulary*

[5] ISO/IEC 17000:2020 *Conformity assessment — Vocabulary and general principles*

[6] ILAC-G8:09/2019 *Guidelines on Decision Rules and Statements of Conformity*

[7] *Ocena usaglašenosti sa specifikacijom*, Laboratorija za metrologiju, FTN, 2021.

Autori: **Doc. dr Marjan Urekar, dr Nemanja Gazivoda, Prof. dr Ivan Župunski,** Univerzitet u Novom Sadu, Fakultet tehničkih nauka, Trg Dositeja Obradovića 6, 21000 Novi Sad, Srbija.
E-mail: urekarm@uns.ac.rs,
nemanjagazivoda@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Urekar, M., Gazivoda, N.

LABORATORIJA ZA METROLOGIJU: UVERENJE O ETALONIRANJU PREMA SRPS ISO/IEC 17025:2017

Rezime: *Izveštavanje o rezultatima je jedan od ključnih aspekata standarda ISO 17025:2017. Uverenje o etaloniranju je krajnji dokument koji, kao izlaz niza procesa unutar akreditovanih laboratorija za ispitivanje i etaloniranje, predstavlja osnovno sredstvo obezbeđivanja dokaza sledivosti merenja, kao i dokumentovanu informaciju o usaglašenosti predmeta provere sa zahtevima niza standarda, zakonskih, pravnih i regulatornih akata. Zahtevi nove verzije standarda ISO 17025 nameću izazove laboratorijama u procesu (re)akreditacije u pogledu šta je i kako potrebno izmeniti u Uverenju. Ovaj rad predstavlja razmatranje na ovu temu sprovedeno u Laboratoriji za metrologiju na Fakultetu tehničkih nauka u Novom Sadu.*

Ključne reči: *metrologija, ISO 17025, laboratorija, uverenje o etaloniranju*

1. UVOD

Izveštavanje o rezultatima je jedan od ključnih aspekata standarda ISO 17025:2017. Uverenje o etaloniranju je krajnji dokument koji, kao izlaz niza procesa unutar akreditovanih laboratorija za ispitivanje i etaloniranje, predstavlja osnovno sredstvo obezbeđivanja dokaza sledivosti merenja, kao i dokumentovanu informaciju o usaglašenosti predmeta provere sa zahtevima niza standarda, zakonskih, pravnih i regulatornih akata. Ovaj rad predstavlja deo istraživanja na ovu temu, sprovedenog u Laboratoriji za metrologiju (LzM) na Fakultetu tehničkih nauka, [1] i [2].

2. UVERENJE O ETALONIRANJU

Tačka 7.x se odnosi na [3], a Tačke 4.x i 5.x na [4]. Navodi iz standarda su dati *italik* fontom indikujući direktni citat standarda. Sa "*" je označen početak komentara na citiran deo.

*7.8.1.2 Rezultati moraju da se daju tačno, jasno, nedvosmisleno i objektivno, obično u izveštaju (npr. izveštaj o ispitivanju ili sertifikat o etaloniranju***) ili izveštaj o uzorkovanju) i moraju da obuhvate sve informacije koje su dogovorene sa korisnikom i koje su neophodne za tumačenje rezultata, kao i sve informacije koje se zahtevaju korišćenom metodom. Svi izdati izveštaji moraju da se čuvaju kao tehnički zapisi.*

NAPOMENA 1 Za potrebe ovog dokumenta izveštaji o ispitivanju i sertifikati o etaloniranju ponekad se nazivaju sertifikati o ispitivanju i izveštaji o etaloniranju, kako je odgovarajuće.

NAPOMENA 2 Izveštaji se mogu izdavati na papiru ili u elektronskom obliku, pod uslovom da su ispunjeni zahtevi ovog dokumenta.

7.8.1.3 Bilo koje informacije navedene u tačkama od 7.8.2. do 7.8.7, o kojima korisnik nije izvešten, moraju da budu lako dostupne.

**5.10.1 Opšte odredbe* bez promena, razdvojeno u više tačaka. Napomene nisu promenjene.

7.8.2 Opšti zahtevi za izveštaje (ispitivanje, etaloniranje ili uzorkovanje)

7.8.2.1 Svaki izveštaj mora da sadrži najmanje sledeće informacije, čime se svodi na najmanju meru svaka mogućnost za nesporazum ili zloupotrebu, osim ako laboratorija ima opravdane razloge da ne uradi tako:

a) naslov (npr. „izveštaj o ispitivanju", „sertifikat o etaloniranju" ili „izveštaj o uzorkovanju");

**5.10.2 a)* bez promene. Termin "uverenje" je i dalje jasno definisan kao u *5.10.1 Napomena 1*, sada u:

*7.8.1 Nacionalne fusnote ***) Sertifikati o etaloniranju se u Srbiji često nazivaju uverenja o etaloniranju.*

b) naziv i adresu laboratorije;

*Nepromenjen prvi deo *5.10.2 b)*. Pun naziv LzM sa odrednicama strukturne pripadnosti institucijama i adresa FTN, kao matične institucije.

c) lokaciju izvođenja laboratorijskih aktivnosti, uključujući i one situacije kada se laboratorijska aktivnost izvodi u objektima korisnika ili na lokacijama udaljenim od stalnih objekata laboratorije, ili u povezanim privremenim ili pokretnim objektima;

*Drugi deo zahteva *5.10.2 b)* izdvojen posebno. Ovde je zanimljiv detalj da je po prethodnom zahtevu navedena primarna adresa matične institucije FTN kao pravnog lica. Dok je LzM bio na istoj adresi kao FTN, ovo nije bila dilema, ali

po preseljenju LzM u drugi objekat u okviru iste institucije, postavljalo se pitanje promene adrese u Uverenju. Pošto je administrativni centar i dalje na staroj adresi, nova adresa LzM će sada biti dodana na postojeću odrednicu mesta etaloniranja: "Laboratorija za metrologiju, NTP-2L, Naučno-tehnološki park Novi Sad, Fruškogorska 1". Ukoliko se etaloniranje obavlja van prostorija LzM, ovde će to biti navedeno, bez potrebe promene zaglavlja. Stari zahtev iz *5.10.8 NAPOMENA 2 Zaglavlja treba da budu što je moguće više standardizovana*, više ne postoji. Pod X1 na Sl. 1 je navedena dodatna informacija o kontakt telefonima i e-mail adresi LzM. Ovo može da deluje kao nelogično u svetlu prethodne tačke (odnose se na LzM, a ne na FTN), ali pošto nije deo zahteva, ova informacija je zapravo dodatno obezbeđenje mogućnosti komunikacije, te se može smatrati ispunjenjem zahteva *7.8.1.3.*

d) jedinstvenu identifikaciju da se svi njegovi delovi prepoznaju kao sastavni deo kompletnog izveštaja i jasnu identifikaciju kraja izveštaja;

*Drugačije formulisana i dopunjena *5.10.2 c)* i *NAPOMENA 1 Izveštaji o ispitivanju i uverenja o etaloniranju u obliku trajnog zapisa treba da sadrže broj strane i ukupan broj strana.* Numerisanje strana nije striktno, ali je najjednostavniji način zadovoljenja ovog zahteva. Jasno se mora naznačiti kraj Uverenja, što nije novi zahtev, ali je sada logično smešten u ovoj tački, dok je prethodno bio deo *4.3.2 Odobravanje i izdavanje dokumenata* pod *4.3.2.3*. Značaj ovoga je da posle oznake kraja Uverenja ne može biti nikakvih naknadno dodatih informacija. Napomena X4 "Prilog: Rezultati etaloniranja" mora da se obriše. Rezultati su sastavni deo kompletnog izveštaja, a ne posebni koji se prilaže uz izveštaj, što je značenje priloga. Ovo bi moglo da dovede korisnika u zabunu da je Uverenje samo prva strana dokumenta, te je potrebno obrisati ovu napomenu radi jasnoće.

e) naziv i informacije za kontakt sa korisnikom;

*Mala izmena *5.10.2 d) naziv i adresu korisnika*. Nazivi, telefoni, adrese korisnika i sl. se menjaju, pa je ovde jasnije naznačeno da je potrebno obezbediti pouzdan način za kontaktiranje korisnika, ne samo adrese. LzM održava bazu svojih korisnika pa je u Uverenjima kao dovoljna informacija naveden naziv i sedište korisnika. Radi formalnog zadovoljenja ove tačke, potrebno je uključiti i npr. e-mail kontakt/odgovorne osobe korisnika. Zbog dvosmislenosti prevoda, moguće je protumačiti da je X1 deo ovog zahteva (omogućiti korisniku kontakt sa LzM), ali uvidom u original, jasno je da to nije slučaj.

f) identifikaciju korišćene metode;

**5.10.2 e)* bez promene. Navodi se prema kom dokumentu LzM (radnom uputstvu) se vrši etaloniranje, u kojem je navedena metoda i sve relevantne informacije (oprema, priprema, postupak).

g) opis, jednoznačnu identifikaciju i, kada je neophodno, stanje predmeta;

**5.10.2 f)* bez promene. Postojeće Uverenje nema deo gde bi moglo da se zapiše stanje predmeta, pa je radi standardizovanja dokumenta potrebno uneti dodatno polje za opis stanja predmeta. Ovo se u uslovima prakse pokazuje kao bitan faktor, pošto klijenti LzM često propuste da sa instrumentom za etaloniranje dostave sve potrebne kablove (često specifičnog tipa) i baterije. Nekad ostave stare istrošene ili neispravne punjive baterije. Osigurači su ponekad pregoreli ili nedostaju, bez rezervnih kompleta. Pošto se neki instrumenti dostavljaju poštom, moguća su i oštećenja u transportu, pa je time još potrebnije ostaviti mesto za zapis stanja predmeta, sa bitnim razlikovanjem napomena "Primećeno po prijemu" i "Naznačeno od strane korisnika". Ovo sve se uglavnom izbegava putem prevencije prethodnim komuniciranjem, ali to i dalje ne obezbeđuje izostanak navedenih pojava.

h) datum prijema predmeta ispitivanja ili etaloniranja i datum uzorkovanja, gde je to kritično za validnost i primenu rezultata;

*Nepromenjen prvi deo *5.10.2 g)*. Datum prijema je kritičan kod ispitivanja/uzorkovanja, što nije delatnost LzM. Kako se ovaj podatak ne može smatrati kritičnim za etaloniranje i Uverenje, nije ga potrebno navoditi. Međutim, postoji opravdanje (*7.8.2.1 …čime se svodi na najmanju meru svaka mogućnost za nesporazum ili zloupotrebu, osim ako laboratorija ima opravdane razloge da ne uradi tako*) kao i dobra praksa, da se zbog jasnoće informacija i olakšavanja praćenja dokumentacije korisniku, ovaj podatak radi potpunosti, ipak uključi u Uverenje, što će biti odlučeno u finalnoj verziji dokumenta.

i) datum(e) obavljanja laboratorijske aktivnosti;

*Drugi deo zahteva *5.10.2 g)* gde se ne navodi specifično etaloniranje, već *aktivnosti*, što može biti od značaja za druge laboratorije (priprema, rad na predmetu, itd.), ali za LzM je to samo etaloniranje, pa ovaj podatak ostaje. Izmena koja će biti uvedena, je podatak ako je proces trajao više dana, što mora biti naznačeno, jer do sada je pisan samo završni dan aktivnosti.

j) datum izdavanja izveštaja;

*Ponovo zahtev prebačen iz *4.3.2.3*. Bez promena.

k) pozivanje na plan uzorkovanja i metodu uzorkovanja koju laboratorija ili druga tela koriste, ukoliko su oni relevantni za validnost ili primenu rezultata;

**5.10.2 h)* bez promene. LzM ne vrši uzorkovanje.

l) izjavu o tome da se rezultati odnose samo na predmete koji su ispitivani, etalonirani, ili uzorkovani;

**5.10.2 k)* sa obrisanim uslovom *ako je važno*, što sada ovu odrednicu čini obaveznom. Na kraju uverenja je potrebno dodati rečenicu "Rezultati navedeni u ovom Uverenju se odnose isključivo i samo na predmet etaloniranja sa datim serijskim brojem, naveden na početku Uverenja."

m) rezultate sa mernim jedinicama, tamo gde je odgovarajuće;

**5.10.2 i)* sada sa obaveznim, ne opcionim, navođenjem mernih jedinica rezultata. Ovo je bio deo originalnog Uverenja, pa nema izmena. Uključeni su i dodatni podaci kada je to relevantno, kao *opseg*, *parametar*, i sl.

n) dodatke, odstupanja ili izostavljanja u odnosu na metodu;

**5.10.2 h)* bez promene. Ovi podaci se upisuju posle navedenih rezultata merenja u delu "Napomene", koji se dodaje kada je to potrebno.

o) identifikaciju osoba koje odobravaju izveštaj;

*Pojednostavljen *5.10.2 j)* bez obaveze potpisivanja Uverenja i navođenja funkcija. Način *identifikacije* nadležnih osoba je na Laboratoriji. Ovde postoji sloboda navođenja dodatnih informacija, pa se LzM odlučila da navede Rukovodioca ili Pomoćnika Rukovodioca koji su nadležni za odobravanje izveštaja. Opcija X3 se briše (izvršilac etaloniranja), dok je potpis pod X2 eliminisan kao nepotreban (fokus je na Laboratoriji kao odgovornoj, ne na pojedincima).

p) jasnu identifikaciju kada su rezultati dobijeni od eksternih isporučilaca.

*Zahtev izvučen iz *5.10.6* i *5.6.2.1.1*. LzM ne koristi rezultate dobijene od eksternih isporučilaca.

NAPOMENA Uključivanjem izjave kojom se specificira da izveštaj ne sme da se reprodukuje, osim u celosti, bez odobrenja laboratorije, može da se osigura da delovi izveštaja neće biti izvučeni iz konteksta.

*Pojašnjena *5.10.2 Napomena 2*. Potrebno je dodati (iako nije obavezno) pre kraja Uverenja: "Ovo Uverenje se ne sme reprodukovati, osim u celosti, bez odobrenja Laboratorije za metrologiju."

7.8.2.2 Laboratorija mora da bude odgovorna za sve informacije koje se daju u izveštaju, osim kada se informacija dobija od korisnika. Podaci dobijeni od korisnika moraju da budu jasno identifikovani. Osim toga, kada se informacija dobija od korisnika i ako ona može da utiče na validnost rezultata, u izveštaju mora da bude navedeno odricanje od odgovornosti. …

*Nov zahtev. Ukoliko su takvi podaci dobijeni od korisnika, u delu „Napomene" pre kraja Uverenja, dodati "Laboratorija se odriče odgovornosti za sledeće podatke dostavljene od strane imaoca predmeta etaloniranja:", pri čemu taksativno navesti sve relevantne podatke. Ovo takođe pokazuje neophodnost sistemskog rešavanja rubrike „Napomene", kako bi mogla lako da se realizuje u Uverenju.

7.8.4 Specifični zahtevi za sertifikate o etaloniranju (Zahtevi ove tačke na Sl. 1 i Sl. 2 navedeni su sa duplim malim slovom.)

7.8.4.1 Pored zahteva koji su navedeni u 7.8.2, sertifikati o etaloniranju moraju da obuhvataju sledeće:

**5.10.4.1* sa izbačenom odrednicom *ako je neophodno za tumačenje rezultata etaloniranja.* Sada su to obavezni zahtevi.

a) mernu nesigurnost rezultata merenja prikazanu u istoj jedinici merenja kao što je merena veličina ili u relativnoj vrednosti u odnosu na merenu veličinu (npr. u procentima);

*Izvučeno iz *5.10.4.1* i *5.6.2.1.1*, dopunjeno *relativnim vrednostima*. Iskazivanje merne nesigurnosti rezultata je sada obavezno. Redovno se primenjuje u LzM.

NAPOMENA Prema ISO/IEC Guide 99 rezultat merenja se uobičajeno prikazuje kao pojedinačno izmerena kvantitativna vrednost koja uključuje jedinicu merenja i mernu nesigurnost.

*Nova napomena sa dodatnim objašnjenjem. U primeni u LzM.

b) uslovi (npr. sredine) pod kojima su obavljena etaloniranja, koji imaju uticaj na rezultate merenja;

**5.10.4.1 a)* bez promene. Standardni deo Uverenja LzM.

c) izjavu kojom se identifikuje kako su merenja metrološki sledljiva (videti Prilog A);

*Dopuna 5.10.4.1. Ova izjava je uključena u postojeća Uverenja kao "Metrološka sledivost". U informativnom *Prilogu A* standarda je data iscrpna analiza ove teme.

d) rezultate pre i nakon bilo kakvog podešavanja ili popravke, ako su dostupni;

**5.10.4.3* bez izmena. LzM ne vrši podešavanja i popravke predmeta etaloniranja.

e) kada je relevantno, izjavu o usaglašenosti sa zahtevima ili specifikacijama (videti 7.8.6);

*Odnosi se na *5.10.4.2* koja je detaljno data u *7.8.6.*

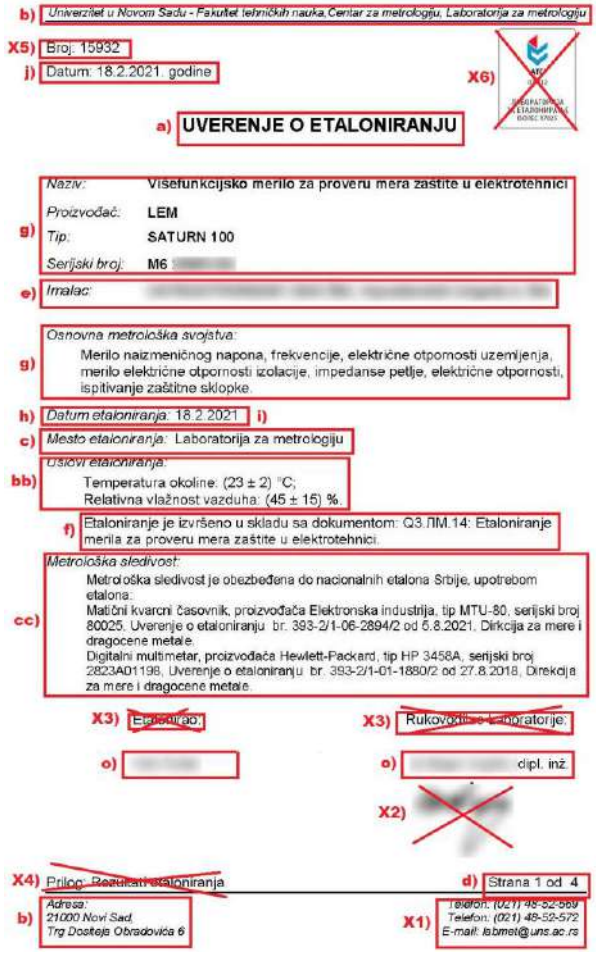
f) kada je to odgovarajuće, mišljenja i tumačenja (videti 7.8.7).

*Odnosi se na *5.10.4.5* koja je detaljno data u *7.8.7.*

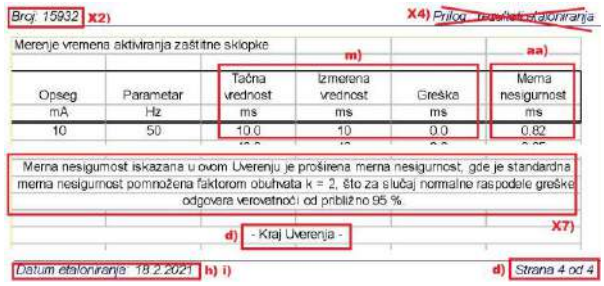
7.8.4.3 Sertifikat o etaloniranju ili oznaka

etaloniranja ne sme da sadrži bilo kakve preporuke za interval etaloniranja, osim kada je to dogovoreno sa korisnikom.

**5.10.4.4*, bez odrednice mogućnosti nametanja pravnim propisima. Preporuka se daje samo na izričit zahtev korisnika (koji mora biti naznačen), pod „Napomene“, uvek za period od 1 godine.



Sl. 1. Uverenje LzM, prva strana. Legenda: *w)* se odnosi na 7.8.2, *ww)* na 7.8.4, *X)* nepotrebni.



Sl. 2. Uverenje LzM, poslednja strana (sažeto).

7.8.4.2 i *7.8.5* se odnose na izveštavanje o uzorkovanju koje se ne radi u LzM.

7.8.6 Izveštavanje u vezi sa izjavom o usaglašenosti i *7.8.7 Izveštavanje u vezi sa mišljenjima i tumačenjima* nisu deo standardnog Uverenja, nego se rade na zahtev korisnika.

5.10.2 c) jedinstvenu identifikaciju izveštaja o ispitivanju ili uverenja o etaloniranju (kao što je serijski broj)

*Ovaj zahtev više ne postoji, ali serijski broj Uverenja (X5) je zadržan zbog jedinstvenog označavanja dokumenta i načina vođenja arhive.

5.6.2.1 Etaloniranje NAPOMENA 1 … Dovoljan dokaz o sledljivosti prikazanih podataka o etaloniranju jeste uverenje o etaloniranju sa logotipom akreditacionog tela, izdato od laboratorije za etaloniranje akreditovane po ovom međunarodnom standardu.

*Takođe izbrisan zahtev. Logotip ATS je uklonjen (X6), Laboratorija sada ima svu odgovornost za navedene podatke.

Tekst X7 nije deo 17025 zahteva, ali je odrednica koja se zahteva po uputstvu EA, ILAC i JGCM. Prema [5], postojeća rečenica se menja sa: “Prijavljena je proširena nesigurnost koja proizilazi iz standardne kombinovane merene nesigurnosti pomnožena sa faktorom pokrivenosti k=2. Procena merne nesigurnosti izvršena je prema “Vodiču za izražavanje nesigurnosti merenja” (JCGM 100:2008). Vrednost merene veličine nalazi se unutar pripisanog intervala sa verovatnoćom oko 95 %. Prijavljena nesigurnost ne uključuje procenu dugoročnih varijacija.”

3. ZAKLJUČAK

Izmene u Uverenju su urađene prema svim zahtevima nove verzije standarda ISO 17025.

4. REFERENCE

[1] Urekar, M.: P*relazak na novu verziju standarda SRPS ISO/IEC 17025:2017 i njegova primena u akreditovanoj Laboratoriji za metrologiju na Fakultetu tehničkih nauka*, 26. skup *Trendovi razvoja*, TREND 2020, Kopaonik, 2020.

[2] Urekar, M.: *Izmene i novi zahtevi u standardu ISO/IEC 17025:2017*, 4. skup *Merno-informacione tehnologije*, FTN, Novi Sad, 2019.

[3] SRPS ISO/IEC 17025:2017

[4] SCS ISO/IEC 17025:2006

[5] *Metrološki vodič*, 3. izdanje, Direkcija za mere i dragocene metale, Srbija, 2008.

¶ (11 pt)

Autori: **Doc. dr Marjan Urekar, dr Nemanja Gazivoda,** Univerzitet u Novom Sadu, Fakultet tehničkih nauka, Trg Dositeja Obradovića 6, 21000 Novi Sad, Srbija.

E-mail: urekarm@uns.ac.rs, nemanjagazivoda@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Razumić, A., Horvatić Novak, A., Štrbac, B., Runje B.

INFLUENCE OF SCAN PARAMETERS ON SURFACE TOPOGRAPHY OBTAINED VIA AFM

Abstract: *At the nano level, the surface condition is quantitatively described by areal topography parameters also known as 3D roughness parameters. In this paper, the measurement of areal topography parameters was conducted by using the atomic force microscope, tapping mode. The influence of scan parameters on the results of surface topography measurements, such as scan speed, scan size, and scan resolution, were analyzed using the design of experiments. In this paper, the values of scanning parameters for selected samples are discussed with the aim of establishing rules which will enable results measured on different atomic force microscopes to be comparable.*
Keywords: *surface topography, atomic force microscope, scan parameters*

1. INTRODUCTION

Over the last three decades, there has been a need to link the surface topography to the function of that same surface [1]. Although linear profile measurement can provide some functional surface data, areal or three-dimensional (3D) measurement is required to actually determine functional information [2]. The areal measurement of surface topography has a number of advantages over line profile measurement. Areal measurement gives a more realistic view of the entire surface and has greater statistical significance [3]. Also, certain profile features are less likely to be omitted by areal measurement, thus a better visual record of the overall surface structure is achieved. The need for areal measurements of surface topography has resulted in the development of areal measurement devices. Microscopes with scanning probes stand out in particular, in which the main representative is the atomic force microscope (AFM) [4].

The atomic force microscope works on the principle of a raster transition of a sharp-tipped probe over the surface of a sample. The main goal of using an atomic force microscope is to obtain information on the surface topography of the measured sample [5]. Measurements can be performed by contact, tapping or non-contact mode. Contact mode is the first developed mode, and it works on the principle of passing the probe over the surface of the sample with constant contact with the sample [6]. Tapping mode is the most common way of scanning by the AFM [7]. It involves passing a probe over the surface of the sample with oscillating contact with the sample. The measurements of the samples in this paper were performed using the tapping mode on the atomic force microscope of the *Oxford MFP-3D Origin* model at the Faculty of Mechanical Engineering and Naval Architecture in Zagreb. There is also a non-contact mode – a mode in which the probe passes over the sample surface, oscillates above the sample surface, without touching the sample [8].

2. SCAN INPUT PARAMETERS

Before the measurement is performed, the input scan parameters are set, which are: scan speed, scan resolution and scan size. Different values can be used for each of these parameters. Parameters such as scanning force and scanning amplitude are set to the optimal value, depending on the sample material and the type and wear of the probe. Measurements were performed on two standards. Two standards with different surface topography were selected. Standard 1 (Figure 1) consists of linear gratings with raised and recessed grooves. Standard 2 (Figure 2) has raised pillars on it.

In order to obtain information on the influence of input parameters on the areal topography parameters, a design of experiment was made and implemented. Prior to the implementation of the design of experiment, the quality of the standard was calculated. Five measurements with the same input parameters, but at five different measuring points, were performed on each of the selected standards. The measurement was performed with the following input parameters: the size of the scanned area 20 μm × 20 μm, resolution 256 and scanning speed 80 μm s^{-1}.

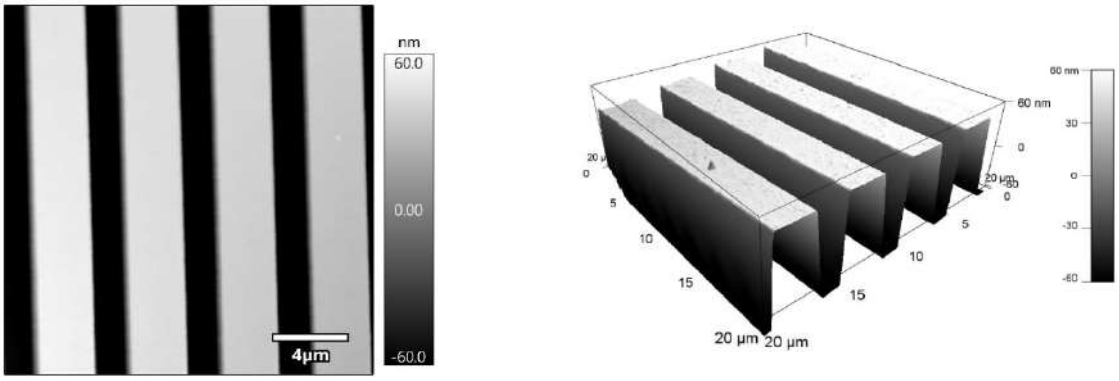


Fig. 1. Standard 1: 2D (left) and 3D (right) form

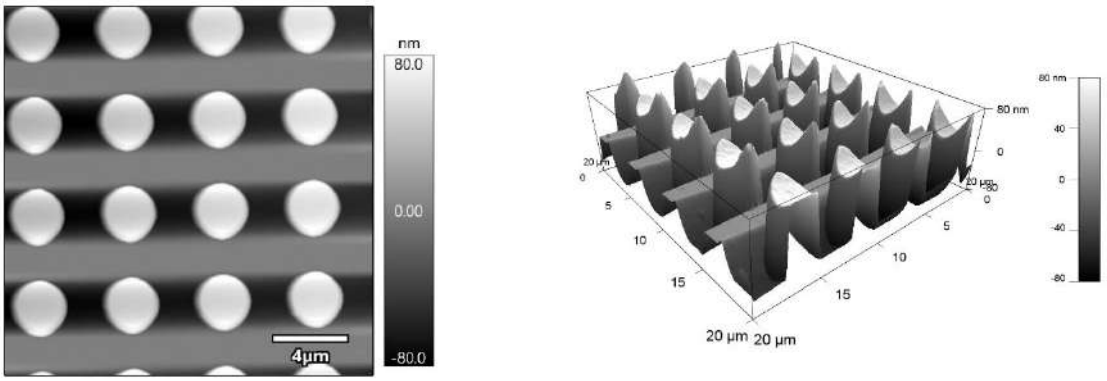


Fig. 2. Standard 2: 2D (left) and 3D (right) form

The measurement was performed with the following input parameters: the size of the scanned area 20 µm × 20 µm, resolution 256 and scanning speed 80 µm s^{-1}. As a result, areal topography parameters were monitored. Observing the most used parameter *Sa*, the quality of the standard is within 1 nm. In other words, by changing the scan location on the standard itself with unchanged other parameters, the surface parameters of the topography are in the range of 1 nm. It can be concluded that the standards are uniform and the design of experiment was performed on them.

3. DESIGN OF EXPERIMENT

The design of experiment shows the significance of the AFM scanning input parameters. A factorial trial plan was selected. The factorial design of experiment implies the performance of experiment for all levels of the selected input variables. Table 1 shows the input variables for the design of experiment. In this design of experiment each variable has two levels, so a two-factor experimental design is implemented.

Table 1. Input variables in the design of experiment

Variable label	Input variable	Type of variable	Measuring unit	Lower value	Higher value
A	Standard	Nominal	–	Standard 1	Standard 2
B	Scan size	Ratio	µm × µm	10 × 10	20 × 20
C	Scan resolution	Ratio	–	256	512
D	Scan speed	Ratio	µm s^{-1}	50	80

The design of experiment was designed using the trial version of Design-Expert software. Considering that this is a two-factor design of experiment, and the number of repetitions of each measurement is 3, the total number of performed measurements is calculated as 3×2^n, where n is the number of input variables. In this case, the number of input variables is 4, so the total number of measurements is 48. Since the selected standards differ in construction, and thus in values of areal topography parameters, the values of areal topography parameters included in the analysis are standardized: each result is reduced by the arithmetic mean of each standard.

As an output, the most used areal topography parameters were monitored, the *Sa* and *Sz* topography parameters. After the implementation and analysis of the design of experiment, the

following results are obtained. The parameter *Sa* was analyzed first. Table 2 shows the significant dependences of the *Sa* parameter on the input scan parameters.

Table 2. Analysis of variance for the developed mathematical model for the parameter *Sa*

Source	Sum of Squares	df	Mean Square	*F*-value	*P*-value	Significance
Model	73.85	4	18.46	18.27	< 0.0001	significant
Model members						
B	31.65	1	31.65	31.32	< 0.0001	significant
AB	32.64	1	32.64	32.30	< 0.0001	significant
AD	4.26	1	4.26	4.22	0.0462	significant
BCD	5.31	1	5.31	5.26	0.0268	significant
Residual	43.45	43	1.01			
Lack of Fit	7.39	11	0.6719	0.5964	0.8175	insignificant
Pure Error	36.06	32	1.13			
Cor Total	117.30	47				

The Model *F*-value of 18.27 implies the model is significant. There is only a 0.01% chance that an *F*-value this large could occur due to noise. *P*-values less than 0.0500 indicate model terms are significant. In this case B, AB, AD, BCD are significant model terms. The Lack of Fit *F*-value of 0.60 implies the Lack of Fit is not significant relative to the pure error. There is an 81.75% chance that a Lack of Fit *F*-value this large could occur due to noise. Since the deviation from the model is not significant, the model is accepted and continues to be analyzed.

Table 3. Quantities that describe the quality of the developed mathematical model for the parameter *Sa*

Standard deviation	1.01
Arithmetic mean	-3.269E-15
Coefficient of variation, %	3.075E+16
Coefficient of determination R^2	0.6296
Adjusted coefficient of determination R_{adj}^2	0.5952
Predicted coefficient of determination R_{pre}^2	0.5385
Adequate precision	13.9763

Table 3 shows the quantities that describe the quality of the developed mathematical model for the parameter *Sa*. The difference between the predicted coefficient of determination R_{pre}^2 in the amount of 0.5361 and the adjusted coefficient of determination R_{adj}^2 which is 0.5931 is less than 0.2. Therefore, it can be concluded that the predicted and adjusted coefficients of determination are in reasonable agreement. Adequate precision measures the signal-to-noise ratio. A ratio greater than 4 is desirable. In this case, the value of adequate precision in the amount of 13.934, which is higher than the minimum required value.

The obtained mathematical model is as follows:

$$Sa = -3.30521E\text{-}15 + 0.811197\ B - 0.824572\ A\ B + 0.297875\ A\ D - 0.332672\ A\ B\ C \quad (1)$$

Also, the design of experiment for the output variable *Sz* was analyzed. Table 4 shows the significant dependences of the *Sz* parameter on the input scan parameters.

Table 4. Analysis of variance for the developed mathematical model for the parameter *Sz*

Source	Sum of Squares	df	Mean Square	*F*-value	*P*-value	Significance
Model	1.411+05	2	70543.34	27.65	< 0.0001	significant
Model members						
B	71717.61	1	71717.61	31.71	< 0.0001	significant
AB	69369.07	1	69369.07	30.67	< 0.0001	significant
Residual	1.148E+5	45	2551.38			
Lack of Fit	31615.01	13	2431.92	0.9354	0.5300	insignificant
Pure Error	83197.24	32	2599.91			
Cor Total	2.559E+05	47				

Table 4 shows the quantities that describe the quality of the developed mathematical model for the parameter *Sz*. The Model *F*-value of 27.65 implies the model is significant. There is only a 0.01% chance that an *F*-value this large could occur due to noise. *P*-values less than 0.0500 indicate model terms are significant. In this case, B and AB are significant model terms.. The Lack of Fit *F*-value of 0.94 implies the Lack of Fit is not significant relative to the pure error. There is an 53.00% chance that a Lack of Fit F-value this large could occur due to noise. Since the deviation from the model is not significant, the model is accepted and continues to be analyzed.

Table 5. Quantities that describe the quality of the developed mathematical model for the parameter *Sz*

Standard deviation	50,51
Arithmetic mean	-9,892E-14
Coefficient of variation, %	5,106E+16
Coefficient of determination R^2	0,5513
Adjusted coefficient of determination R_{adj}^2	0,5314
Predicted coefficient of determination R_{pre}^2	0,4895
Adequate precision	12,1430

Table 5 shows the quantities that describe the quality of the developed mathematical model for the parameter *Sz*. The difference between the predicted coefficient of determination R_{pre}^2 in the amount of 0.4895 and the adjusted coefficient of determination R_{adj}^2 which is 0.5314 is less than 0.2. Therefore, it can be concluded that the predicted and adjusted coefficients of determination are in reasonable agreement. Adequate precision measures the signal-to-noise ratio. A ratio greater than 4 is desirable. In this case, the value of adequate precision in the amount of 12.1430, which is higher than the minimum required value.

In the end, the obtained mathematical model is as follows:

Sz = -8,44056E-14 + 38,6538 B + 36,0156 A B (2)

4. CONCLUSION

The paper analyzes the influence of scanning parameters such as scan size, scan resolution, scan speed as well as the influence of sample topography on the areal topography parameters *Sa* and *Sz*. The analysis was performed by applying the factor design of experiment in order to obtain the functional ratio of the input variables to the output variables *Sa* and *Sz*. Statistically significant input variables of the model were included in the obtained expressions. The output size *Sa* is statistically significantly affected by scan size and the interactions of the input quantities: standards with different topographies and scan size; standards with different topographies and scan speed; standards with different topographies, scan size and scan speed. The output size *Sz* is statistically significantly affected by the scan size and the interaction of the input quantities: standards with different topographies and scan size. The obtained mathematical model will be used in estimating the components of measurement uncertainty due to the influence of the topography of the sample and the scan parameters.

Acknowledgments:
The authors acknowledge funding from the European Regional Development Fund (ESI ERDF) for the Innovative Croatian Solutions for the Global Automotive Industry (FAT) project.

5. REFERENCES

[1] P. Wüst, A. Edelmann, and R. Hellmann, 'Areal Surface Roughness Optimization of Maraging Steel Parts Produced by Hybrid Additive Manufacturing', *Materials*, vol. 13, no. 2, p. 418, Jan. 2020.

[2] R. Leach (auth.) and R. Leach (eds.), *Optical Measurement of Surface Topography*, 1st ed. Springer-Verlag Berlin Heidelberg, 2011.

[3] L. Blunt and X. Jiang, *Advanced Techniques for Assessment Surface Topography: Development of a Basis for 3D Surface Texture Standards*. 2003. Accessed: Sep. 08, 2021.

[4] A. Razumić, A. Horvatić Novak, B. Runje, and M. Carević, 'Measurement of surface topography using an atomic force microscope', 2020, Accessed: Sep. 08, 2021.

[5] A. Razumić, A. Horvatić Novak, B. Štrbac, V. Alar, and B. Runje, 'The influence of filtering on surface topography parameters obtained by the AFM', *21th International Conference on Materials, Tribology & Recycling: MATRIB 2021*, p. 418, 2021.

[6] F. S. Russell-Pavier, L. Picco, J. C. C. Day, N. R. Shatil, A. Yacoot, and O. D. Payton, '"Hi-Fi AFM": high-speed contact mode atomic force microscopy with optical pickups', *Meas. Sci. Technol.*, vol.29, no.10, p.105902, 2018

[7] A. Labuda *et al.*, 'Tapping Mode AFM Imaging in Liquids with blueDrive Photothermal Excitation', *Micros.Today*, vol. 26, no. 6, pp. 12–17, Nov. 2018

[8] A. Rao *et al.*, 'Characterization of nanoparticles using Atomic Force Microscopy', *J. Phys.: Conf. Ser.*, vol. 61, pp. 971–976, Apr. 2007

Authors: **research assistant Andrej Razumić[1], postdoctoral researcher Amalija Horvatić Novak[1], assistant professor Branko Štrbac[2], full professor tenure Biserka Runje[1]** [1]University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Department of Quality, Ivana Lučića 5, 10000 Zagreb, Croatia; [2]University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia
E-mail: andrej.razumic@fsb.hr
amalija.horvatic@fsb.hr
strbacb@uns.ac.rs
biserka.runje@fsb.hr

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE**
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Tóth, T., Varga, P., Hudák, R.

DETERMINATION OF POLYMERS DENSITY USING INDUSTRIAL COMPUTED TOMOGRAPHY

Abstract: *The paper deals with the determination of the density of materials using industrial computed tomography. The density of eight different polymer samples and rubber was evaluated by industrial computer tomography Carl Zeiss Metrotom 1500. The scanning was performed without and with 0,25mm thick copper filter. The results were compared with the values of the material sheets and the density values, calculated on the basis of the volume obtained from the CT data and the weight of the given sample. The results show that the use of a filter has only a minimal effect on the density value, the maximum difference was 0.066 g.cm-3. When compared to the table value, the biggest difference in the textite was 0.051 g.cm-3. Based on the results computed tomography is a suitable tool for determining the densities of materials suitable for scanning.*
Key words: *industrial computed tomography, density, measurement*

1. INTRODUCTION

Density is a derived physical quantity that expresses the ratio of the weight of a measured object to its total volume. Using scales and similar devices, measuring the weight of an object is relatively easy, but determining the total volume can be more complicated. It can be obtained by calculating the individual dimensions of the object, or, for example, by the hydrostatic method. However, this creates a problem for geometrically complex and hollow objects. The aim was to design a suitable density determination methodology using industrial computed tomography to determine volume and density.

Nowadays, X-ray computed tomography (CT) finds application in several areas of medicine and technology, where it is used as an imaging device, or in the field of materials analysis, where it is used as a method for non-destructive imaging. It is also used in length metrology, where it is used to evaluate the dimensional and shape characteristics of objects. The advantage of CT is that it allows you to measure the internal and external geometry of objects without their destruction. [3]

Based on the densities of the scanned materials, CT makes it possible to determine the total and local volume of simple products, products of complicated geometric shapes, as well as hollow bodies. The basic condition for determining the volume of an object is quality surface determination - reconstruction of the object's surface.

2. METHODOLOGY

Scanning was performed on an industrial computed tomography Metrotom 1500 (Carl Zeiss, Germany). It is a device with a surface detector with a resolution of 1024x1024 pixels and an output of 225 kV.

Data processing was performed in VG StudioMAX software (Volume Graphics, Germany) and in its Measurement module.

Table 1. Metrotom 1500 specification

Detection technology	Area detector
Distance radiator - detector	1500 mm
Maximum voltage	225 kV
Maximum g current	1000 μA
Maximum power	225 W
Number of pixels on the detector	1024 x 1024
Pixel size	400 x 400
Scanned volume	Φ300 x 300 mm
Software	Computing software: ZEISS METROTOM OS Analysis software: ZEISS CALYPSO, VGStudio MAX

For scanning wereselected 8 samples of polymeric materials were. Table 2 lists show the individualmaterials and their catalogue densities.

Table 2. Analysed materials with density

Material	Density (gcm^{-3})
Textit	1,40
Polyamid (PA)	1,14
Polypropylene (PP)	0,91
Polyethylene (PE)	0,95
Polyvinylchlorid (PVC)	1,42
Gum	1,1
Polytetrafluoroethylene (PTFE)	2,16
Polyurethane (PU)	1,26

Individual scans were scanned without/with a mechanical copper filter with a thickness of 0.25 mm. The mechanical filter serves to eliminate soft radiation and reduce noise and artifacts generated during scanning. The individual samples used are rectangular and cylindrical in shape. while they are dimensionally different. The samples were separated by polystyrene and thus their mutual contact was prevented, which allowed good segmentation of individual samples. Individual samples were segmented from the whole, the surface determination was performed only on the given sample and subsequently, the density of the sample was evaluated on the basis of the achieved shade of gray.

T he gray value for surface determination is calculated from the relation (Equation 1):

$$\text{Isosurface}=\frac{\text{Background+Material}}{2} \qquad (1)$$

The isosurface edge detection method (ISO-50%) uses the average of the gray background (air) and gray material values to determine the mean ISO value. which is used for surface determination of the material surface.

The density of the samples was determined in two ways:

1. Weigh samples and CT scan volume
2. Weighing samples and volume from the hydrostatic test

The samples were weighed on a RADWAG PS 6000.R2 analytical balance.

Sampling process:

1. Scanning all samples in one scan without a filter
2. Scanning all samples in one scan without filter
3. Scanning 1 group of samples with a mechanical filter
4. Scanning 2 groups of samples with a mechanical filter

2.1 Scanning all samples

All samples were scanned with and without a mechanical filter at the device settings listed in Table 3.

Table 3. Scanning parameters

Voltage (kV)	160
Current (µA)	600
Integration time (ms)	1000
Gain	8
Filter (mm)	0,25
Voxel size (µm)	146,29
Number of projections	1000

On FIG. 1. shows the distribution of all samples at the time of scanning.

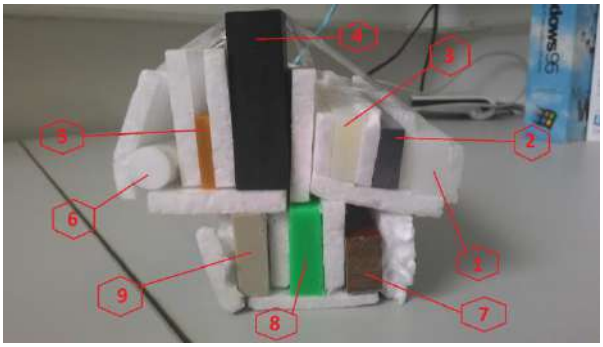


Fig. 1. Scanning part distribution,
1 – Polyethylene, 2 – Polyvinylchlorid,
3 – Polyamid, 4 – Gum, 5 – Polyurethane,
6 – Polytetrafluoroethylene, 7 – Textit,
8 – Polyethylene, 9 - Polypropylene

2.2 Scanning groups of samples

The samples were divided into two groups, which reduced the scanning volume and it was possible to achieve higher scanning accuracy. The settings listed in Table 4 were used for scanning.

Table 4. Scanning parameters

Voltage (kV)	160
Current (µA)	400
Integration time (ms)	1000
Gain	8
Filter (mm)	0,25
Voxel size (µm)	106,53
Number of projections	1000

In Fig. 2. the distribution of all samples at the time of scanning is shown.

Fig. 2 Groups of samples
A – PP, PE (B), B – PA, Gum, PTFE

3. EVALUATION OF RESULTS

3.1 Density calculation using weight and volume from CT

Volumes for individual samples were obtained from scanning all samples with/without the filter. Based on the relationship:

$$\rho = \frac{m}{V} \tag{2}$$

where, weight m (g) and volume V (cm^3)

A comparison of the results for scanning with/without a mechanical filter shows that the difference in volume change used to calculate the density is minimal. Table 5 shows the calculated densities for scanning with a filter, without a filter for scanning all samples, and the difference in the material density obtained.

Table 5. Densities for scanning of whole material with/without filter

Material	Density with Filter (gcm^{-3})	Density without filter (gcm^{-3})	Difference (gcm^{-3})
Textit	1.3488	1.3691	0.0203
PA	1.1382	1.1479	0.0097
PP	0.9167	0.9124	-0.0043
PE (B)	0.952	0.9524	0.0004
PVC	1.3703	1.4079	0.0376
Gum	1.5169	1.5446	0.0277
PTFE	2.1552	2.2122	0.057
PU	1.2174	1.2455	0.0281
PE (Z)	0.9575	0.9614	0.0039

Scanning groups of samples improved the size of the voxel (space water) from 146.29 µm to 106.53 µm. For this reason, the reconstruction of the surface of the object should be more accurate and the density results should be more accurate.

Table 6 compares the density results for group A when scanning with the filter, the density values from scanning all samples with the filter, and the difference values.

Table 6. Densities for Group A

Material	Density with Filter (gcm^{-3})	Density all materials (gcm^{-3})	Difference (gcm^{-3})
PP	0.9183	0.9124	-0.0059
PE (B)	0.9533	0.9524	0.0009

Table 7 compares the density results for group B when scanning with the filter, the density values from the scanning of all samples with the filter and the difference of the values.

Table 7. Densities for Group B

Material	Density with Filter (gcm^{-3})	Density all materials (gcm^{-3})	Difference (gcm^{-3})
PA	1.1382	1.1500	0.0118
Gum	1.5169	1.5557	0.0388
PTFE	2.1552	2.2212	0.0660

The results show. that for material group A the voxel size has a negligible effect on the calculation of the sample volume and thus on the determination of the material density. For group B, the impact is more pronounced but still at a negligible level.

3.2 Density and volume calculation based on hydrostatic test

Lastly, a hydrostatic test was performed to check the density of the samples. The measuring cup used was filled with distilled water and the whole experiment took place at a constant temperature of 20 °C. The individual materials were gradually placed in the liquid, and a change in the level in the measuring cup was recorded. For samples with a density lower than the density of distilled water at (9.9821 gcm^{-3} at 20 °C), it was not possible to determine their volume as they were buoyed by the liquid. These materials are polypropylene and polyethylene. The rubber sample was large in size and it was not possible to measure its density. Table 8 compares the volumes of samples obtained by CT, the hydrostatic method and their difference.

For polyamide, the minimum difference between the volume determined by CT and the hydrostatic method is recorded. The biggest difference is in the case of polyurethane, where the difference is at the level of 2 cm^3. The accuracy of volume determination by the hydrostatic method is affected by the scale on the measuring cup used.

Table 8. Volumes from CT data and hydrostatic method

Material	Volume CT (cm^3)	Volume hydro (cm^3)	Difference (cm^3)
Textit	8.919	8	-0.919
PA	12.083	12	-0.083
PVC	19.497	20	0.503
PTFE	13.444	12	-1.444
PU	6.180	4	-2.180

Upon sampling, it was found that the rubber material was not homogeneous, as seen in Fig. 3 and contains a lot of impurities/inclusions (white dots) and pores (black dots in the materials)

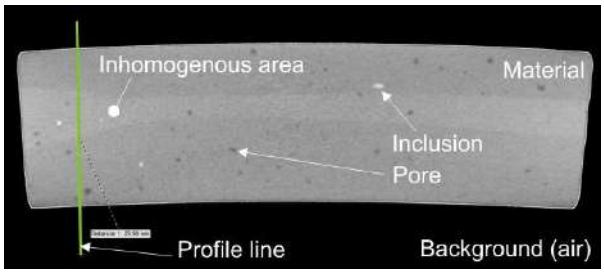


Fig. 3 Section of gum with profile line

By creating a profile line through the rubber section (green line Fig. 3), we obtained a profile of gray values on the basis of which it is possible to determine the differences in a given material. The monitored section (profile line) is delimited by the green and red lines and the course of the gray values along the profile line is shown in Fig. 4.

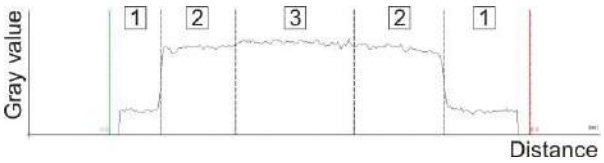


Fig. 4 Gray values along the profile line
1 – Background, 2 – Material,
3 – Inhomogenous area

The graph shows that the background (air) has an average value of gray at 4300, an average value of the majority material at 15800 and an average value of gray "inhomogenous area" at 16800. The difference between the materials is 1000 values of gray.

Previous data show that the density determined from CT is at the level of 1.52 gcm^{-3}. When the gray value changes by 1000 values, the density of the inhomogeneous part of the rubber are at the level of 1.625 gcm^{-3}, which is a difference of 0.105 gcm^{-3}. This is an insignificant change, but it is visible on the CT scan. The benefit of sampling is therefore the ability to determine the homogeneity and internal defects of materials.

ACKNOWLEDGEMENT

This work is a part of these projects VEGA 1/0168/21, VEGA 1/0179/19, KEGA 016TUKE-4/2021 and KEGA 041TUKE-4/2019.

4. REFERENCES

[1] Kruth, J.P., Bartscher, M., Carmignato, S., Schmitt, R., De Chiffre, L., Weckenmann, A., *Computed tomography for dimensional metrology*, CIRP Annals,Volume 60, Issue 2,2011,Pages 821-842,ISSN 0007-8506, https://doi.org/10.1016/j.cirp.2011.05.006.

[2] Freyburger, Ch., et al. *Measuring wood density by means of X-ray computer tomography*, Annals of forest science, 2009, 66.8:804.http://www.afs-journal.org/articles/forest/full_html/2009/08/f09029/f09029.html

[3] Phillips, D. H.; Lannutti, J. J. *Measuring physical density with X-ray computed tomography*. NDT & E International, 1997, 30.6: 339-350. http://www.sciencedirect.com/science/article/pii/S0963869597000200

[4] Sinka, I.C., Burch, S.F., Tweed, J.H., Cunningham, J.C., *Measurement of density variations in tablets using X-ray computed tomography*, International Journal of Pharmaceutics, Volume 271, Issues 1–2, 2004, Pages 215-224, ISSN 0378-5173, https://doi.org/10.1016/j.ijpharm.2003.11.022.

Authors: **Assoc. prof. Ing. Teodor Tóth, PhD., Ing. Patrik Varga, Prof. Ing. Radovan Hudák, PhD.,** Technical University of Kosice, Faculty of Mechanical Engineering, Department of Biomedical Engineering and Measurement, Letná 9, 042 00 Sever, Kosice, Slovakia, Phone.: 055 602 3224.

E-mail: teodor.toth@tuke.sk
patrik.varga@tuke.sk
radovan.hudak@tuke.sk

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Ranisavljev, M., Štrbac, B., Hadžistević, M., Matin, I.

OPTIMIZACIJA MERENJA RAVNOSTI NA KOORDINATNOJ MERNOJ MAŠINI PRIMENOM TAGUČI DIZAJNA EKSPERIMENTA

Rezime: *Zbog složenosti procesa merenja na koordinatnim mernim mašinama, postoji mnogo faktora koji utiču na kvalitet rezultata merenja. Cilj ove studije jeste, primenom Taguči dizajna eksperimenta koji analizira glavne uticajne faktore na kvalitet rezultata merenja, optimizovati proces merenja na mernim mašinama tako da se dobiju najbolje performanse sa aspekta tačnosti i merne nesigurnosti. Studija slučaja je sprovedena na toleranciji ravnosti i merena je ravnost na četiri radna predmeta čije greške oblika ravne površine se značajno razlikuju.*

Ključne reči: *Taguči dizajn eksperimenta, tačnost, merna nesigurnost, koordinatne merne mašine*

1. UVOD

Konstantan porast zahteva za većim kvalitetom radnih predmeta u pogledu tačnosti njihovih dimenzionih i geometrijskih karakteristika stvara potrebu za korišćenjem metroloških sistema visokih performansi kao što su koordinatne merne mašine (KMM) [1]. Koordinatne merne mašine se odlikuju visokom fleksibilnošću u pogledu merenja velikog broja različitih radnih predmeta. Pored fleksibilnosti, KMM pružaju visoku tačnost i ponovljivost rezultata merenja.

Proces merenja na koordinatnoj mernoj mašini se odvija u dve nezavisne faze: prikupljanje tačaka sa površine radnog predmeta i obrada prikupljenih podataka u softveru KMM. Prikupljanje tačaka kontaktnom metodom se vrši pomoću mernog senzora sa mernim pipkom, gde merni pipak vrši neposredan kontakt sa površinom radnog predmeta i vrši registrovanje koordinata tačaka u diskretnom modu ili u modu skeniranja (scanning).

Proces merenja na KMM uvek je praćen varijacijama rezultata merenja koje potiču od geometrijskih grešaka elemenata strukture KMM, grešaka mernog senzora, uslova okoline (temperatura, vlažnost vazduha), vibracija, stanja radnog predmeta (greške oblika, valovitost, hrapavost), strategije merenja koja je upotrebljena (broj i raspored tačaka, algoritam fitovanja podataka), iskustva operatera itd.

Svi navedeni faktori, u većoj ili manjoj meri, doprinose porastu merne nesigurnosti. Merna nesigurnost predstavlja „sumnju“ u validnost rezultata merenja [2]. Pošto rezultat merenja predstavlja aproksimaciju vrednosti karakteristike kvaliteta koji se meri, zbog postojanja greške merenja, uz svaki rezultat merenja neophodno je priložiti kvantitativni pokazatelj nesigurnosti merenja [3].

Strategija merenja, predstavlja jedan od najbitnijih faktora za kvalitet rezultata merenja. Odabir optimalne strategije merenja ne predstavlja lak zadatak čak i kada se radi o relativno jednostavnim radnim predmetima. Strategija merenja treba da bude takva da pruži najrealnije informacije o stvarnoj površini radnog predmeta [4].

U ovom radu, problematika pronalaženja optimalnih parametara strategije merenja je sprovedena kroz studiju koja je uključivala 4 različita radna predmeta. Karakteristika kvaliteta koja je merena na ovim radnim predmetima je ravnost. Hrapavost mernih površina na radnim predmetima se značajno razlikuje. Za faktore strategije merenja odabrani su: broj uzorkovanih tačaka, prečnik vrha mernog pipka, merno mesto u radnom prostoru KMM i temperatura. Postavka i redosled sprovođenja eksperimenta je formiran pomoću Tagučijevog dizajna eksperimenta.

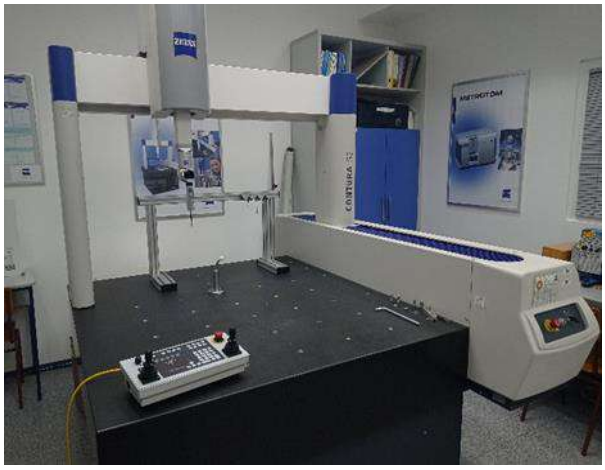
Cilj eksperimenta je bio pronalaženje kombinacije nivoa odabranih faktora koji će dati najmanje odstupanje izmerene ravnosti i referentne vrednosti ravnosti i najmanju mernu nesigurnost. Referentne vrednosti ravnosti radnih predmeta (pločica) su dobijene merenjem na KMM više klase tačnosti od one koja je upotrebljena za sprovođenje ove studije. Tačnost merenja je dobijena kao razlika između vrednosti merenja ravnosti na KMM i referentne vrednosti ravnosti, a merna nesigurnost je dobijena pomoću podataka o standardnoj devijaciji izmerenih vrednosti ravnosti.

2. EKSPERIMENTALNO ISTRAŽIVANJE

2.1 Materijali i metode

U cilju dobijanja eksperimentalnih rezultata korišćena je KMM Carl Zeiss Contura G2 RDS, koja je prikazana na slici 1. Maksimalna dozvoljena greška ove mašine iznosi (MPE_E=1.9+L/330 ,gde je

L izraženo u mm). Merni senzor koji je upotrebljen u eksperimentu je VAST XXT, koji se nalazi na RDS glavi.



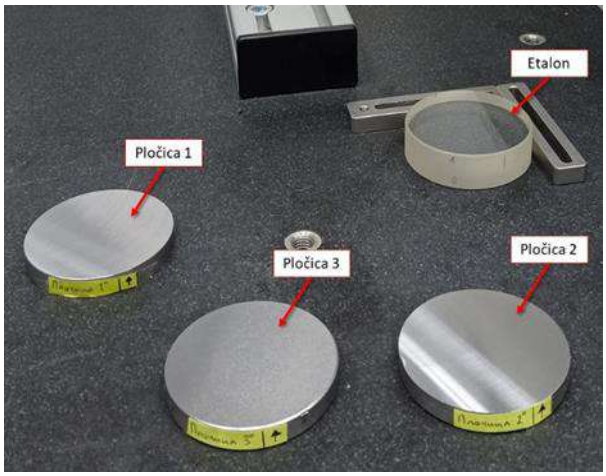
Sl. 1. KMM Carl Zeiss Contura G2 RDS

Dobijanje podataka o referentnim vrednostima ravnosti uzoraka sprovedeno je u metrološkoj laboratoriji „Orao“ u Bijeljini. Referentne vrednosti ravnosti uzoraka prikazane su u tabeli 1.

Tabela 1. Reerentne vrednosti ravnosti uzoraka

Radni predmet	Ravnost [mm]
Pločica 1	0,02
Pločica 2	0,0086
Pločica 3	0,0067
Etalon	0,0002

Uzorci na kojima je vršen eksperiment su 4 različite kružne pločice. Svaka od pločica je imala drugačije vrednosti površinske hrapavosti i greške oblika. Jedan od četiri uzorka je bio etalon za ravnost, plan-paralelno staklo. Ostali uzorci su bili od čelika neutvrđenog hemijskiog sastava. Uzorci su prikazani na slici 2.



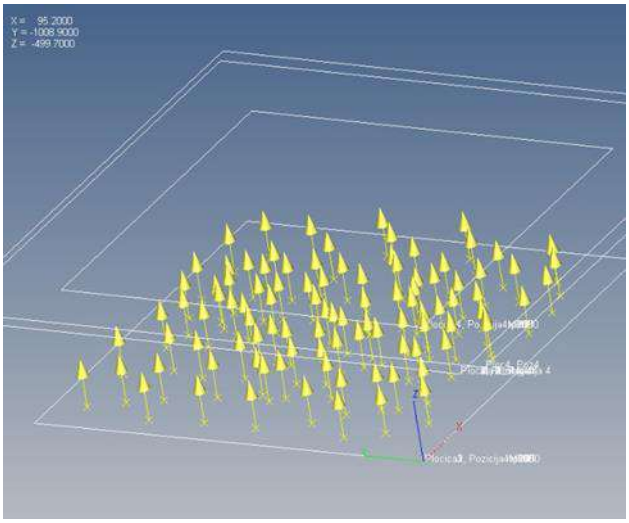
Sl. 2. Uzorci pločica

Faktori strategije merenja koji su uzeti u obzir su: broj uzorkovanih tačaka, prečnik vrha mernog pipka, merno mesto i temperatura. Faktori i njima pripadajući nivoi su prikazani u tabeli 2.

Tabela 2. Faktori i njima pripadajući nivoi

Faktori	Broj nivoa	Vrednost nivoa
Prečnik pipka [mm]	2	0,75 3
Temperatura ℃	2	20 26
Broj tačaka	4	10 25 60 100
Merno mesto	4	1 2 3 4

Faktor broja tačaka predstavlja broj uzorkovanih tačaka na površini radnog predmeta. Raspored tačaka na površini pločica je uzet slučajnim odabirom. Uzorkovanje tačaka je vršeno u diskretnom modu („tačka po tačka“). Raspored tačaka za jednu kombinaciju uticajnih faktora je prikazan na slici 3. Metoda koja je korišćena za dobijanje supstitutivne geometrije je metoda najmanjih kvadrata (*Least squares - LS*).



Sl. 3. Uzorkovane tačke u diskretnom modu

Kako bi se ispitao uticaj mehaničke filtracije, za potrebe studije izabrana su dva različita prečnika mernog pipka. Vrednosti prečnika mernih pipaka su dati u tabeli 2.

Faktor „merno mesto“ je uključen u studiju kako bi se ispitali uticaji geometrijskih grešaka KMM. Naime, odabrana su četiri položaja u radnom prostoru KMM na kojima su uzorci mereni.

Kako bi se ispitao uticaj okoline na rezultate ravnosti uzoraka u studiju je uključena temperatura. Merenja su vršena na dve različite temperature, 20 °C i 26

2.2 Postavka Taguči dizajna eksperimenta

Za formiranje plana eksperimenta odabran je Taguči dizajn eksperimenta (*Taguchi design of experiment*). Na osnovu utvrđenih faktora i njihovih nivoa (dva faktora na četiri nivoa – 4^2 i dva faktora na dva nivoa – 2^2) odabran je Taguči *L16* dizajn eksperimenta. Svaki eksperiment je ponovljen 3 puta kako bi se dobili podaci o standardnoj devijaciji za svaku kombinaciju faktora i nivoa. Redosled izvođenja razmatranog eksperimenta prikazan je u tabeli 3.

Tabela 3. Taguči *L16* dizajn eksperimenta

Br. tačaka	Merno mesto	Prečnik pipka	Temperatura
10	1	0.75	20
10	2	0.75	20
10	3	3	26
10	4	3	26
25	1	0.75	26
25	2	0.75	26
25	3	3	20
25	4	3	20
60	1	3	20
60	2	3	20
60	3	0.75	26
60	4	0.75	26
100	1	3	26
100	2	3	26
100	3	0.75	20
100	4	0.75	20

3. REZULTATI I DISKUSIJA

Obrada podataka je izvršena u softverskom paketu Minitab 17. Optimizacija procesa merenja ravnosti izvršena je za svaki uzorak pločica ponaosob, ali zbog ograničenog prostora prikazaće se rezultati studije za uzorak 1, odnosno pločicu 1. Preko metode analize varijanse (*ANOVA*) utvrdiće se statistička signifikantnost pojedinih faktora. Pomoću dijagrama glavnih uticaja utvrdiće se optimalni nivoi faktora koji daju minimalno odstupanje izmerene ravnosti i referentne ravnosti date u tabeli 1. Na osnovu izračunate standardne devijacije i podataka iz potvrde o etaloniranju (samo za etalon) utvrdiće se merna nesigurnost za merenje ravnosti prema standardu ISO 15530-3:2011 [5].

3.1 Analiza eksperimentalnih rezultata

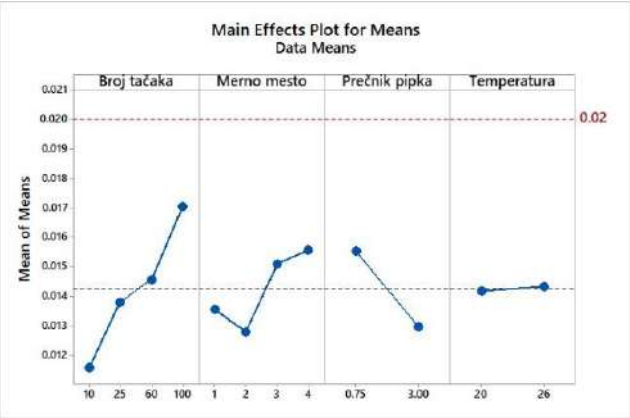
Rezultati ANOVA analize prikazani su u tabeli 4. Rezultati se odnose na uzorak „pločica 1“. Na osnovu podataka moguće je uočiti da su statistički signifikantni faktori „Broj tačaka“ i „Prečnik pipka“, pošto je njihova *p* vrednost manja od praga značajnosti 0,05 (α=0,05, za interval poverenja 95%). Na dijagramu glavnih uticaja za srednje vrednosti ravnosti (slika 4.) uočava se najveći raspon tačaka za faktor „Broj tačaka“ u odnosu na druge faktore, što implicira da je taj faktor najznačajniji kada su u pitanju srednje vrednosti izmerene ravnosti. Optimalne vrednosti nivoa svih faktora se biraju na taj način što se sa dijagrama glavnih uticaja posmatraju one srednje vrednosti koje su „najbliže“ referentnoj vrednosti 0,02 mm za pločicu 1. Referentna vrednost, na dijagramu glavnih uticaja je prikazana kao horizontalna isprekidana linija sa vrednosti 0,02 na ordinati.

Na osnovu prethodno iznetog, optimalne vrednosti nivoa faktora za dobijanje ravnosti su: Broj tačaka = 100; Merno mesto = 4; Prečnik pipka = 0,75; Temperatura =°C.

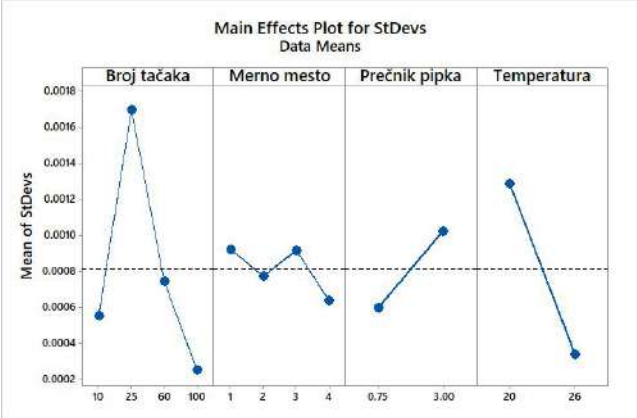
Ako se analiziraju rezultati prikazani dijagramom glavnih uticaja na standardnu devijaciju (slika 5.), temperatura nosi epitet glavnog uticajnog faktora na rasipanje rezultata merenja.

Tabela 4. Rezultati *ANOVA* analize

Izvor	Stepeni slobode	Seq SS	Adj SS	Adj MS	F	p
Broj tačaka	3	0,000061	0,000061	0,000020	8,53	0,010
Merno mesto	3	0,000020	0,000020	0,000007	2,81	0,117
Prečnik pipka	1	0,000026	0,000026	0,000026	10,97	0,013
Temperatura	1	0,000000	0,000000	0,000000	0,04	0,855
Rezidualna greška	7	0,000017	0,000017	0,000002		
Ukupno	15	0,000124				



Sl. 4. Dijagram glavnih uticaja faktora na srednje vrednosti izlazne karakteristike kvaliteta – ravnost



Sl. 5. Dijagram glavnih uticaja faktora na standardnu devijaciju izlazne karakteristike kvaliteta – ravnost

Za „Broj tačaka“ i „Merno mesto“ promena je nelinearna. Optimalni nivoi faktora za dobijanje minimalnog rasipanja rezultata su: Broj tačaka = 100; Merno mesto = 4; Prečnik pipka = 0,75; Temperatura = 26℃.

3.2 Tačnost merenja

Tačnost merenja je dobijena kao razlika između referente vrednosti i vrednosti merenja na KMM. Rezultati eksperimenta su pokazali da je srednje odstupanje izmerene ravnosti od referentne ravnosti za pločicu 1, 2, 3 i etalon iznosi: -0,00574; -0,00321; -0,00164 i 0,0004, respektivno.

3.3 Izračunavanje merne nesigurnosti prema ISO 15530-3:2011

Prema navedenom standardu merna nesigurnost se izračunava prema formuli (1):

$$U=k\cdot\sqrt{u_{cal}^2+u_p^2+u_w^2+u_b^2} \qquad (1)$$

Na osnovu opšte formule, podataka iz potvrde o etaloniranju etalon pločice i podataka o standardnoj devijaciji pločica od čelika izračunata je proširena merna nesigurnost, *U*, za pločicu 1, 2, 3 i etalon iznosi 5,966; 3,071; 2,417; 0,333 µm, respektivno.

4. ZAKLJUČAK

Na primeru merenja ravnosti 4 različita uzorka prikazan je uticaj faktora strategije merenja na izlaznu karakteristiku kvaliteta. Sprovođenjem Taguči dizajna eksperimenta pokušao se pronaći kompromis između faktora broja tačaka, mernog mesta, prečnika pipka i temperature kako bi se dobilo najmanje odstupanje izmerene ravnosti od referentne vrednosti ravnosti i najmanja merna nesigurnost. Takođe je uočeno da hrapavost mernih površina ima značajan uticaj na veličinu proširene merne nesigurnosti.

5. LITERATURA

[1] Parthiban, M., Harinath, M., and Kirubakaran, M.: *Measurement of roundness on the bearing by varying probe length in CMM* Mater. Today Proc., vol. 42, pp. 1393–1403, 2020.

[2] ISO/IEC GUIDE 98-3:2008 Uncertainty of measurement – Part 3: Guide to the experssion of uncertainty in measurement.

[3] Feng, C. X. J., Saal, A. L., Salsbury, J. G., Ness, A. R. and Lin, G. C. S.: *Design and analysis of experiments in CMM measurement uncertainty study* Precis. Eng., vol. 31, no. 2, pp. 94–101, 2007.

[4] Štrbac, B., Rodić, D., Delić, M., Savković, B., and Hadžistević, M.: *Investigation of Functional Dependency between the Characteristics of the Machining Process and Flatness Error Measured on a CMM* Meas. Sci. Rev., vol. 21, no. 6, pp. 158–167, 2021.

[5] ISO 15530-3:2011 Geometrical product specifications (GPS) – Coordinate measuring machines (CMM): Technique for determing the uncertainty of measurement – Part 3: Use of calibrated workpieces or measurement standards.

Autori: **Ass. MSc. Miloš Ranisavljev, Doc. dr Branko Štrbac, Prof. dr Miodrag Hadžistević, dr Ivan Matin,** Univerzitet Novi Sad, Fakultet Tehničkih Nauka, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2350, Fax: +381 21 454-495.

E-mail: mranisavljev97@uns.ac.rs
strbacb@uns.ac.rs
miodrags@uns.ac.rs
matini@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Đokić, Nj., Moljević, S., Medaković, V., Gojković, R.

OCJENA DOBAVLJAČA U AUTOMOBILSKOJ INDUSTRIJI

Rezime: *Ocjena dobavljača jedna je od najvažnijih aktivnosti vezanih za lanac snabdijevanja za automobilske kompanije koje rade sa više dobavljača. Cilj procesa ocjene dobavljača je smanjenje rizika kupovine, maksimiziranje ukupne vrijednosti za kupca i razvijanje bliskosti i dugoročnih veza između kupaca i dobavljača. Budući da se dobavljači razlikuju s obzirom na njihove različite karakteristike, samim tim su i odnosi sa dobavljačima različiti. U radu je prikazan način na koji se prati i razvija ocjena dobavljača u jednom preduzeću iz oblasti automobilske industrije koje posluje na teritoriji Bosne i Hercegovine. Ocjena dobavljača na mjesečnom, kvartalnom, polugodišnjem i godišnjem nivou urađena je ručnom (manuelnom) i automatskom metodom.*

Ključne riječi: *ocjena dobavljača, kriterijumi za izbor dobavljača, SAP, automobilska industrija*

1. UVOD

Povećanje i raznolikost zahtjeva kupaca, razvoj novih tehnologija u komunikacionim i informacionim sistemima, konkurencija na globalnom nivou, smanjenje vladinih propisa i povećanje svijesti o zaštiti životne sredine, prisilili su kompanije da se fokusiraju na upravljanje lancem snabdijevanja. Izraz upravljanje lancem snabdijevanja koristi se preko 20 godina i bavi se upravljanjem materijalima/snabdjevenijem od isporuke sirovina do kraja njihovog životnog vijeka i mogućeg recikliranja ili ponovne upotrebe [1]. Fokusira se na to kako firme koriste procese, tehnologiju i sposobnost svojih dobavljača da poboljšaju konkurentsku prednost [2]. Dakle, izbor dobavljača je jedan od najvažnijih problema donošenja odluka, budući da izbor pravih dobavljača značajno smanjuje troškove kupovine i poboljšava korporativnu konkurentnost [3]. Proces izbora dobavljača ima značajnu ulogu u smanjenju troškova, poboljšanju profita i kvaliteta proizvoda, a preduzeća često pogrešno shvataju problem izbora dobavljača kao donošenje odluka po jednom kriterijumu, uzimajući u obzir samo faktore troškova prilikom donošenja odluka [4].

Cilj ovog rada je prikaz integrisanog modela za problem ocjene dobavljača. Ocjena dobavljača se bazira na primjeni informacionog sistema SAP, kao i na ručnom unosu na osnovu iskustva i angažovanosti SQE inženjera (Inženjer kvaliteta dobavljača), koji reaguje na sve promjene od strane dobavljača i koji je u stalnom kontaktu sa istim. Rad je organizovan na način da su kriterijumi za izbor dobavljača definisani u drugom poglavlju, studija slučaja je prikazana u trećem, a zaključna razmatranja su data u četvrtom poglavlju.

2. KRITERIJUMI ZA OCJENU DOBAVLJAČA

U automobilskoj industriji cijena je bila jedan od glavnih kriterijume [5], ali, postepeno, i drugi kriteriji kao što su kvalitet i tehničke mogućnosti [6] su uzeti u razmatranje pri izboru dobavljača. U literaturi postoji veliki broj radova o tome kako kupci treba da biraju svoje dobavljače, uz opšti konsenzus o brojnim faktorima koji utiču na uvođenje individualnog izbora, u rasponu od cijene, percipirane kvalitete, isporuku prema drugim kriterijumima specifičnijim za određenu industriju [7]. Kriterijumi korišćeni u ovom radu prilagođeni su potrebama preduzeća koja pripadaju automobilskoj industriji. U tabeli 1 su prikazani kriterijumi i podkriterijumi za ocjenu dobavljača. Glavni kriterijumi za ocjenu dobavljača su kvalitet, cijena, isporuka i tehnologija. Pod kvalitetom se podrazumijeva upravljanje nabavkama (*Project procurement management* - PPM) odnos, broj reklamacija, kolika je efikasnost i reagovanje na 8D izvještaje i sertifikate koje posjeduje dobavljač. Pod cijenom se podrazumijeva nivo cijene i uslovi plaćanja. Isporuka podrazumijeva sve isporuke koje su isporučene na vrijeme, i količinsku preciznost, da li postoji manjak ili višak materijala. Pod tehnologijom se smatra učinak procesnog audita, sposobnost menadžmenta, inovacije, primjena alata i sposobnosti tima, podrška inženjeringa, reagovanja u slučaju pojave neusaglašenosti. Za kriterijume za ocjenu dobavljača mogu se posmatrati i uzeti u obzir mnogi drugi faktori, kao što su komunikacija između dobavljača i kupca, pouzdanost i dugogodišnja tradicija, fleksibilnost kao jedan od faktora, brzina prilagođavanja dobavljača u zavisnosti od stanja na tržištu i fokusiranje prema svojim kupcima. Kriterijumu

kvalitet ima najznačajnije podkriterijume koji se odnose direktno na reagovanje dobavljača na probleme i način na koji će se problemi riješiti. Kriterijum tehnologija ima najviše podkriterijuma zbog direktnog uvida u proizvodnju kod dobavljača odlaskom u audit, na taj način se mogu uvidjeti pojedinosti koje se odnose na sposobnosti zaposlenih, podršku inženjera prilikom rješavanja problema itd.

Tabela 1. Kriterijumi i podkriterijumi ocjene dobavljača

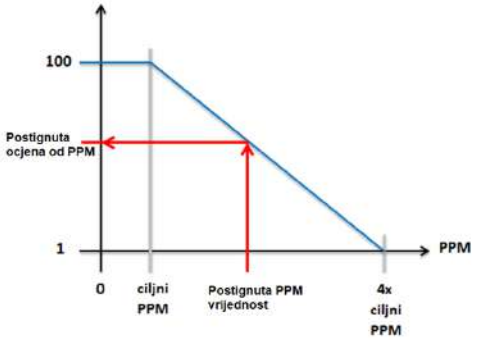
	KRITERIJUMI			
	KVALITET	CIJENA	ISPORUKA	TEHNOLOGIJA
PODKRITERIJUMI	PPM Reklamacije 8D efikasnost i reagovanje Sertifikacija	Nivo cijene Uslovi plaćanja	On-time isporuka Količinska preciznost	Učinak procesnog audita Sposobnost menadžmenta Inovacija Alatke i sposobnosti Podrška inženjeringa Reagovanje

Uspjeh nabavke preduzeća uveliko zavisi o tome koliko dobro dobavljači rade. Takođe je važno da dobavljač i kupac imaju istu ideju o tome šta je zadovoljavajući kvalitet. Moraju se dogovoriti o osnovnim zahtjevima transakcije, načinu na koji se zahtjevi trebaju realizovati, načinu provjere ispunjenosti zahtjeva i mjerama koje treba preduzeti kada očekivanja nisu ispunjena.

2.1 Kvalitet

Rezultat kvaliteta se bazira na četiri podkriterijuma koji uključuju PPM, reklamacije, 8D efikasnost i reagovanje i sertifikate dobavljača. PPM rezultat se računa tako što se ukupan broj neusaglašenih dijelova podijeli sa ukupnim brojem isporučenih dijelova. Neusaglašeni dijelovi su neusaglašeni tek nakon sortiranja odbijene isporuke. PPM se računa jednačinom (1) čiji je rezultat prikazan na slici 1.

$$\text{PPMisporuka}100=\frac{\left(\frac{99}{\text{PPM koeficijent -1}}\right)\text{x}(\text{ PPM stvarni-PPM ciljni})}{\text{PPM ciljni}} \quad (1)$$



Sl. 1. Grafikon funkcije PPM-a

gdje je:

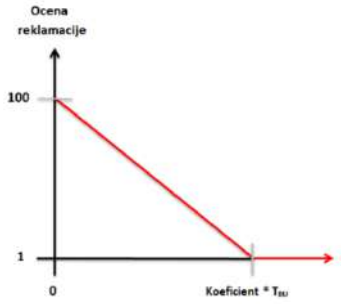
PPM koeficijent = 4; PPM isporuka (%) = 100%, ako je PPM < PPM cilj; PPM isporuka (%) = 1%, ako je PPM > 4 x PPM cilj.

Ocjena zavisi od broja reklamiranih komada, u zavisnosti od odnosa vrijednosti reklamiranih komada u odnosu na ukupno nabavljenu količinu. Kad se izvrši „presjek“ na dijagramu dobija se ukupna ocjena.

Kriterijumi za reklamacije se računa na osnovu broja reklamacija gdje se odbijaju povezane reklamacije.

$$\text{Ocena reklamacije}=100\times\left(1-\frac{1}{\text{Koeficijent}\times T_{BU}}\times\frac{N_{ORekl}}{P_{UVol}}\times 10^{9}\right) \quad (2)$$

gdje je:TBU – BU specifični godišnji cilj u [/1 bn EUR]; BU – oznaka za diviziju mehatronika i elektronika (BiH); NoRekl – broj reklamacija (broje se reklamacijski zapisnici RZ, RRZ, RKZ, RKG, RI); RZ – reklamacija na ulaznoj kontroli; RRZ – reklamacija iz proizvodnje; RKZ – reklamacija kupca iz proizvodnje; RKG – opomena kupca iz proizvodnje; RI – reklamacija gotovog proizvoda, u slučaju da je već neusaglašeni materijal ugrađen; Pu_{Vol} – izračunata nabavna količina; Koeficijent = 2,5 – empirijski usvojeno, u zavisnosti je od matematičke funkcije.



Sl. 2. Grafikon funkcije PPM-a

Period pregleda za broj reklamacija je 6 mjeseci. U zavisnosti od planirane godišnje realizacije i ukupne vrijednosti reklamacijskih zapisnika na godišnjem nivo, dobija se ocjenu reklamacije. Rezultat 8D efikasnosti i reagovanja se daje od strane odgovornog inženjera kvaliteta dobavljača (SQE-P) ručnim unosom u informacioni sistem SAP. U tabeli 2 prikazane su opcije ocjene kriterijuma efikasnosti u rješavanju 8D izvještaja od strane dobavljača.

Tabela 2. 8D efikasnost i reagovanja

Rezultat	8D efikasnost i reagovanje
100	Na vrijeme, uspješno zatvoren 8D
75	Kašnjenje, uspješno zatvoren 8D
50	Na vrijeme, 8D potrebna korekcija
25	Kašnjenje, 8D potrebna korekcija
1	Nema odgovora

Tabela 3. Sertifikati

Rezultat	Sertifikati
100	ISO/TS 16949 i ISO 14001
75	ISO 9001 i ISO 14001
50	ISO/TS 16949
25	ISO 9001
1	Bez sertifikacije

Rezultat sertifikacije se računa automatski prema tabeli 3 i baziran je na pribavljenim sertifikatima dobavljača koji su uneseni u sistem preko informacionog sistema SAP.

2.2 Cijena

Rezultat cijene se bazira na dva podkriterijuma: nivo cijene i uslovi plaćanja. Nivo cijene se računa automatski prema poređenju između trenutne važeće cijene i određene tržišne ili prosječne cijene. Ako tržišna ili prosječna cijena za poređenje ne postoji, rezultat se bazira na 80% SAP transakcije. Rezultat uslova plaćanja se računa na osnovu poređenja između trenutnih uslova plaćanja i ciljnih uslova plaćanja (90 dana konsignacije), što je prikazano u Tabeli 4.

Tabela 4. Uslovi plaćanja

Rezultat	Uslovi plaćanja
100	90 dana i konsignacija
75	75-89 dana
50	60-74 dana
25	30-59 dana
1	0-29 dana

2.3 Isporuka

Rezultat isporuke se bazira na on-time rezultatu i rezultatu količinske preciznosti. Rezultat on-time isporuke se računa sistemskom provjerom svake narudžbe i poređenjem planiranog datuma isporuke sa stvarnim datumom isporuke. Računa se standardnom kalkulacijom u SAP transakciji.

$$\text{On time isporuka} = \text{Planirano vrijeme ispor.} - \text{Stvarno vrijeme isporu} \quad (3)$$

Rezultat količinske preciznosti isporuke se računa putem informacijskog sistema SAP. SAP provjerava primljenu količinu i poredi je sa naručenom količinom. Ako se količina ne poklapa, sistem računa odstupanje i pretvara je u varijaciju na sljedeći način:

$$\text{Količinska preciznost} = 100 \times \frac{\text{Naručena količina-Isporučena količina}}{\text{Naručena količina}} \quad (4)$$

2.4 Tehnologija

Rezultat tehnologije je baziran na sljedećim podkriterijumima: rezultati procesnih audita (70%), sposobnost menadžmenta (8%), prijedlozi za inovacije i rješavanje problema (4%), alati i sposobnosti i podrška inženjeringa (13%) i reagovanja (5%), navedene podkriterijume ocjenjuje SQE-P.

3. STUDIJA SLUČAJA

Studija slučaja je urađena u preduzeću koje pripada automobilskoj industriji i koje posluje na području BiH. Dobavljači su svrstani u klase A, AB, B i C. Ukupan rezultat dobavljača se bazira na kriterijumima kvaliteta, cijene, isporuke i tehnologije kako je prethodno opisano.

Klasifikacija dobavljača, doprinos kriterijuma i podkriterijuma ukupnoj ocjeni, izvori podataka, minimalna učestalost ocjenjivanja i minimalna učestalost komunikacije su prikazani u Tabeli 5.
Na kraju operacije ocjenjivanja informacioni sistem SAP ispisuje ocjenu u vidu tzv. semafora tj. grafikona sa podacima što je prikazano na slici 3.

Kritično područje na koje treba obratiti pažnju i dalje je upravljanje kvalitetom dobavljača. Iako se performanse dobavljača vremenom poboljšavaju, kvalitet dobavljača još uvijek ne zadovoljava u potpunosti stalna promjenjiva očekivanja performansi. Kontinuirano praćenje performansi dobavljača nije jedino vrijeme kada bi kompanije trebale ocjenjivati dobavljače, za većinu kompanija, procjena dobavljača je ključna za njihovu filozofiju kvaliteta. Oko 80% firmi procjenjuje mogućnosti dobavljača direktno posjetom višefunkcionalnog tima dobavljaču. Bilo koji materijal ili komponente u poluproizvodu, gotovom proizvodu ili sirovinskom materijalu koje dobavljač isporučuje moraju se uzeti u obzir za izračunavanje PPM-a i odlučivanje o tome koji dobavljač mora biti izabran za poslovanje.

U posljednje vrijeme poslovno okruženje se promijenilo, a konkurentnost zavisi od mnogo više faktora nego samo od aktivnosti koje se dešavaju u organizaciji. Zbog toga je od vitalnog značaja da se posebna pažnja posveti ključnim odlukama koje mogu poboljšati rezultate kompanije, kao što je izbor dobavljača. Uspješan izbor dobavljača poboljšaće i performanse organizacije.

4. ZAKLJUČAK

Parametri kvaliteta i dalje su jedna od najvažnijih karika u automobilskoj industriji. Iako je većina standarda kvaliteta ispunjena i dalje je dug put, s tim je nadogradnja kvaliteta najvažniji izazov za industriju autokomponenti. Da bi se u potpunosti postigla izvrsnost kvaliteta u automobilskoj industriji neophodno je da se implementira standard IATF 16949:2016 (International Automotive Task Force).

Osim tradicionalnih unosa cijene, isporuke, stope reklamacije, sistem ocjenjivanja dobavljača

trebao bi uključivati i troškove kvaliteta dobavljača. Problemi s kojima se suočava industrija dobavljača automobilskih komponenti trebaju se detaljno analizirati i moraju se detaljno istražiti s obzirom na rad različitih kompanija, sa različitim shvatanjima automobilske industrije. Problemi se razlikuju od regije do regije i od kompanije do kompanije. Kompanija treba ocjenjivati performanse dobavljača, jer bez ocjenjivanja menadžment ne može donositi odluke prema dobavljačima, a onda dobavljač ne može poboljšati i ukloniti nedostatke jer nema adekvatnih povratnih informacija od strane kupca. Dobavljače treba ocjenjivati i da bi se olakšalo praćenje i poboljšanje performansi i povećala konkurentnost smanjenjem vremena ciklusa narudžbe i nivoa zaliha. Na taj način se i formiraju poslovne odluke koje mogu uticati na ukupno poslovanje kompanije.

Tabela 5. Klasifikacija dobavljača

Klasifikacija dobavljača	Ukupna procjena		Kriterijum	Prikupljeni podaci	Minimum procjene	Minimalna frekvencija komunikacije
Dobavljač A (90 -100 poena)	Kvalitet 30%	30%	PPM	SAP automatska kalkulacija	mjesečno	godišnje
		30%	Reklamacije	SAP automatska kalkulacija	mjesečno	godišnje
		30%	8D efikasnost i reagovanje	Ocjena SQE na osnovu kriterijuma	kvartalno	godišnje
		10%	Sertifikacija	Intranet applikacija / SAP	kvartalno	godišnje
Dobavljač AB (80 -89 poena)	Cijena 30 %	80%	Nivo cijene	SAP automatska kalkulacija	mjesečno	godišnje
		20%	Uslovi plaćanja	SAP automatska kalkulacija	mjesečno	godišnje
Dobavljač B (60 -79 poena)	Isporuka 30%	60%	On-time isporuka	SAP automatska kalkulacija	mjesečno	godišnje
		40%	Količinska preciznost	SAP automatska kalkulacija	mjesečno	godišnje
Dobavljač C (0 -59 poena)	Tehnologija 10 %	70%	Učinak procesnog audita	Ocjena SQE na osnovu kriterijuma	godišnje	godišnje
		8%	Sposobnost menadžmenta	Ocjena SQE na osnovu kriterijuma	godišnje	godišnje
		4%	Inovacija/Rješavanje problema	Ocjena SQE na osnovu kriterijuma	godišnje	godišnje
		8%	Alatke i sposobnosti	Ocjena SQE na osnovu kriterijuma	godišnje	godišnje
		5%	Podrška Inženjeringa	Ocjena SQE na osnovu kriterijuma	godišnje	godišnje
		5%	Reagovanje	Ocjena SQE na osnovu kriterijuma	godišnje	godišnje

Sl. 3 Grafikon ocjene dobavljača

6. LITERATURA

[1] Tan, K. C. (2002). *Supply chain management: practices, concerns, and performance issues*. Journal of Supply Chain Management, 38(4), 42-53.

[2] Farley, G. A. (1997).*Discovering supply chain management: a roundtable discussion. APICS-the performance advantage*,7,38-39.

[3] Teli, Ghodsypour, S. H., & O'brien, C. (2001). *The total cost of logistics in supplier selection, under conditions of multiple sourcing, multiple criteria and capacity constraint*. International journal of production economics, 73(1), 15-27.

[4] Frej, E. A., at all. (2017). *A multicriteria decision model for supplier selection in a food industry based on FITradeoff method*. Mathematical Problems in Engineering, 2017

[5] Fujimoto, T. (2001). *The Japanese automobile parts supplier system: the triplet of effective inter-firm routines*. International Journal of Automotive Technology and Management, 1(1), 1-34.

[6] Birchall, D. W., at all (2001). *Capabilities in strategic knowledge sourcing and assimilation: a new look at innovation in the automotive industry*. International Journal of Automotive Technology and Management, 1(1), 78-91.

[7] Purchase, S., & Lin, X. *Investigating supplier selection using repertory grid technique*. In 2006 IEEE International Conference on Service Operations and Logistics, and Informatics (pp. 432-435).

Autori: **Njegoslav Đokić dipl. inž. maš., prof. dr Slaviša Moljević, prof. dr Vlado Medaković, Ranka Gojković, ma,**
Univerzitet u Istočnom Sarajevu, Mašinski fakultet Istočno Sarajevo, Vuka Karadžića 30, 71123 Istočno Novo Sarajevo, BiH, Tel: +387 57 340 847,
E-mail: njego888@gmail.com
slavisa.moljevic@ues.rs.ba
vlado.medakovic@ues.rs.ba
ranka.gojkovic@ues.rs.ba

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Bijelić, M., Bijelić, Z., Bijelić, Ž., Milanović, B.

SISTEMSKO UPRAVLJANJE TEHNOLOŠKIM RAZVOJEM KOMPANIJA KOJE PROIZVODE PROIZVODE VISOKOG STEPENA POUZDANOSTI

Rezime: *Globalna konkurencija, krize, recesije i drugi problemi prisiljavaju korporacije da proaktivno traže rješenje za svoje razvojne probleme. U ovakvim složenim uslovima privređivanja, poslovni entiteti u nerazvijenim zemljama ne smiju slijepo slijediti stavove i principe kompanija razvijenih zemalja. Korporacije sa prostora nerazvijenih zemalja koje proizvode proizvode visokog stepena sigurnosti da bi bile konkurentne moraju izgraditi upravljačke mehanizme za optimalno sistemsko integrisano upravljanje tehnološkim razvojem na bazi ekonomije znanja. Tradicionalno kod proizvoda visokog stepena pouzdanosti. najveći udio cijene koštanja proizvoda čini znanje ugrađeno u razvoj proizvoda i tehnološki razvoj. Sa globalnim rastom ekonomije znanja, udio znanja u tehnološki razvoj u kompanijama koje proizvode proizvode visokog stepena je dobio dodatni impuls, pa je tehnološki razvoj postao ključni faktor uspješnog privređivanja. U radu je kteiran orginalan model za optinizaciju stepena integrisanog tehnološkog razvoja primjenom tehnologije fazi logike.*

Ključne reči: *sistemsko upravljanje, tehnološki razvoj, sigurnost, pouzdanost.*

1. UVOD

Proizvodi visokog stepena sigurnosti i pouzdanosti su proizvodi u kojima je tradicionalno u najvećem dijelu u cijenu koštanja ugrađeno tehnološko znanje. Zbog ove činjenice proizvodi visokog stepena sigurnosti i pouzdanosti imaju visoku tržišnu cijenu. U savremenim uslovima otvorenog globalnog tržišta i ovi proizvodi su izloženi sve većoj konkurenciji i imaju uzuzetno jaku spregu tri osnovne komponente konkurentnosti: kvalitet, troškovi i cijena. Kompanije koje proizvode ove proizvode u novonastalim okolnostima moraju svoj razvoj graditi na ekonomiji znanja, odnosno tehnologiji inteligentnog privređivanja.

Proizvodi visokog stepena sigurnosti i pouzdanosti, posmatrano sa čisto tehničkog aspekta su izuzetno složeni tehnički sistemi. Moraju imati više paralelnih podsistema koji obezbjeđuju veću sigurnost i pouzdanost. Sam proizvodno-tehnološki proces mora imati visok stepen sigurnosti i pouzdanosti. Posebno visok stepen pouzdanosti mora imati mjerna oprema i mjerni alati. Materijali, komponente i gotovi sklopovi koji se ugrađuju u proizvod visokog stepena sigurnosti i pouzdanosti moraju biti visokog nivova kvaliteta. U svremenim uslovima privređivanja, na bazi ekonomije znanja, kompanije koje proizvode predmetne proizvode pored visokog stepena tehničko-tehnoloških znanja koja imaju direktan uticaj na tehnički nivo sigurnosti i pouzdanosti proizvoda, moraju koristiti i upravljačka znanja veoma bitna za planirnje, organizovanje, vođenje i kontrolu integrisanog proizvodno-tehnološkog procesa. U integrisani upravljački sistem moraju biti ugrađeni aspekti vezano za ekonomsku uspješnost kompanije, za bezbjednost sa aspekt ekologije i zdravlja i života ljudi. Kvalitet upravljanja ljudskim resursima u ovim kompanijamma je faktor koji ima veliki uticaj na stepen sigurnosti i pouzdanosti proizvida. Kompanije koje proizvode proizvode visokog stepena sigurnosti i pouzdanosti moraju imati kompetentne kadrove u menadžerskim strukturama, koji u procesu donošenja odluka korste savremena znanja i koji imaju visok autoritet među zaposlenim. Kompanije svoju organizaciju moraju graditi na savremenim korporativnim i preduzetničkim principima.

Naučno-istraživački problem kojim se bavi ovaj rad su pitanja vezana za sistemsko upravljanje integrisanim tehnološkim razvojem kompanija koje proizvode proizvode visokog stepena sigurnosti i pouzdanosti. Prvi cilj rada je da se dokaže da je uspješno upravljanje kompanijma koje proizvode proizvode visokog stepena sigurnosti i pouzdanosti, moguće primjenom sistemskog upravljanja integrisanim tehnološkim razvojem. Drugi cilj je da se razvije model za optimizaciju integrisanog tehnološkog razvoja kompanija koje proizvode proizvode visokog stepena sigurnosti i pouzdanosti.

2. SISTEMSKA ANALIZA UPRAVLJANJA TEHNOLOŠKIM RAZVOJEM

2.1 Opšte o upravljanje tehnološkim razvojem

Tehnološki razvoj je razvojna promjena koja u organizacionom entitetu za rezultat ima efikasnije i efektivnije stvaranje vrijednosti [9]. Tehnološki razvoj čine stalne, mnogobrojne, raznovrsne promjene na najrazličitijim tehnološkim rješenjima, iz kojih rezultuju tehnološka rešenja višeg kvaliteta i korisnosti i nova supstituirajuća rješenja [1, 11]. Upravljanje podrazumijeva da se objekat, odnosno realni sistem posmatra kao sistem kojeg čine odabrane preformanse upravljanja. Tehnološki razvoj kompanija je izuzetno složen i dinamičan proces koji se odvija pod jakim uticajima konkurencije na tržišta i bližeg, šireg i globalnog okruženja. Kompanije svoj tehnološki razvoj moraju programirati na bazi savremenih i stemskih znanja i mehanizama upravljanja. U takvim uslovima efikasno i efektivno upravljanje tehnološkim razvojem moguće je na principima sistemskog kibernetskog upravljanja. Pored otvorenosti i dinamičnosti, upravljivost je treća osnovna karakteristika kibernetskog sistema. Stepen upravljivosti tehnološkim razvojem je prvenstveno funkcija znanja koje se danas temelji na ekonomiji znanja [4, 12, 20]. Za proizvode visokog stepena sigurnosti i pouzdanosti bazno upravljanje tehnološkim razvojem i je čisto tehničko-tehnološki aspekt. Sledeći aspekt je bezbjednosne prirode i isti se kod nekih proizvoda vrednuje više od čisto tehničko-tehnološkog aspekta. Međutim postoje i netehnički aspekti koji se moraju uzeti u obzir u toku odlučivanja o razvojnim promjenama tehnološkog razvoja. Predviđanje tehnoloških razvojnih promjena zbog neizvjesnosti budućnosti za kompanije je najsloženije najrizičnije razvojno pitanje.

2.2 Proizvodi visokog stepena sigurnosti i pouzdanosti

Osnovna karakteristika proizvoda visokog stepena sigurnosti i pouzdanosti je da su to proizvodi koji po pravilu imaju veoma visok stepen integrisanog kvaliteta, visoke troškove razvoja i proizvodnje i visoku tržišnu cijenu. Najveći dio cijena koštanja ovih proizvoda čine troškovi ispitivanja i testiranja: dijelova, komponenti , posklopova, sklopova i drugih repromaterijala, proizvedenih u sopstvenim tehnološkim procesima ili kod koperanata. Repromaterijali za ove proizvode u veoma malom broju se nabvljaju na slobodnom tržištu, jer se u fazi nabavke sa dobavljačem ugovara nivo kvaliteta. Na gotovim proizvodima visoke sigurnosti i pouzdanosti vrše se završna ispitivanja najčešće pod nadzorom kupca. Na osnovu podataka o nivou kvaliteta u cijelom procesu na završnim ispitivanjima primjenom egzaktnih matematičkih modela određuje se nivo sigurnosti i pouzdanosti i vijek trajanja kao i provjera drugih projekovanih preformansi. Operativna kontrola kvaliteta u korporacijama koji proizvode ove proizvode je potpuno autonomna od top menadžmenta.

2.3 Kompanije koje razvijaju i proizvode proizvode visokog stepena sigurnosti i pouzdanosti

U vremenu dinamičnih promjena kompanije svoj tehnološki razvoj ne mogu graditi na revolucionarnim tehnološkim promjenama, već isključivo na tehnološkim inovacijama. Industrija 4.0 se ne može smatrati novom tehnološkom epohom, već se radi o automatizaciji na bazi svremenih informacionih sistema [5]. Današnje kompanije upravljanje ekonomskim, pa time i tehnološkim razvojem, grade na velikom broju inovacija u svim sverama poslovnog upravljanje, a veoma rijetko na revolucionarnom impulsnom tehnološkom razvoju. Inovacija ne mora biti tehnička. Inovacija predstavlja sve ono što donosi promjene u potencijalu proizvodnja bogatstva kod već postojećih resursa. [10]. Kompanije koje proizvode proizvode visoog stepena kvaliteta svoj tehnološki razvoj grade na kombinaciji sopstvenog proaktivnog i adaptivnog tehnološkog razvoja. Zbog ovakvog pristupa moraju stalno da ulažu u nova znanja primjenjujući sistem trajnog učenja [4, 16,]. Za ove kompanije se može reći da su prosvećene organizacije. Pored kontinualnog ulaganja u obrazovanje, efikasno upravljaju i drugim aspektima upravljanja ljudskim resursima kao što je motivacija i organizaciona klima i kultura [17]. Ove kompanije su nosioci upravljanja ekologijom, razvoja korportivnog upravljanja, upravljanja na bazi savremnog preduzetništva i po pravilu menadžment regrutuju iz redova svojih zaposlenih. Zapošljavaju većinom mlađe kadrove tehničko-tehnološke struke primjenjujući razne testove ocjene sposobnosti i znanja. Posebnu vrijednost ovih kompanija čini društvena odgovornost. Veoma brzo i efikasno prilagođavaju unutrašnju pravnu regulativu nastalim zakonskim promjenama na državnom i lokalnom nivou. Imaju visok nivo poslovne etike i nizak stepen korupcije. Ove kompanije veoma brzo uspostavljaju dinamičku razvojnu ravnotežu [9]. Koriste mehahanizam programskog, a ne strategijskog razvoja i projektnu i horizontalnu organizacionu strukturu na svim hijerarhijskim nivoima. Za kompanije

koje proizvode proizvode visokog stepena pouzdanost može se reći da imaju efikasan i efektivan sistem integrisnog menadžmenta bez kojeg ne bi bilo moguće uspješno upravljati razvojem i proizvodnjom proizvoda visokog stepena sigurnosti i pouzdanosti.

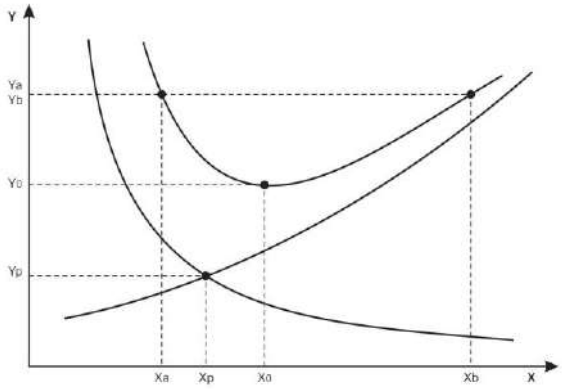
3. MODEL SISTEMSKOG INTEGRISANOG UPRAVLJANJA TEHNOLOŠKIM RAZVOJEM

Efikasno i efektivno upravljanje integrisanim vrijednostima sistema podrazumijeva primjenu upravljačkih modela razvojnog karaktera [2]. U takve modele spadaju i modeli kreirani na principima upravljanja integrisanim razvojnim promjenama [8]. Opšti model razvijen na bazi naučne doktrine „Ekonomija oprtimuma, optimalni tehnološki progres i optimalno privređivanje“ može se uspješno primjeniti za modeliranje upravljačkog matematičkog modela za sve vrste razvojnih promjena, pa time i za integrisani tehnološki razvoj [6]. Primjenom tehnologije fazi logike može se odrediti integrisana vrijednost sistemskog tehnološkog razvoja [8,18].

Ako kompaniju koja proizvodi proizvode visokog stepena sigurnosti i pouzdanosti predstavimo kao sistem čiji ulazi su komponente integrisanog tehnološkog razvoja (X_1, X_2,...X_n), a izlaz komponente kriterijuma vrednovanja upravljanja (Y_1, Y_2,...Y_m), najjednostavnije je integrisane vrijednosti za tehnološki razvoj (X) i integrisanu vrijednost kriterijuma vrednovanja tehnološkog razvoja (Y) odrediti primjenom matematičke ponderacije. U cilju stvaranja uslova za optimizaciju primjenljivu u praksi u procesu odlučivanja o razvojnim promjenama vezano za tehnološki razvoj, a primjenom postupka diferencijalnog računa, najzahtjevniji i najkreativniji dio modeliranja je projektovanje matematičke funkcije koja predstavlja funkcionalnu zavisnost između Y i X. Za rješenje ovog problema potrebna su multidisciplinarna znanja i ekspertsko iskustvo [3, 6, 8]. Na osnovu iskustva autora, za potrebe odlučivanja o tehnološkim razvojnim promjenama veoma uspješno se može koristiti polinomska funkcija data jednačinom opšteg oblika (1) i grafičkom ilustracijom na slici 1.

$$Y = Y_1 + Y_2 = aX^m + b/X^n + p \qquad (1)$$

U jednačini (1) parametri a, b. p, n i m se određuju u procesu modeliranja za svaki problem i situaciju posebno. Ne postoji nikakvo pravilo kako se to treba raditi. Ključ je ekspertsko znanje i iskustvo.



Sl. 1. Polinomska funkcija

U postupku modeliranja veoma korisno je koristiti tabelu (1) kao alat za uspješnije kreiranje vrijednosti ulaza i izlaza primjenom fazi logike.

Tabela 1. Opšte vrijednosti ulaza i izlaza

X	X_1	X_2	X_3	X_4
Y_1	A_1	B_1	C_1	D_1
Y_2	A_2	B_2	C_2	D_2
Y	A_1+A_2	B_1+B_2	C_1+C_2	D_1+D_2

Matematička jednačina koja zadovoljavajuće može da odražava zavisnost investicionih ulaganja (Y) i integrisanog stepena tehnološkog razvoja (X) kod kompanija koje proizvode naoružanje i vojnu opremu je jednačina (2).

$$Y = X^3/3 + 9\,600\,/X \qquad (2)$$

4. SINTEZA REZULTATA ISTRAŽIVANJA I PRIMJERI DOBRE PRAKSE

Na osnovu postavljenog problema i ciljeva istraživanja datih u uvodu rada, postavljene su sljedeće istraživačke hipoteze:

1. Tehnološki razvoj kompanija koje proizvode proizvode visokog stepena sigurnosti i pouzdanosti, danas se temelji na sistemskom upravljanju, koristeći ekonomiju znanja i sopstvena integrisana tehnološka i upravljačka znanja.
2. Na bazi opšteg modela upravljanja integrisanim razvojnim promjenama, može se kreirati model za optimizaciju integrisanog tehnološkog razvoja kompanija koje proizvode proizvode visokog stepena sigurnosti i pouzdanosti.
3. Kompanije koje proizvode proizvode visokog stepena sigurnosti i pouzdanosti u izraženoj konkurentnosti i uslovima dinamičnih promjena, svoj tehnološki razvoj grade na osnovu strategije inovacije

proizvoda i tehnologija.

Sve navedene hipoteze su potvrđene sa velikom vjeravatnoćom.

Istraživanja su sprovedena metodom naučnog posmatranja, logičkog zaključivanja, metodom matematičkog modeliranja, metodom indukcije i dedukcije i metodom sistemske analize i sinteze. Istraživanja su sprovedena na uzorku od 10 kompanija koje proizvode proizvode visokog stepena igurnosti i pouzdanosti od strane autora rada.

Primjeri dobre prakse:

1. Livnica eksploziva u ratnim uslovima u Republici Srpskoj i proizvodnja elektronski blizinskih upaljača [7].
2. Modeliranje integrisane bezbjednosti složenih sistema [3].
3. Modeliranje energetskih sistema [2] i
4. Modeliranje trajnog učenja [4]

5. ZAKLJUČCI

Shodno naučnoj doktrini „Ekonomija optimuma, optimalni tehnološki progres i optimalno privređivanje“ i na bazi opšteg modela optimizacije integrisanim razvojnim promjenama razvijen je matematički model za upravljanje integrisanim tehnološkim razvojem. Razvijeni model može se veoma uspješno i koristiti u praksi u procesu odlučivanja o tehnološkom razvoju kompanija koje proizvode proizvode visokog stepena sigurnosti i pouzdanost.

6. REFERENCE

[1] Adižes, I.: *Upravljanje promenama,* Prometej, Novi Sad. 1996.

[2] Bijelić, Z., Milanović, B., Bijelić, M.: *Upravljanje integrisanim kvalitetom planinskih vodotokova male energetske vrijednosti,* Konferencija Vodovod i kanalizacija '21, Zbornik radova, pp 163-170, Vrnjačka Banja, 2021.

[3] Bijelić, Z., Bijelić, M., Bijelić, Ž.: *Sistemsko upravljanje integrisanom bezbjednošću složenih sistema u fazi razvoja,* Međunarodna konferencija Bezbjednosni inženjering, Zbornik radova, pp 235-240, Kladovo, 2021.

[4] Bijelić, Z., Milanović, B., Bijelić, Ž., Bijelić, M.: *Model trajnog sistemskog učenja u funkciji optimalnog razvoja graditeljstva u Srbiji,* Naučna konferencija INDIS 2021, Novi Sad, 2021.

[5] Bijelić, Z. Bijelić, M.: *Industrija 4.0 faktor integrisanog tehnološkog razvoja,* Naučni skup Nauka i praksa 2019, Banja Luka, 2019.

[6] Bijelić, Z., Milanović, B.: *Optimalno privređivanje - Ekonomija budućnosti,* Monografija Ekonomska teorija u periodu 1958-2018 Institut ekonomskih nauka, p.p. 291-303, Beograd, 2018.

[7] Bijelić, Z., Milanović, B., Miletić, D.: *Development of mathematical model for optimal management of technological development shanges,* Međunarodna konferencija MMA 2018, Zbornik radova, p.p. 297-300, 2018.

[8] Bijelić, Z.: *Model optimizacije upravljanja integrisanim razvojnim promjenama,* Druga doktorska disertcija, Fakultet tehničkih nauka, Novi Sad, 2018.

[9] Bulat, V.: *Opšti zakon dinamičkog uravnoteženja,* ICIM, Kruševac, 2000.

[10] Draker, P.: Inovacije i preduzetništvo, PS Grmeč, Beograd, 1996.

[11] Đurić, *Tehnološki i tržišni razvoj,* Mongrafija Održivi razvoj poljoprivrede i zaštita životne sredine, p.p.121-126, Megatrend univerzitet primenjenih nauka, Beograd, 2003.

[12] Gluhov, B.: *Ekonomija Znanja,* Visoka poslovna škola, Novi Sad, 2011.

[13] Jovanović, L.: *Upravljanje tehnološkim razvojem,* Privredni pregled, Beograd, 2001.

[14] Milanović, B., Bijelić, Z., Bijelić, M.,Bijelić, Ž, (2021), *Sistemska analiza mogućnosti i ograničenja razvoja i proizvodnje električne energije u malim obnovljivim izvorima,* Kongres o procesnoj industriji, Zbornik radova, pp 173-181, Novi Sad. 2021.

[15] Sendić, R.: *Upravljanje rastom i razvojem preduzeća,* Savremena administracija, Beograd, 1993.

[16] Sengi, P.: Peta disciplina, Asse books, Novi Sad, 2003.

[17] Šiber, B.F.: *Menadžment ljudskih potencijala,* Golden marketing, Zagreb, 1999.

[18] Tadić, N. i drugi: *Teorija fazi skupova – Primena u rešavanju menadžment problema,* Mašinski fakultet, Kragujevac, 2006.

[19] Todić, V. i drugi: Tehnološka logistika i preduzetništvo, FTN Izdavaštvo, Novi Sad, 2011.

[20] Tisen, R. i dr.: *Dividenta znanja,* Adižes, Novi Sad. 2006.

[21] Zelenović,D., Todorović, J.: *Efektivnost sistema u mašinstvu,* Naučna knjiga, Beograd, 1990.

Autori: **Prof. dr Zdravko Bijelić, Mitar Bijelić, Željka Bijelić, mr. Biljana Milanović.**

Institut, LOGOS“ u osnivnju Novi Sad, Srbija.

E-mail: bijelićzdravko51@gmail.com

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE**
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Rašković Depalov, V., Pavlović, K.

TYPES OF INNOVATION AND DEGREE OF INNOVATION: MORE OR THE SAME?

Abstract: *Although innovation is considered to have strategic role for competitive existence of the company, this term has been elusive in the literature. In order to make clarification among innovation terminology, authors started with Oslo Manual definition of innovation, and then went through literature building: distinction between invention and innovation, definition and forming types of technological and non-technological innovation, and distinction among incremental, modular, architectural, radical, and disruptive degrees of innovation. Such an understanding will contribute to clear the link between the business/innovation strategy and different types and degrees of innovation, which has been poorly addressed/understood also in the existing literature.*
Key words: *invention, innovation, types of innovation, degree of innovation.*

1. INTRODUCTION

Innovation is seen to be building block of new venture, source of competitive advantage for existing ventures, and growth source for the economy of the country. In the existing literature [1, 2, 3, 4, 5], there is no common ground for the understanding and/or differentiation among types of innovation, innovation degree, novelty, patent, prototype, improvement, invention, innovation, etc.

In order to set a ground for an innovation understanding, the authors will start with Oslo Manual definition of the innovation, paragraphs 145. and 150: "145. An innovation is the implementation of a new or significantly improved product (goods or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations. 150. A common feature of an innovation is that it must have been implemented. A new or improved product is implemented when it is introduced on the market. New processes, marketing methods or organizational methods are implemented when they are brought into actual use in the firm's operations" [4].

This definition stresses three things: 1. novelty – degree of innovation, 2. implementation, and 3. types of innovation.

Novelty is part of the innovative idea where new change occurred. On the novelty "spectrum", there are from incremental till radical one. This will be discussed further in section 3. As a result of the novelty, innovative product has functionality and advantages - the list of measurable evidence, quantified non/technological performances.

When an innovative idea is transformed into a prototype, it is an **invention.** All functionalities and advantages are tested and proved.

Only when invention goes to the market or is in internal use for making business, it is then an **innovation**. It can be in different forms, from technological till nontechnological one. These types of innovation will be further discussed in next section.

2. TYPES OF INNOVATION

The Oslo Manual definition stresses 4 types of innovation. In the literature, there are also business model innovation [3, 6, 7], supply chain innovation [3], management innovation [8, 9, 10], and open innovation [11]. The list is going to be changed eventually.

There are two distinct groups among different types of innovation [12]: 1. technological, and 2. non-technological type of innovation.

2.1 Technological types of innovation

Technological type of innovation consists of: product innovation, and process innovation.

Product innovation represents changes in components, resources, architecture of the product which result in changed product, or it is new to the world product, put on the market or is used internally, with revenue generation. What and how much a product is changed, is matter of degree of innovation, from incremental till radical or disruptive one. This will be discussed in section 3.

Process innovation means changes in a production, and/or technology, implemented in the company, in order to achieve efficiency. What and

how much a process is changed, is matter of degree of innovation, from incremental till radical or disruptive one.

2.2 Non-technological types of innovation

Some of the non-technological types of innovation will be introduced here: marketing innovation, organizational innovation i.e. management innovation, business model innovation, supply chain innovation, and open innovation.

Marketing innovation refers "to the implementation of new marketing methods that entail noteworthy changes in any of the marketing mix elements, such as the product design or packaging, product placement, promotion, or pricing (OECD/Eurostat, 2005)" [12]. It also refers to changes in brand strategies, opening new markets, addressing customer needs, and repositioning products in the market to increase sales [12].

Mostly in the literature, marketing innovation is seen inseparable from product innovation. But growing trend in development of new distribution channels, branding strategies, communication types or pricing mechanisms show how these marketing innovations positively influence business [12, 13]. Examples of marketing innovations are job to be done, co-creation process, pop-up stores, interactive packaging with QR codes, fully recyclable or compostable packaging, personalised advertising using geolocation, RFID technology to follow products through the supply chain, individualised pricing, participative pricing mechanism, flat rate, etc.

Management innovation is also known in literature as organizational innovation, managerial innovation, and administrative innovation [9, 12]. The authors decided to stress management over organizational innovation because it covers broader spectrum.

Management innovation addresses creation, from incremental till state of the art, and implementation of: 1. the business practices - new methods for organizing management processes, such as knowledge management, lean production, quality management, balance score card, Six Sigma, etc., 2. workplace organization – new methods for organizing management practice, structure or techniques, such as "first use of a new system of employee responsibilities, teamwork, decentralization, integration or de-integration of departments, education/training systems" [9], M-form structure, spaghetti organization, etc., or 3. external relations – new ways of organizing relationships with stakeholders, such as "first use of alliances, partnerships, outsourcing, or subcontracting" [9], P&G's Connect and Develop innovation process, etc. in order to foster organization objectives [5, 7, 9, 10, 11].

Business model innovation means implemented changes at value proposition, value capture – profit formula, and value creation and delivery – key resources and key processes, the interrelations between the elements, and the value network [6, 7].

Business model innovation, BMI, changes the industry. Three types of BMI will be introduced [3]: 1. industry model innovation - "innovating the industry value chain by moving into new industries, redefining existing industries, or creating entirely new ones by identifying/leveraging unique assets of the", e.g. Apple's iPod, Netflix's streaming service, Uber's taxi service, etc., 2. revenue model innovation - "revenue generation through offering reconfiguration of the product/service/value mix and pricing models", e.g. Rolls Royce's "Power-by-the-hour" BM, Xerox's "Pay-per-copy", etc. and/or 3. enterprise model innovation - "innovating the role played in the value chain by changing extended enterprise and networks with employees, suppliers, customers, and others, including capability/asset configuration", e.g. Dell's "Made-to-order", Nespresso's "Exclusive pod coffee", etc.

Supply chain innovation is an implemented "change, incremental or radical, within the supply chain network, supply chain technology, or supply chain processes, or combinations of these, that can take place in a company function, within a company, in an industry or in a supply chain in order to enhance new value creation for the stakeholder" [3]. Examples of supply chain innovations are DIY, on-demand warehousing, collaborative mobile robots, truck platooning, blockchain, etc.

Chesbrough introduced the open innovation concept. It is, on the one hand, the use of external knowledge to accelerate internal innovation and, on the other hand, the use of external paths to reach the internal knowledge market. There are two types of open innovation: 1. Inbound open innovation - the acquisition of external innovative technology, meaning the company internalizes externally developed innovative technologies. Inbound OI activities involve cooperation with other companies or universities, participation of R&D institutions for product development, etc., 2. Outbound open innovation - the external exploitation of the technology developed by the company. Outbound OI activities include licences, the sale of patents, spin-off, etc. [11].

3. DEGREE OF INNOVATION

The degree of innovation defines how "new" is an innovation.

There are following degrees of innovation [1, 2]: 1. degree from the novelty perspective, and 2. from impact perspective.

Novelty, in degree sense, can go from improving/upgrading of an existing product; or creating a new component/s; or a new way of connecting components into a new architecture; till making existing knowledge of the architecture and components unusable.

Novelty is an intellectual property, which is the subject of patenting.

From impact perspective, we talk about disruptive innovation. Clayton Christensen introduced this term. “Disruptive” business has to either originate in a low-end market and move upstream to higher value markets, or it has to create a “new market foothold,” meaning it creates a new market where none existed. Disruption describes a degree in which business model of a smaller company with fewer resources is able to successfully challenge established incumbent businesses [14].

3.1 Degree of innovation from novelty perspective

Innovation degree from the novelty perspective are [15]: incremental innovation, modular innovation, architectural innovation, and radical innovation.

Incremental - degree of - innovation represents the lowest degree of innovation. It is gradual and continuous improvements which bring something new in the existing concepts, in the existing market. There is a difference between incremental innovation and improvement. Improvement is iterative and focuses on optimizing existing systems and eliminating defects. It does not bring anything new. Incremental innovation is the creation of something new and different from what we’ve experienced before. That new and differently done - novelty in the product, or other types of innovation, can be copied in less than one year. Examples of incremental innovation are: improved bioreactor, composition of the mixture for coating the pipes for smoke extraction, etc.

Modular - degree of - innovation means that the novelty is in the concept of manufacturing one or more components in the product, or other types of innovation. That change requires new knowledge for making one or more components, but the architecture of the knowledge remains unchanged. Modular degree of innovation requires more than one year to be copied. Harvard Business School professors, Henderson and Clark (1990) introduced modular innovation [15]. Examples of modular innovation are component for transmitting the information in digital phone, pedals on bicycle, etc.

Architectural - degree of - innovation means reconfiguring of an existing system or the way the components, which are not innovative ones, are connected. It changes the way the system works and how those components contribute to that functioning. For this degree of innovation new architectural knowledge is needed. Competition cannot easily notice this innovation and they need new knowledge to copy. Harvard Business School professors, Henderson and Clark (1990) also introduced architectural degree of innovation [15]. Examples of architectural innovations are Apple Computer in music downloads, IBM with the Personal Computer, etc.

Radical - degree of - innovation means revolutionary technological changes implemented into company or put on the market. This innovation breaks the previous technological paradigm and creates a new path. It refers only to “new technologies, and to the invention of new products, and they do not pertain to new business models” [15]. Examples of radical innovation are radio, TV, PC, washing machine, etc.

3.2 Degree of innovation from impact perspective

Disruptive – degree of - innovation from the impact perspective are: 1. disruptive innovation for existing market - low-end footholds occur because incumbents mainly pay attention on their most profitable and demanding customers with ever-improving products and services, and they pay less attention to less-demanding customers. “This opens the door to a disrupter focused (at first) on providing those low-end customers with a “good enough” product” [14] under low price. Examples are: mini mills, Netflix, Wikipedia, etc., and 2. disruptive innovation for new or emerging market segments – disrupters create a market where none existed. They find a way to turn non-consumers into consumers. Examples are Apple iPhone, Uber, Linux, etc.

Disruptive innovations don’t catch on with mainstream customers until quality catches up to their standards. “Once that’s happened, they adopt the new product and happily accept its lower price” [14].

Disruptive innovation is “a business model problem” [17].

4. CONCLUSION

Innovation is something new that creates value. “Something” refers to types of innovation,

technological and/or non-technological innovation. “New” refers to new to the company, country, region, or world-wide. It can go from incremental till radical degree. “Value” refers to the implementation on the market – value for the customer, in the company – value for the company, and/or for the planet – value for the planet.

Types of innovation indicate in which form the innovation is – is it in product, process, business model, management, supply chain, marketing or open collaboration.

Degree of innovation from novelty point shows how new innovation is – is it incremental, modular, architectural or radical.

Degree of innovation from impact point shows how industry is changed – is it disruptive through existing market or through establishing new market.

Understanding what degree of innovation type company would like to developed, e.g. architectural degree of process innovation, influences the innovation strategy that should be align with business strategy of the company.

Fostering the degree of innovation is also in the strategic intent of the company. In order to do that, understanding technological vs. non-technological types of innovation, and the importance of their combination, are essential for the business success [1].

5. REFERENCES

[1] Amaraa, N., Landryb, R., Becheikhb, N., Ouimetc, M.: *Learning and novelty of innovation in established manufacturing SMEs*, Technovation, 28, p.p. 450–463, 2008.

[2] Kovacs, A., Marullo, C., Verhoeven, D., Van Looy, B.: *Radical, Disruptive, Discontinuous and Breakthrough Innovation: more of the same?*, Academy of Management Annual Meeting Proceedings, No. 1, 2019.

[3] Kahn, B.K.: *Understanding innovation*, Business Horizons 61, p.p. 453-460, 2018.

[4] Gault, F., *Defining and measuring innovation at all sectors in the economy*, Research Policy, 47, p.p. 617-622, 2018.

[5] Fernandes, M., Alves, R., Vasconcelos, R., Galina, R.: *Literature on organizational innovation: past and future*, Innovation & Management Review, Vol. 15 No. 1, p.p. 2-19, 2018.

[6] Geissdoerfer, M., Vladimirova, D., Evans, S.: *Sustainable business model innovation: A review*, Journal of Cleaner Production, Volume 198, Pages 401-416, 2018.

[7] Johnson, M.W., Christensen, C.M., Kagermann, H.: *Reinventing Your Business Model*, HBR, December 2008.

[8] Vaccaro, G.I., Jansen, J.P.J., Van Den Bosch, A.J.F., Volberda, W.H.: *Management Innovation and Leadership: The Moderating Role of Organisational Size*, Journal of management studies 49:1, p.p. 28-51, 2012.

[9] Damanpour, F.: *Footnotes to Research on Management Innovation*, Organization Studies 2014, Vol. 35(9), p.p. 1265–1285, 2014.

[10] Birkinshaw, J., Hamel, G. and Mol, M.J.: *Management innovation*, Academy of Management Review, Vol. 33, No. 4, p.p. 825-845, 2008.

[11] Bigliardi, B., Ferraro, G., Filippelli, S., Galati, F.: *The influence of open innovation on firm performance*, International Journal of Engineering Business Management, Volume 12, p.p. 1–14, 2020.

[12] Bodlaj, M., Kadic-Maglajlic, S., Vida, I.: *Disentangling the impact of different innovation types, financial constraints and geographic diversification on SMEs' export growth*, Journal of Business Research, 2018 Volume 108, p.p. 466-475, 2020.

[13] Purchase, S., Volery, T.: *Marketing innovation: a systematic review*, Journal of Marketing Management, 36:9-10, p.p. 763-793, 2020.

[14] Christensen, C.M., Raynor, M.E., McDonald, R.: *What Is Disruptive Innovation?* HBR, 2015.

[15] Henderson, R., Clark, K.B.: *Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms.* Administrative Science Quarterly, 35, p.p. 9-30, 1990.

[16] Rakic, K.: *Breakthrough and Disruptive Innovation: A Theoretical Reflection*, Journal of Technology Management & Innovation vol.15, no.4, Santiago dic., 2020. .

[17] Petzold, N., Landinez, L., Baaken, T.: *Disruptive innovation from a process view: A systematic literature review*, Creativity and Innovation Management, Volume28, Issue2, p.p. 157-174, 2019.

Authors: **dr Vesna Rašković Depalov,** University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Phone.: +381 63 89 25 825

Dr Katarina Pavlović, EDUCONS University, Faculty for project and innovation management, Bože Jankovića 14, 11000 Belgrade, Serbia, Phone: +381 63 81 60 177

E-mail: raskovicv@uns.ac.rs
katarina.pavlovic@pmc.edu.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE**
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Đorđević, V., Dašić, P., Pravdić, P.

OCENA SPOSOBNOSTI PROCESA NA PRIMERU POGONSKOG ZUPČANIKA

Rezime: *U radu su definisane osnovne karakteristike kvaliteta pogonskog zupčanika koje je potrebno kontrolisati i prikazani su eksperimentalni podaci merenja, na osnovu dokumentacije preduzeća Petoletka DOO - Hidraulika. Prema merenjima sprovedenim u procesu kontrole, izvršena je ocena stabilnosti procesa. Osnovni koncept je baziran na upoređivanju podataka dobijenih iz procesa kontrole i izračunatim kontrolnim granicama, pa na osnovu toga se donosi zaključak o samom procesu.*
Ključne reči: *sposobnost procesa, indeksi, pogonski zupčanik, kvalitet*.

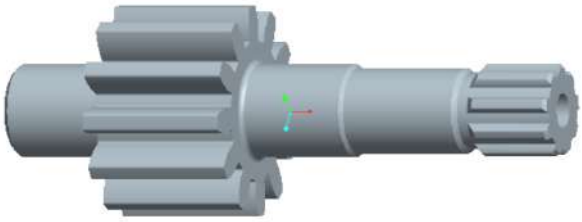
1. UVOD

Statistička kontrola danas zauzima značajno mesto u procesu unapređenja kvaliteta. Početak primene statističkih metoda je vezan za početak dvadesetog veka, ali veća primena počinje tokom Drugog svetskog rata kada se organizuje velikoserijska proizvodnja. Statističke metode pomažu da se kontrola u tehnološkim i poslovnim procesima usmeri na faktore koji najviše utiču na te procese. Na osnovu toga se zaključuje koje korektivne mere treba preduzeti da bi se osigurao stabilan i zadovoljavajući kvalitet.

2. POGONSKI ZUPČANIK

Preduzeće Petoletka DOO – Hidraulika u svom proizvodnom programu ima veliki broj hidrauličnih pumpi koje proizvode u velikim serijama i za domaće i inostrano tržište. Samim tim važno im je da obezbede precizan i kvalitetan proces izrade i kontrole zupčanika koji su sastavne komponente jednog dela njihovog proizvodnog programa.

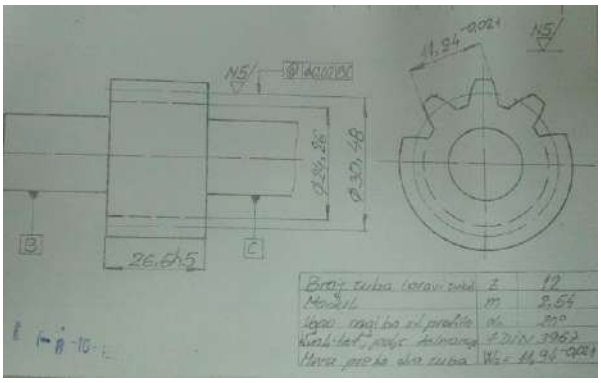
Na slici 1. je prikazan pogonski zupčanik ZPB F16 21 05 (i.š. 757856), modeliran u programu ProEngineer Wildfire 5.0.



Sl. 1. Pogonski zupčanik

Realan prikaz istog pogonskog zupčanika iz procesa proizvodnje i kontrole i skica dela sa potrebnim kotama i podacima su prikazani na slikama 2 i 3.

Sl. 2. Zupčanik ZPB F16 21 05



Sl. 3. Skica zupčanika ZPB F16 21 05

Na narednoj slici prikazan je kontrolni list operacije za navedeni zupčanik.

Na ovom dokumentu su navedeni svi podaci vezani za obradu zupčanika: mašina na kojoj se komad obrađuje, rezni alat i režimi obrade. Takođe, navedena je i kota koja se kontroliše, uz toleranciju i kvalitet obrade. Na skici zupčanika su dati i podaci o broju zuba (pravi zubi), modulu zupčanika, kvalitetu i polju tolerancije, uglu nagiba profila i meri preko dva zuba.

Sl. 4. Kontrolni list operacije

3. OCENA SPOSOBNOSTI PROCESA

Sposobnost procesa određuje da li je proces u prisustvu opštih, prirodnih poremećaja u mogućnosti da zadovolji zahteve kupca [1]. Ako su granice zahteva veće ili jednake sa prirodnom tolerancijom, može se reći da je proces sposoban. Sposobnost procesa se procenjuje računanjem indeksa sposobnosti i potencijala procesa. Kada je proces pod kontrolom, manja je verovatnoća da se kontrolna promenljiva nađe izvan kontrolnih granica [2].

Indeks potencijala procesa Cp je mera rasipanja procesa i predstavlja odnos propisane i prirodne tolerancije [3].

Indeks sposobnosti procesa Cpk uzima u obzir i centriranost, odnosno udaljenost srednje vrednosti od nominalne. Indeks sposobnosti procesa Cpm naspram Cp i Cpk uzima u obzir i disperziju i kvadratno odstupanje srednje vrednosti od nominalne i predstavlja efikasniju ocenu sposobnosti procesa [4].

Proces je sposoban ako je raspon zahteva veći ili jednak od raspona procesa. To je osnovni uslov sposobnosti procesa. Raspon zahteva, odnosno tolerancijsko polje T je područje između gornje i donje granice zahteva [5].

Sposobnost procesa je mera za duži vremenski period uticaja parametara procesa, jer proces u sebi obuhvata uticaj radnika, mašine, materijala, metoda i radnih uslova. Najmanji zahtev za rasipanje procesa proizvodnje iznosi X±3σ (standardna odstupanja - 6σ) u odnosu na sredinu procesa. To obuhvata 99,73% proizvedenih proizvoda koji se nalaze u granicama 0,6÷0,7 polja tolerancije karakteristika proizvoda [6].

Pet pokazatelja sposobnosti procesa i opreme Cp, CPU, CPL, k i Cpk predstavljaju potpun skup pokazatelja ocene sposobnosti - kvaliteta procesa, kao što je prikazano u tabeli 1 [3, 7].

Mnoge japanske kompanije u različitim industrijskim granama primenjuju svih 5 pokazatelja. Široko se koriste ne samo za ocenu procesa, već i za donošenje odluke o kupovini proizvoda. U osnovi interesantni su indeksi Cp i Cpk, primenjeni u Japanu (Sulivan 1984.) i automobilskoj industriji SAD (Ford od 1984.) [3, 7].

Najčešće, sposobnost procesa se ocenjuje korišćenjem dva indeksa: indeksa potencijala Cp i indeksa sposobnosti Cpk.

Proces je sposoban kada su indeksi [3, 7]:

- preciznosti Cp≥1,33 (atributivna ocena: precizan) i
- tačnosti Cpk≥1,33 (atributivna ocena: tačan-podešen).

Mogućnosti procesa, korišćenjem ovih navedenih indeksa, mogu se oceniti na sledeći način [3, 7]:

- ako je Cp≥1,33 i |Cp–Cpk|≤0,1 |Cp| mogućnosti procesa su visoke (proces je precizan i tačan),
- ako je 1≤Cp≤1,33 i |Cp-Cpk|≤0,1 |Cp| mogućnosti procesa su zadovoljavajuće, ali je neophodno stalno praćenje i monitoring procesa,
- ako je Cp<1 mogućnosti procesa su nezadovoljavajuće i pod hitno je potrebno preduzeti mere unapređenja mogućnosti procesa (povećanje tačnosti tehnološkog procesa zamenom ili remontom opreme…).

Tabela 1. Pet pokazatelja sposobnosti procesa

Pokazatelji	Zavisnost	Naziv
Cp	$\frac{GGT - DGT}{6 \cdot \sigma}$	Potencijal procesa
CPU	$\frac{GGT - \overline{X}}{3 \cdot \sigma}$	Pokazatelj sposobnosti procesa u odnosu na gornju granicu odstupanja
CPL	$\frac{\overline{X} - DGT}{3 \cdot \sigma}$	Pokazatelj sposobnosti procesa u odnosu na donju granicu odstupanja
k	$\frac{2 \cdot \lvert m - \overline{X} \rvert}{GGT + DGT}$	Koeficijent odstupanja srednje vrednosti procesa od sredine tolerantnog polja
Cpk	$\min\{CPL, CPU\} = (1 - k) \cdot Cp$	Indeks sposobnosti procesa

4. MERENJE I OCENA PROCESA PREKO INDEKSA SPOSOBNOSTI

Mera koja se kontroliše u ovom primeru je data na skici i dokumentu sa slike 3. To je mera 30,48mm. Tolerancija je ±0,010. Ukupan broj kontrolisanih komada je 30.

Nakon obavljenih svih merenja, vidimo da se izmerene vrednosti kreću u rasponu 30,479mm do 30,483mm, što odgovara navedenoj toleranciji. Sve dobijene vrednosti merenja su prikazane na slici 5.

n \ r	1	2	3	4	5
1	30,480	30,479	30,479	30,480	30,480
2	30,481	30,481	30,480	30,481	30,480
3	30,483	30,483	30,482	30,482	30,482
4	30,482	30,482	30,483	30,483	30,482
5	30,481	30,481	30,480	30,480	30,480
6	30,480	30,479	30,479	30,480	30,479
ΣX	182,887	182,885	182,883	182,886	182,883
$\overline{X}$	30,481	30,481	30,481	30,481	30,481
ωi	0,003	0,004	0,004	0,003	0,003

Sl. 5. Rezultati merenja zupčanika

Na osnovu dobijenih rezultata merenja pristupa se obradi podataka, odnosno izračunavanju svih potrebnih indeksa potencijala i sposobnosti procesa. Obrada podataka se izvodi prema obrascima navedenim u tabeli 2.

Tabela 2. Obrasci i rezultati obrade podataka

Obrasci	Rezultati
$\overline{\overline{X}} = \frac{\sum_{i=1}^{r} \overline{X}_i}{r}$	$\overline{\overline{X}} = 30{,}4808$
$\overline{\overline{\omega}} = \frac{\sum_{i=1}^{r} \overline{\omega}_i}{r}$	$\overline{\overline{\omega}} = 0{,}0034$
dn – usvojena vrednost	dn=2,534
$\overline{\sigma} = \frac{\overline{\omega}}{d_n}$	$\overline{\sigma} = 0{,}001342$
$\sigma = \sqrt{\frac{\sum_{i=1}^{r}\left(X_i - \overline{\overline{X}}\right)^2}{r \cdot n - 1}}$	$\sigma = 0{,}001342$
TNM=6·σ	TNM=0,008051
TNP=6·σ	TNP=0,007941
$C_p = \frac{T}{6 \cdot \sigma}$	$C_p = 2{,}518523$
$C_{pk} = \frac{\Delta krit.}{3 \cdot \sigma}$	$C_{pk} = 2{,}317041$
$\Delta krit. = GGT - \overline{\overline{X}}$	0,0092
$\Delta krit. = \overline{\overline{X}} - DGT$	0,0108
$f_p = \frac{6 \cdot \sigma}{T} \cdot 100\%$	$f_p = 39{,}70581$

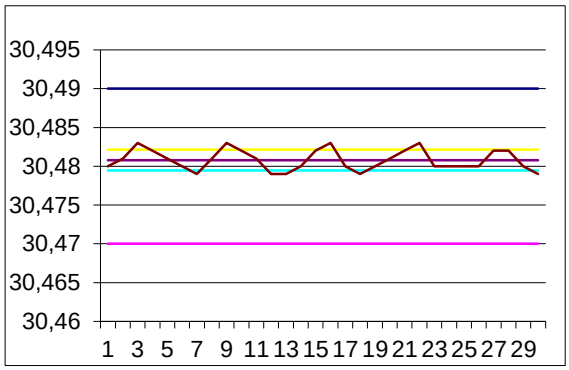
Svi izračunati rezultati iz obrade podataka i eksperimentalno dobijeni rezultati merenja se objedinjuju u jednom dokumentu, koji je prikazan na sledećoj slici.

Sl. 6. Obrada podataka

Vrednosti koje su dobijene merenjem su prikazane i grafički, u dva grafika koji su prikazani na naredne dve slike.

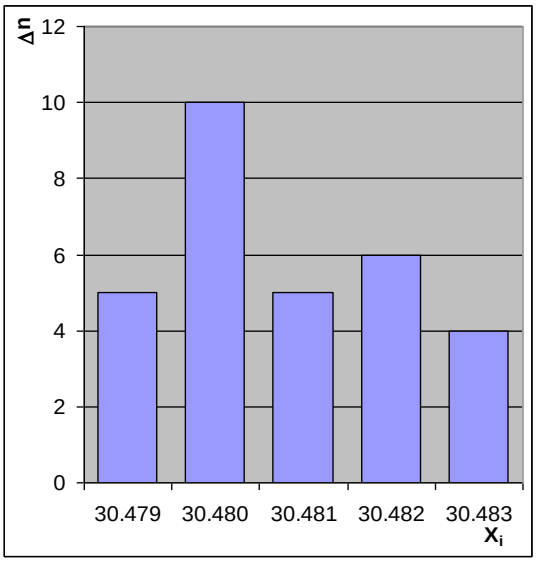
Na prvom grafiku (slika 7.) je prikazana zavisnost dobijenih brojčanih vrednosti merenja i broja izvršenih merenja. Vidimo da se izmerene vrednosti kreću u okviru tolerancije. Data je nazivna mera na crtežu, a minimalna i maksimalna izmerena vrednost se nalaze u okviru propisane tolerancije. Vrednost X treba da se nalazi između 30,47mm i 30,49mm i to je zadovoljeno, kao što vidimo iz izmerenih vrednosti.

X=30,48mm
Xmin=30,479mm
Xmax=30,483mm
T=0,020



Sl. 7. Grafik rezultata merenja

Na drugom grafiku (slika 8.) je prikazan histogram raspodele, odnosno zavisnost izmerenih vrednosti i broja ponavljanja istih vrednosti.
Svi ovi podaci su uneti u napomeni u dokumentu na kom se nalaze grafici i naveden je podatak o procentu škarta - 0%.

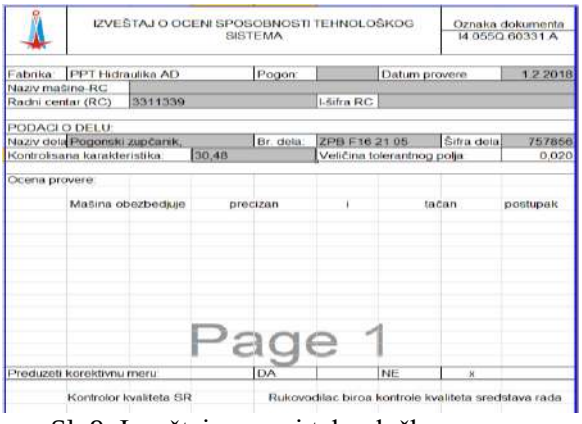


Sl. 8. Histogram raspodele rezultata merenja

Na kraju ostaje analiza rezultata merenja i izračunatih vrednosti. Iz rezultata dobijenih obradom podataka, vidimo da je vrednost potencijala procesa veća od 1,33 (Cp=2,518523), što nam govori da je proces precizan. Takođe, vrednost indeksa sposobnosti procesa je veća od 1,33 (Cpk=2,317041), što nam govori da je proces tačan – podešen.

Apsolutna vrednost razlike potencijala i indeksa sposobnosti procesa je |Cp–Cpk|=0,201482 i ona je manja od vrednosti 0,1|Cp|=0,2518523, što nam govori da su mogućnosti procesa visoke (proces je i precizan i tačan).

Na osnovu svih ovih pokazatelja zaključujemo da mašina obezbeđuje precizan i tačan postupak i sve to unosimo u konačan izveštaj o sposobnosti tehnološkog procesa. Ovaj izveštaj je prikazan na slici 9. Takođe, naglašavamo da nije potrebno preduzimati nikakve korektivne mere.


IZVEŠTAJ O OCENI SPOSOBNOSTI TEHNOLOŠKOG SISTEMA

Oznaka dokumenta: I4.055Q.60331 A

Fabrika:	PPT Hidraulika AD	Pogon:		Datum provere	1.2.2018
Naziv mašine-RC					
Radni centar (RC)	3311339		I-šifra RC		

PODACI O DELU:

Naziv dela	Pogonski zupčanik,	Br. dela:	ZPB.F16.21.05	Šifra dela	757856
Kontrolisana karakteristika	30,48		Veličina tolerantnog polja		0,020

Ocena provere:

Mašina obezbeđuje	precizan	i	tačan	postupak

Page 1

Preduzeti korektivnu meru:	DA	NE	x

Kontrolor kvaliteta SR | Rukovodilac biroa kontrole kvaliteta sredstava rada

Sl. 9. Izveštaj o oceni tehnološkog procesa

5. ZAKLJUČAK

Ocena sposobnosti procesa i opreme se može, pored pokazatelja sposobnosti procesa, izvesti i pomoću krivih rasipanja i kontrolnih karata. Bilo koja metoda da se koristi, ocenom se dobija odgovor da li se može obezbediti zahtevani nivo kvaliteta proizvoda, sa stanovišta procesa, radnika, mašina, alata i pribora.

Nijedna aktivnost upravljanja kvalitetom nije moguća bez poznavanja sposobnosti procesa. Prednost indeksa pokazatelja sposobnosti je u tome što se aktivnost usmerava na prevenciju pojave neusaglašenosti, defektnih proizvoda, odnosno škarta. Naravno, pomoću ovih podataka proces može da se prati i stalno unapređuje.

6. REFERENCE

[1] Wu, C.W., Pearn, W.L., Kotz, S.: *An overview of theory and practice on process capability indices for quality assurance*, International Journal of Production Economics, 117 (2):338 – 359, 2009.

[2] Montgomery, D. C.: *Introduction to Statistical Quality Control*, John Wiley & Sons, Inc, 7th edition, 2013.

[3] Lazić, M.: *Sposobnost procesa - merenje i ocena kvaliteta procesa*, 38. nacionalna konferencija o kvalitetu festival kvaliteta, FQ2011.

[4] Chandra, M. J.: *Statistical quality control*, CRC Press, 2001.

[5] Kovačić, G., Kondić, Ž.: *Statistička analiza sposobnosti procesa proizvodnje stretch folije*, Tehnički glasnik 6, 2(2012), 191-198, 2012.

[6] Alagić, I.: *Osiguranje kvaliteta procesa mašinske obrade kočionog diska 1J0 615 601 korištenjem SPC tehnika kvaliteta*, 3. Naučno-stručni skup sa međunarodnim učešćem "KVALITET 2003", Zenica, B&H, 13. i 14 Novembar 2003.

[7] Lazić, M.: *Alati, metode i tehnike unapređenja kvaliteta*, univerzitetski udžbenik, Mašinski fakultet Kragujevac, 2006.

[8] Kolarević, M., Radičević, B., Premović, B., Živković, O.: *Indeksi za ocenu sposobnosti procesa*, IMK-14, Istraživanje i razvoj, Godina XVI, Broj (37) 4/2010.

[9] Oakland, S. J.: *Statistical Process Control*, Fifth Edition, Butterworth Heinemann, 2003.

Autori: **M.Sc. Violeta Đorđević, Hon.D.Sc. Predrag Dašić, Dr Predrag Pravdić,** Akademija strukovnih studija Šumadija, odsek Trstenik, Radoja Krstića 19, 37240 Trstenik, Srbija, Tel: +381 37 714 121, Fax: +381 37 714 121;
E-mail: vdjordjevic@asss.edu.rs
dasicp58@gmail.com
ppravdic@asss.edu.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Zahar Đorđević, M., Puškarić, H.

SOFTWARE SOLUTION FOR THE EVALUATION OF THE BUSINESS PROCESS PERORMANCE IN MANUFACTURING SMEs BASED ON TIFNs

Abstract: *Business success of an enterprise largely depends on the success of business process management (BPM). Very important task for business managers in Small and Medium-sized Enterprises (SMEs) is to timely identify low performance of business processes and determine ways to improve it. In order to help managers in decision making, different software solutions for the evaluation and ranking of business processes, respecting their Key Performance Indicators (KPIs), have been created. The software solution presented in this paper is based on the fuzzy mathematical model which uses AHP with Triangular intuitionistic fuzzy numbers (TIFNs). It enables managers in SMEs to evaluate the performance of business processes and determine which process has the weakest performance and requires improvement.*
Key words: *Business Process Management; KPIs; Fuzzy Logic; TIFNs*

1. INTRODUCTION

Nowadays, in order to achieve success on the market, SMEs have to be focused on their business processes. It is widely recognized that good BPM is crucial for effectiveness of high level of business performance. It provides achievement of business objectives by the management and continuous improvement of business processes [1]. Performances of business processes need to be monitored and managed, which is possible to accomplish by monitoring and managing their KPIs [2].

During the management of business processes managers from SMEs are faced with multicriteria decision making problems, which can be very complex. Making decisions in these situations require analysis at a large amount of data at once, which is a difficult task. At the same time, it is necessary to monitor the values of KPIs, as well as their importance, which may be different within the process. If there is a large number of processes, the problem becomes even more complicated.

With the development of modern information science, modern expert systems and software solutions are increasingly emerging, helping the managers of these companies in decision making. Based on the entered data and built-in rules, they can effectively solve specific class of problems. This is especially important when it is necessary to perform complicated mathematical operations.

Software solutions discussed in this paper are based on the mathematical models which use the theory of fuzzy sets, where the uncertainties and imprecisions which occur are modelled by fuzzy numbers. These imprecisions are mostly related to the use of linguistic statements in description of the corresponding input data, and fuzzy numbers deal with these imprecisions in a very good manner.

Authors in [3] presented a fuzzy expert system which helps in the evaluation of development process performance. This system is based on triangular fuzzy numbers, and it can point to the critical phase of the development process and also time period with the weakest managing.

In the paper [4] an expert system, which determines the processes and products safety in the food chain during a given period of time was presented. It can help HACCP team to identify less secure processes and take appropriate management actions in order to improve management in the critical time periods.

Authors in [5] proposed the software solution to support supplier selection. This software is based on triangular fuzzy numbers and TOPSIS method and it can lead to savings in the purchase of medical implants by reducing the number of possible suppliers.

Gacic et al. [6] used MATLAB GA toolbox to develop a software solution which can solve the problem of Ranking and Optimization of Key Performance Indicators of the Strategy Process in manufacturing companies. It enables ranking of indicators, ranking of companies and comparing the strategy processes in different organizations.

Tadić et al. [7] presented a software solution which helps decision makers to make consensus in their opinions in order to evaluate weight vectors of business goals of internal processes. It is based on the model which uses the fuzzy delphi method with triangular fuzzy numbers.

All of these software solutions are based on the mathematical models in which the uncertainties and imprecisions are modelled by triangular fuzzy

numbers. For better dealing with these uncertainties, mentioned models could be improved by using different type of fuzzy numbers, for example triangular intuitionistic fuzzy numbers (TIFNs).

This paper provides the software solution based on the mathematical model partly developed in [8], and it is based on TIFNs. The program developed in [8] is based on the mathematical model where AHP method is used for the calculation of KPIs weights within each business process. This software solution ranks the manufacturing companies using the TOPSIS method, respecting both KPIs weights and values, and enables managers of these SMEs to benchmark KPIs of business processes with the best company in order to identify strengths and weaknesses in performance management.

Authors assumed that TIFNs present better way for the modelling of the human way of thinking than triangular fuzzy numbers. Unlike the program developed in [8], the software solution presented in this paper considers only one enterprise and the processes in it. It enables managers of the manufacturing enterprise to determine which process has the weakest performance and needs improvement.

2. THE PROBLEM STATEMENT

Developed software solution presented in this paper intend to assess and rank the business processes performance management success in a manufacturing SME, respecting the relative importance and values of KPIs.

Decision maker of an manufacturing SME estimates relative importance of KPIs*i*,*i'* in analogy to AHP method, using fuzzy pair-wise comparison matrix, at the level of each business process *p*:

$$\left[\tilde{w}_{ii'}^{p}\right]; i, i' = 1,..,I; p = 1,..,P \quad (1)$$

He makes judgments based on his/her knowledge and experience, so degree of uncertainty and imprecision exists. For that reason, he uses 5 predefined linguistic terms which means: slightly more important, a bit more important, more important, strongly more important and absolutely more important. These terms are modelled by TIFNs, while each TIFN is defined by six values, described in [8]:

$$\tilde{w}_{ii'}^{p} = \{\left(a_{ii'1}^{p}, a_{ii'2}^{p}, a_{ii'3}^{p}\right), \left(a_{ii'1}^{p\prime}, a_{ii'2}^{p}, a_{ii'3}^{p\prime}\right)\} (2)$$

According to AHP, KPIs' weights are calculated, using the fuzzy geometrical mean method [9].

$$\tilde{w}_{i}^{p} = \frac{\tilde{m}_{i}^{p}}{\sum_{i=1}^{I} \tilde{m}_{i}^{p}} \quad (2)$$

$$\tilde{m}_{i}^{p} = \sqrt[I]{\tilde{w}_{i1}^{p} \cdot \ldots \cdot \tilde{w}_{iI}^{p}}; i = 1,..,I; p = 1,..,P \quad (3)$$

After that, decision maker estimates values of KPIs. He uses 7 terms, named: very low value, low value, almost low value, middle value, fairly high value, high value and very high value. They are also modelled by TIFNs, in accordance to [8]:

$$\tilde{v}_{i}^{p} = \{(b_{i1}^{p}, b_{i2}^{p}, b_{i3}^{p}), (b_{i1}^{p\prime}, b_{i2}^{p}, b_{i3}^{p\prime})\} \quad (4)$$

Depending on the type of KPI, which can be benefit or cost, the linear normalization procedure is done:

for benefit-type of KPIs:

$$\tilde{r}_{i}^{p} = \{(\frac{b_{i1}^{p}}{b_{3}^{+}}, \frac{b_{i2}^{p}}{b_{3}^{+}}, \frac{b_{i3}^{p}}{b_{3}^{+}}), (\frac{b_{i1}^{p\prime}}{b_{3}^{+}}, \frac{b_{i2}^{p}}{b_{3}^{+}}, \frac{b_{i3}^{p\prime}}{b_{3}^{+}})\}$$

for cost-type of KPIs:

$$\tilde{r}_{i}^{p} = \{(\frac{b_{1}^{-}}{b_{i3}^{p}}, \frac{b_{1}^{-}}{b_{i2}^{p}}, \frac{b_{1}^{-}}{b_{i1}^{p}}), \left(\frac{b_{1}^{-}}{b_{i3}^{p\prime}}, \frac{b_{1}^{-}}{b_{i2}^{p}}, \frac{b_{1}^{-}}{b_{i1}^{p\prime}}\right)\} \quad (4)$$

After that, the weighted normalized KPIs values are calculated as:

$$\tilde{d}_{i}^{p} = \tilde{w}_{i}^{p} \cdot \tilde{r}_{i}^{p}; i = 1,..,I; p = 1,..,P \quad (5)$$

Then, the fuzzy ratings of performance management success at the level of each business process are calculated as:

$$\tilde{O}^{p} = \frac{\sum_{i=1}^{I} \tilde{d}_{i}^{p}}{I}; i=1,...,I; p=1,...,P \quad (6)$$

At the end, by using defuzzification procedure [10] representative scalars of these ratings are obtained and ranked:

$$O^{p} = defuzz\left(\tilde{O}^{p}\right) \quad (7)$$

3. THE SOFTWARE SOLUTION AND ILLUSTRATIVE EXAMPLE

Developed software solution uses HTML, CSS and JavaScript, for the front end, in order to display the interface and interact with the user, while the background data processing is performed using the PHP language for the backend.

Software was tested on data given from one manufacturing SME operating in the Republic of Serbia. Four business processes observed in this enterprise were: purchasing process (p=1), production process (p=2), marketing and sales process (p=3) and after sales service process (p=4), in accordance to [8]. It is assumed that the importance of this processes is equal. On the basis of the literature, for each of these processes appropriate KPIs were defined (see [8]).

When the program starts, it is necessary to choose dimension of the pair-wise comparison matrix for the observed process (Fig. 1).

Fig. 1. Choosing of matrix dimension

Then, it necessary to fill in the data on the level of each of observed business process (Figures 2, 3, 4, 5). This is done in accordance to explanation given in Section 2.

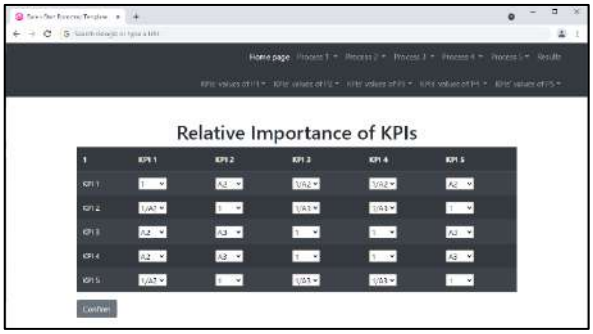


Fig. 2. Relative importance for process 1

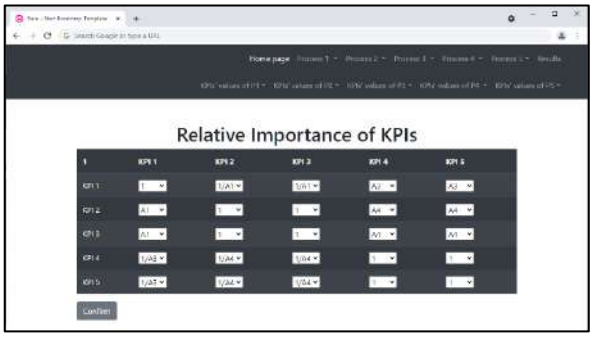


Fig. 3. Relative importance for process 2

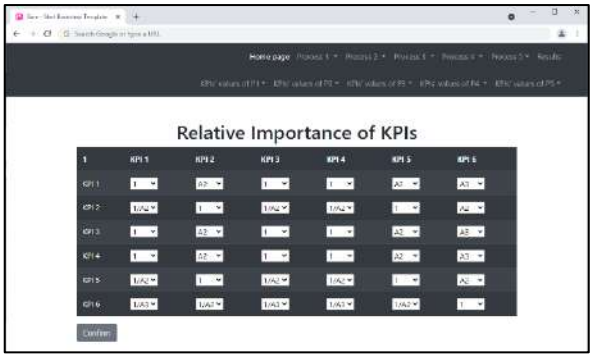


Fig. 4. Relative importance for process 3

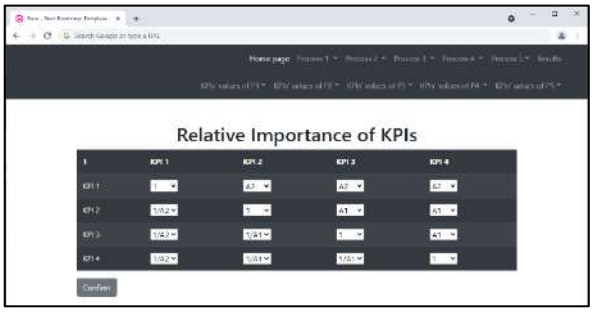


Fig. 5. Relative importance for process 4

This is followed by choosing the number of KPIs for each process and filling in the data about fuzzy assessments of the KPIs' values, at the level of each business process. These assessments are presented in Figures6-9.

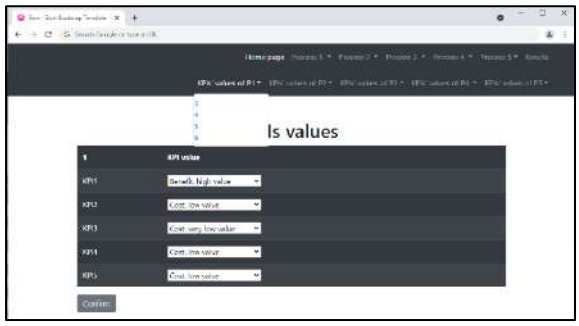


Fig. 6. KPIs values for process 1

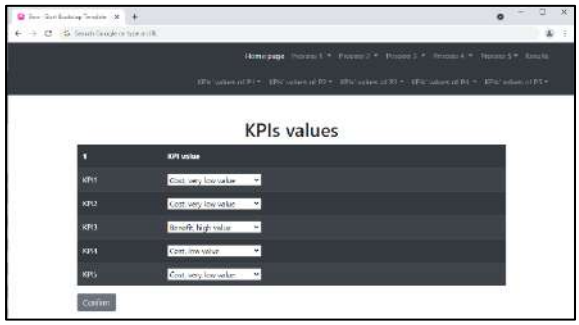


Fig. 7. KPIs values for process 2

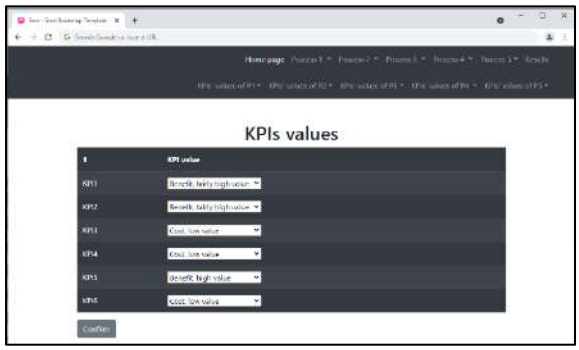


Fig. 8. KPIs values for process 3

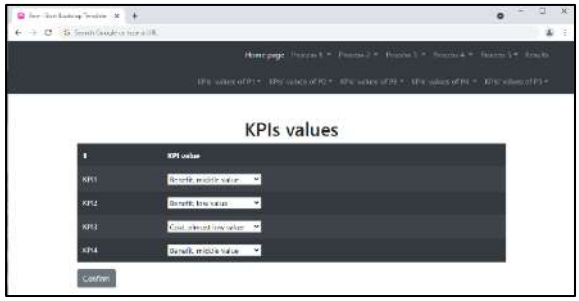


Fig. 9. KPIs values for process 4

When all input data has been entered, the program performs the calculation of the scalar ratings of performance management success at the level of each business process. Obtained results are shown on Figure 10.

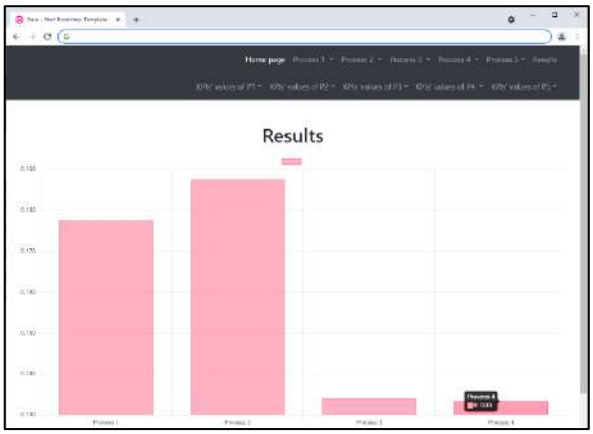


Fig. 10. Obtained results

It can be noticed that in observed manufacturing SME, process with the best performance management is process p=2, i.e. production process, and processes with the lowest performance management is process p=4, i.e. after sales service process. This means that manager of observed enterprise should focus his attention and resources on improving the after sales service. This can be done in different ways, depending on the manager's opinion and available resources.

4. CONCLUSION

Successful management of business processes performance is crucial for SMEs operating in today's competitive environment. In order to survive in the market, enterprises must constantly be focused on their business processes and their improvement.

In this paper, new software solution for the evaluation of performance management success in business processes was presented. This program is based on the intuitionistic fuzzy numbers which are more complex for the calculations than regular triangular fuzzy numbers. So, the developed program could be very useful because it greatly shortens the time required to obtain a solution. It is easy to use and very flexible. It allows the observation of five business processes at the same time, and up to six KPIs within each process.

By using the proposed program, manager of the enterprise can easily identify business process with the lowest value of performance management success. This enables him to take appropriate actions for improving of that business process, which will result in increasing of business effectiveness.

5. REFERENCES

[1] Pereira, J. L., Freitas, A. P.: *Towards a characterization of BPM tools' simulation support: the case of BPMN process models*, International Journal for Quality Research, 13(4), p.p. 783-796, 2019. doi: 10.24874/IJQR13.04-02

[2] Parmenter, D.: *Key Performance Indicators: Developing, Implementing, and Using Winning KPIs* (Third Ed.). John Wiley & Sons, Inc., Hoboken, 2015.

[3] Puskaric, H., Zahar Djordjevic, M.: *Determination of a development process performance using developed fuzzy expert system.* 7th International Quality Conference, Center for Quality, Faculty of Engineering, Kragujevac, 24th may, 2013.

[4] Zahar Djordjevic, M., Puskaric, H.:*Management of process safety in food chain*, International Journal for Quality Research 7(1), p.p. 141-152, 2013.

[5] Zahar Djordjevic, M., Puskaric, H., Djordjevic, A.*: Evaluation and ranking of artificial hip prosthesis suppliers by using a fuzzy topsis methodology.* International Journal for Quality Research 8(2), p.p. 155-168, 2014.

[6] Gacic, M., Nestic, S., Zahar Djordjevic, M., Stefanovic, M.*A Model for Ranking and Optimization of Key Performance Indicators of the Strategy Process.* International Journal of Industrial Engineering and Management, 6(1), p.p. 7-14, 2015.

[7] Tadić, D., Zahar Đorđević, M., Puškarić, H., Aleksić, A.:*New fuzzy delphi method for evaluation of business goals.* 9th International Quality Conference, Center for Quality, Faculty of Engineering, Kragujevac,June 2015.

[8] Zahar Đorđević, M.: *Business process performance management in small and medium-sized manufacturing enterprises* (in Serbian). (Doctoral dissertation, University of Kragujevac, Serbia, 2020).

[9] Kaur, P.:*Selection of Vendor Based on Intuitionistic Fuzzy Analytical Hierarchy Process*, Advances in Operations Research, p.p. 1-10, 2014.

[10] Nagoorgani, A., Ponnalagu, K.: *A New Approach on Solving Intuitionistic Fuzzy Linear Programming Problem*, Applied Mathematical Sciences, 6(70), p.p. 3467-3474, 2012.

Autori: **Zahar Đorđević Marija,**University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia; **Puškarić Hrvoje,** Academy of Professional Studies Sumadija, Kosovska 8, 34000 Kragujevac, Serbia.
E-mail: maja_199@yahoo.com
hpuskaric@asss.edu.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Žižakov, M., Vasić, S., Delić, M., Vulanović, S.

UTICAJ MENADŽMENTA KVALITETOM NA PERFORMANSE ORGANIZACIJE: PREGLED LITERATURE I KLJUČNIH STAVOVA U OBLASTI

Rezime: *U poslednje dve decenije, menadžment kvalitetom je jedan od najzastupljenijih pristupa poboljšanju kvaliteta u preduzećima, koji se implementira u cilju poboljšanja organizacionih performansi Međutim, rezultati emprijiskih istraživanja u oblasti pokazuju da menadžment kvalitetom, ipak, ne daje uvek očekivane rezultate, odnosno, da nema uvek pozitivan uticaj na performanse organizacije, što nije u skladu sa teorijskim osnovama. Cilj ovog rada jeste identifikacija literaturnih izvora, uzroka ovakvih rezultata, i definisanje smernica za postizanje pozitivnih uticaja menadžmenta kvalitetom na performanse organizacije.*
Ključne reči: *Menadžment kvalitetom; Performanse organizacije; ISO 9001*

¶

1. UVOD

Menadžment kvalitetom, možemo predstaviti kao filozofiju koja teži stalnom unapređenju svih funkcija ogranizacije. Pod pojmom kvaliteta ne podrazumeva se samo kvalitet proizvoda/usluge, već i kvalitet poslovanja, koji obuhvata odnose sa korisnicima i dobavljačima, ali i kvalitet same organizacije, odnos sa zaposlenima, resursima, i radna kultura [1-3]. Shodno rečenom, visok nivo zrelosti kulture kvaliteta, pozitivno utiče na ostvarivanje konkurentske prednosti organizacije i podstiče osvajanje novih i postojećih tržišta [4-7]. Međutim, postoje istraživanja koja govore nasuprot rečenom. Rezultati emprijiskih istraživanja u oblasti pokazuju da menadžment kvalitetom, ipak, ne daje uvek očekivane rezultate, odnosno, nema uvek pozitivan uticaj na performanse organizacije, što nije u skladu sa prethodno navedenim teorijskim osnovama [8-12]. Delić i drugi (2014) u svom istraživanju navode, da je prilikom ispitivanja uticaja menadžmenta kvalitetom na performanse organizacije, od velikog značaja uska povezanost praktičnih aspekata menadžmenta kvalitetom, svesti i znanja rukovodstva i zaposlenih o organizacionoj kulturi, kao i uslova okruženja u kome posluju ispitivane organizacije, što ujedno može predstavljati i potencijalni uzrok kontradikcije rezultata istraživanja u oblasti [13]. S obzirom da u proteklih četrdeset godina akademska zajednica nije podarila uniformno mišljenje o ovim vezama, potrebno je pronaći stvaran uzrok kontradikcije rezultata, a shodno tome i, definisati određene smernice, koje bi trebalo da doprinesu ostvarenju pozitivnog uticaja menadžmenta kvalitetom na performanse organizacije. Postavlja se pitanje „Šta menadžment kvalitetom treba da omogući, da bi bio u funkciji podrške performansama organizacije?“.

2. PREGLED LITERATURE

2.1 Menadžment kvalitetom

Menadžment kvalitetom jeste model upravljanja, koji u literaturi opisan kroz različite ključne faktore koji su definisani kombinovanjem različitih modela izvrnosti menadžmenta kvalitetom npr. Nacionalna nagrada za kvalitet - Malcolm Baldrige, Evropska nagrada za kvalitet - EFQM, Demingova nagrada i model poslovne odličnosti po Kanji-u itd. [14]. Pregledom literature, izvšena je sinteza ključnih faktora, a u daljem tekstu dat je kratak opis onih sa najvećom učestanošću: liderstvo, orijentacija na korisnike, menadžment zaposlenima, planiranje kvaliteta, učenje, kontinualno unapređenje, menadžment nabavkom.

2.2 Organizacione performanse - Inovacije

Organizacione performanse predstavljaju učinak koji organizacija ostvaruje. Postoje različiti prilazi, modeli i koncepti u opisu organizacionih performansi. U ovom radu, fokus će biti na inovacijama, iz razloga što su one poslednjih godina, neophodne po organizaciju za opstanak na tržištu [15]. Performanse inovacija, posmatraju se kroz inovacije proizvoda i inovacije procesa [7,16, 17,18].

2.3 Veza između menadžmenta kvalitetom i inovacija

Studije su ukazale da menadžment kvalitetom može obezbediti pogodno okruženje za obučavanje i podsticanje zaposlenih ka istraživanju i razvoju, stvarajući na takav način,

prilike za primenu principa i tehnika menadžmenta kvalitetom u inovativnim aktivnostima, na pronalaženju novih tržišta i kupaca, za promociju razmene znanja i neprestano unapređivanje sistema i radnih procesa, većeg kvaliteta proizvoda/usluge, većeg zadovoljstva kupaca i zaposlenih, sniženih troškova, kao i poboljšanih finansijskih i inovacijskih performansi [2,4-7]. S druge strane, uspostavljanje standarda sistema menadžmenta može sprečiti razvoj inovacija procesa, jer uniformnost procesa može negativno uticati na kreativnost kod zaposlenih, koja je neophodna za stvaranje inovacija. Pored toga, posvećenost liderstva i uključivanje zaposlenih u praksi je ograničenog karaktera i obično su zaposleni uključeni da se bave samo malim opsegom poboljšanja sistema menadžmenta [12]. Dakle, neki istraživači zagovaraju pozitivnu vezu između upravljanja kvalitetom i performansi inovacija [2-7,19]. Drugi, umesto toga, ističu da upravljanje kvalitetom ne postiže očekivane rezultate [8-12]. Stoga, pitanje upravljanja kvalitetom koji podržava adekvatno okruženje i kulturu inovacija je i dalje predmet razmatranja akademskih krugova.

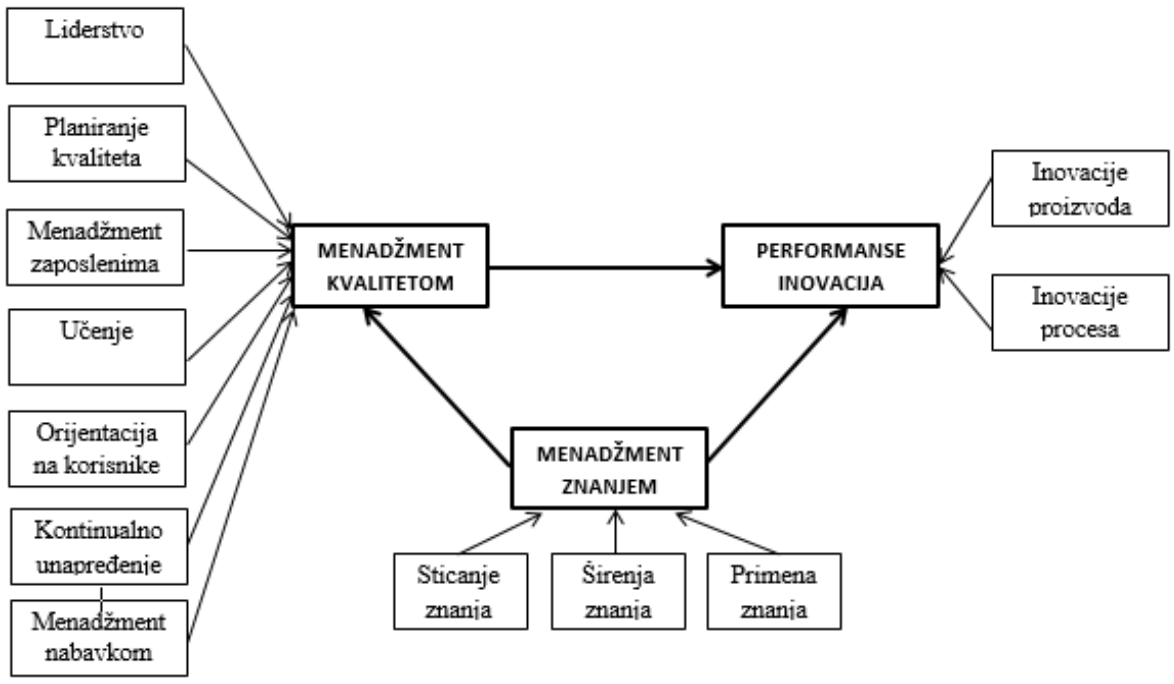
2.4 Uzroci odsustva pozitivnog uticaja menadžmenta kvalitetom na performanse inovacija

Pregledom literature, identifikovani su različiti uzročni faktori koji mogu da dovedu do odsustva pozitivnog uticaja menadžmenta kvalitetom na performanse inovacija. Interni faktori kao što su odsustvo liderstva i znanja, timskog rada, mogu dovesti do neuspeha u funkcionicanju menadžmenta kvaliteta i samim tim odsustva pozitivnog učinka [20-22].

Pored toga, menadžment znanjem se u literaturi javlja kao vrlo bitan elemenat u ostvarivanju pozitivnog učinka menadžmenta kvalitetom i pozitivnog uticaja na inovacije. Sticanje znanja kroz određene obuke unutar i izvan organizacije, širenje znanja među zaposlenima i zainteresovanim stranama, učenje i primena znanja su neophodni. Oni menjaju svest zaposlenih kao i njihove stavove i perspektivu prema bilo kojim organizacionim promenama koje doprinose ostvarenju inovativnih performansi [4,23]. Iz tog razloga, menadžment znanjem čini sastavni deo istraživačkog modela.

3. ISTRAŽIVAČKI MODEL

Istaživački model prikazan na slici 1. obuhvata: menadžment kvalitetom, menadžment znanjem i performanse inovacija. Menadžment kvalitetom je nezavisna varijabla, menadžment znanjem medijator, dok performanse inovacija predstavljaju zavisnu varijablu. Model pretpostavlja da menadžment znanjem, kao ključni medijator, značajno doprinosi i blagotvorno deluje u ostvarivanju pozitivnog uticaja menadžmenta kvalitetom na performanse inovacija, odnosno, implementaciju menadžmenta kvalitetom, koja se, suštinki, zasniva na sprovođenju kontinuiranih inovacija u radu organizacije.



Sl. 1. Istraživački model

4. SMERNICE

Sumiranjem rezultata, dolazimo do zaključka da je ipak ljudski faktor, taj koji ima najveću ulogu u prihvatanju, implementiranju i primeni menadžmenta kvalitetom, a samim tim i razvoju inovacija. Ukoliko liderstvo nije posvećeno i ne uključuje zaposlene u sistem menadžmenta, ni uvođenje menadžmenta znanjem neće doprineti ostvarivanju pozitivnog uticaja na inovacije. Na osnovu analize naučne literature i standarda ISO 10018:2020 - Menadžment kvalitetom – Uputstvo za angažovanje ljudi, u daljem tekstu su prikazane smernice koje bi mogle da doprinesu ostvarivanju pozitivnog uticaj menadžmenta kvalitetom na performanse inovacija [24]. Liderstvo bi trebalo da razvije viziju i misiju budućeg stanja kao i strategije, koje bi poboljšale ostvarivanje željenih ishoda i u kojima su uključeni svi zaposleni. Takođe, lidestvo bi trebalo da stvori kulturu i da obezbedi neophodne resurse i ukloni sve prepreke, kako bi zaposleni mogli da se usklade sa vizijom budućeg stanja i svojom podrškom dopinesu pozitivnom organizacionom uspehu i društvenoj koristi [25,26,27]. Zaposleni treba da razumeju koja je njihova uloga u primenjivanju strategije, za koje aktivnosti su odgovorni i na koji način da ih realizuju [24,27]. Lideri bi trebalo bi da imaju posvećenost prema svom radu. Propagiranje entuzijazma motiviše sve zaposlene, što u končanom ishodu, može rezultati povećanjem uspeha organizacije. Liderima su za ostvarenje vizije potrebni zaposleni, kojima pružaju podršku i podstiču ih u ostvarivanju doprinosa, uključivanjem u svakodnevne aktivnosti donošenja odluka, planiranja, unapređenja kvaliteta, razvoj inovacija i sl. [24]. Organizacije koje nagrađuju učešće zaposlenih u donošenju odluka, omogućavaju veću motivisanost i posvećenost kod zaposlenih, pri poboljšanju kvaliteta procesa, proizvoda/usluge [28]. Razvoj timskog rada povećava inovativnost i razmenu znanja, i poboljšava kompetetnost zaposlenih [23], [29]. Pored toga, obuke zaposlenih znatno utiču na svest zaposlenih o ključnim pitanjima menadžmenta kvaliteotm, pa su glavni pokretači efektivnog obavljanja posla i povećanja motivacije kod zaspolenih [30].

5. ZAKLJUČAK

Istraživanje pokazuje da se samo kroz vrhunsku praksu menadžmenta kvalitetom može uspostaviti odgovarajuće okruženje koje će biti povoljno za razvoj inovacija. Zaposleni su motivisani i posvećeni, ako se nalaze u okruženju, koje je pogodno za stvaranje i deljenje znanja, kao i kontinuirano unapređenje kroz inovacije.

U poglavlju 4. date su smernice koje bi trebalo da dovedu do pozivtinog uticaja menadžmenta kvalitetom na performanse inovacija u organizaciji.

6. REFERENCE

[1] ISO Online Browsing Platform, https://www.iso.org/obp/ui/#iso:std:iso:9000:ed-4:v1:en , last accessed 2021/10/10.

[2] Prajogo, D. I., Sohal, A. S.: *TQM and Innovation: A literature review and research framework*, Technovation, 21(9), p.p. 539–558, 2001.

[3] Leker, J., Herzog, P.: *Open and closed Innovation - Different innovation cultures for different strategies*, International Journal of Technology Management, 52(3-4), p.p. 322-343, 2012.

[4] Yusr, M.M., Mokhtar, S.S.M., Othman, A.R.: *The effect of tqm practices on technological innovation capabilities: Applying on Malaysian manufacturing sector*, International Journal for Quality Research, 8(2), p.p. 197-216, 2014.

[5] Santos-Vijande, M.L., Lez, L.I.A. lvarez-G.: *Innovativeness and organizational innovation in total quality oriented firms: The moderating role of market turbulence*, Technovation, 27(9), p.p. 514–532, 2007.

[6] D., Gotzamani, K., Gkana, V.: *Relationship between quality management, innovation and competitiveness, Evidence from Greek companies Kafetzopoulos*, Journal of Manufacturing Technology Management 26(8), p.p. 1177-1200, 2015.

[7] Long, C.S., Abdul Aziz, M.H., Kowang, T.O., Ismail, W.K.W.: *Impact of TQM practices on innovation performance among manufacturing companies in Malaysia*, South African Journal of Industrial Engineering, 26(1), p.p. 75-85, 2015.

[8] Singh P. J., Smith A. J. R.: *Relationship between TQM and innovation: an empirical study*, Journal of Manufacturing Technology Management, 15(5), p.p. 394-401, 2004.

[9] Bourke, J., Roper, S.: *Innovation, quality management and learning: Short-term and longer-term effects*, Research Policy, 46(8), p.p. 1505-1518, 2017.

[10] Cole, R. E., & Matsumiya, T.: *When the pursuit of quality risks innovation*, The TQM Journal, 20(2), p.p. 130–142, 2008.

[11] Perdomo-Ortiz, J., Gonza'lez-Benito, J., Galende, J.: *Total quality management as a forerunner of business innovation capability*, Technovation, 26(10), p.p. 1170–1185, 2006.

[12] Manders, B., Vries, H. J. De, Blind, K.: *ISO 9001 and product innovation: A literature*

review and research framework, Technovation, 48-49, p.p. 41–55, 2015.
[13] Delić M., Radlovački V., Kamberović B., Maksimović R., Pečujlija M.: *Examining relationships between quality management and organisational performance in transitional economies*, Total Quality Management & Business Excellence, Vol. 25, No 3-4, pp. 367-382, 2014.
[14] Singh, V., Kumar, A. and Singh, T.: *Impact of TQM on organisational performance: The case of Indian manufacturing and service industry*, Operations Research Perspectives. Elsevier, pp. 199–217, 2018.
[15] Antunes, M. G., Quirós, J. T. and Justino, M. do R. F.: *The relationship between innovation and total quality management and the innovation effects on organizational performance*, International Journal of Quality and Reliability Management, 34(9), pp. 1474–1492, 2018.
[16] Zeng, J., Zhang, W., Matsui, Y., Zhao, X.: *The impact of organizational context on hard and soft quality management and innovation performance*, International Journal of Production Economics 185, p.p. 240-251, 2017.
[17] K., Bin, C.S., Zailani, S., Aghapour, A.H.: *The impact of soft TQM and hard TQM on innovation performance: The moderating effect of organisational culture Kanapathy*, International Journal of Productivity and Quality Management, 20(4), p.p. 429-461, 2017.
[18] Ooi, K.B., Lin, B., Teh, P.L., Chong, A.Y.L.: *Does TQM support innovation performance in Malaysia's manufacturing industry?*, Journal of Business Economics and Management, 13(2), p.p. 366-393, 2012.
[19] Vujović, A., Jovanović, J., Krivokapić, Z., Soković, M., Kramar, D.: *The relationship between innovations and quality management system*, Tehnicki Vjesnik, 24(2), p.p. 551-556, 2017.
[20] Anu P. Anil, Satish K.P.: *TQM practices and its performance effects – an integrated mode*, International Journal of Quality and Reliability Management 36(8), p.p. 1318-1344, 2019.
[21] Escrig-Tena, A.B., Segarra-Ciprés, M., García-Juan, B., Beltrán-Martín, I.: *The impact of hard and soft quality management and proactive behaviour in determining innovation performance*, International Journal of Production Economic 200, p.p. 1-14, 2018.
[22] Khurana, V., *Management of Technology and Innovation*, Delhi: Ane Books India, 2007.
[23] Hung, Y. R., Lien, Y. B., Fang, S. C., McLean, G. N.: *Knowledge as a facilitator for enhancing innovation performance through total quality management*, Total Quality Management & Business Excellence, 21(4), p.p.425-438, 2010.
[24] ISO Online Browsing Platform, https://www.iso.org/obp/ui/#iso:std:iso:10018:ed-2:v1:en , last accessed 2021/10/15.
[25] Liao, S. H., Chang, W. J., Wu, C. C.: *Exploring TQM-Innovation relationship in continuing education: A system architecture and propositions*, Total Quality Management & Business Excellence, 21, p.p. 1121–39, 2010.
[26] Ana B. Escrig-Tena, Mercedes Segarra-Ciprés, Beatriz García-Juan, Inmaculada Beltrán-Martín: *The impact of hard and soft quality management and proactive behaviour in determining innovation performance*, International Journal of Production Economics, Elsevier, 200, p.p. 1-14, 2018.
[27] Shan, A.W., Ahmad, M.F., Nor, N.H.M. *The Mediating Effect of Innovation between Total Quality Management (TQM) and Business Performance*, IOP Conference Series: Materials Science and Engineering, 2016.
[28] Kaynak, H.: *The relationship between total quality management practices and their effects on firm performance*, Journal of operations management, 21(4), pp. 405-435, 2013.
[29] Modarres, M., Pezeshk, J.: Impact of total quality management on organisational performance, International Journal of Business Environment, 9(4), p.p. 356-389, 2017.
[30] Honarpour, A., Jusoh, A., Nor, K: Total quality management, knowledge management, and Innovation: an empirical study in R & D units, Total Quality Management & Business Excellence, 29(1), p.p. 1-19, 2017.

¶

Autori: **M.Sc Marina Žižakov, M.Sc Stana Vasić, Prof. dr Milan Delić, Prof. dr Srđan Vulanović,** Univerzitet Novi Sad, Fakultet Tehničkih Nauka, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2123.
E-mail: marinazizakov@uns.ac.rs
vasic.stana@uns.ac.rs
delic@uns.ac.rs
srdjanv@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE**
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Vasić, S. Žižakov, M., Delić, M., Vulanović, S.

RELATIONSHIP BETWEEN QUALITY 4.0, QUALITY MANAGEMENT PRACTICES AND INDUSTRY 4.0: THE VITAL ROLE OF IMPLEMENTATION BARRIERS

Abstract: *The purpose of this study is to review the vital theoretical concepts regarding the nature of the relationship between Industry 4.0, Quality 4.0, and Quality Management theory, in general. Predominant literature sources suggest that these concepts are tightly related in providing strong foundations for building the organizational and managerial structures in Industry 4.0. Moreover, some scholars pinpoint that shortcomings of quality management practices could foster implementation barriers and potentially negatively affect the Industry 4.0 practical aspects. Thus, bearing in mind the importance of constitutional factors of these relations, a literature review discussing their anatomy is provided, wrapped, and presented, through the potential research framework, with a strong emphasis on future studies in the field.*
Keywords: *Quality 4.0; Barriers; Industry 4.0; Quality management*

1. INTRODUCTION

The new industrial revolution presents the opportunity to master the latest innovations. Industry 4.0 (I 4.0) is strongly connected to Quality 4.0, focusing on quality planning, quality control, quality assurance, and quality improvement [1]. However, through the literature review, it is found that there are various Barriers for QM in Industry 4.0. Thus, these Barriers were addressed to overcome them through future research.

2. INDUSTRY 4.0

Industry 4.0 is identified as an intelligent industry, able to digitize the companies' production processes using the technical results of the third industrial revolution [2]. This industrial revolution challenges organizations by increasing the level of competitiveness. The strategic impacts of Industry 4.0 are emphasized in terms of meeting customer needs in the most efficient manner [3].

3. QUALITY 4.0

Quality 4.0 blends new technologies with traditional quality methods aiming to improve operational excellence, performance, and innovation [3]. There is progress in a series of strategic quality goals, according to QC (Quality Control), QA (Quality Assurance), QM (Quality Management), and finally QR (Quality Responsibility). With innovative technology for connectivity and intelligent computation, the ability to trace quality and safety is maximized in all product and service characteristics [4]. Various studies have outlined other barriers to a QM system in the Industry 4.0 era. E.g., it is a paradox that enterprises are struggling with the complexity of data for Industry 4.0, considering the core of the QMS system like ISO 9001 is data management [5].

3.1 Quality management

Characteristics of QM in the industrial transformation are improving products, processes, and service quality [6]. The main goal of QM is ensuring the products/services of an organization are consistent [7]. The quality management system includes all the activities of the global management that determine the quality policy, objectives, and responsibilities, as well as their implementation [8].

3.1.1 Quality planning

Quality planning is essential for successful Quality management implementation and achieving the company's strategic objectives, which results in improving customer satisfaction and performance [9]. Industry 4.0 requires Quality 4.0, with a strong focus on quality planning [1]. Quality managers have a leading role in implementing QM in creating quality policy, establishing the visions, creating values, strategic goals, and systems. Additionally, for improving the quality and enhancing the company's performance, strategic quality development planning is necessary [9].

3.1.2 Quality control

Many challenges arise regarding quality control under the uncertainty of the industrial sector's rapid evolution [8]. It is increasingly challenging to utilize standard methods to control quality and inspect the production process when customized

products are manufactured in small batch sizes. Thus, it is vital to integrate and apply the tools of Industry 4.0 to Quality control [8].

3.1.3 Quality assurance

Quality assurance is a significant part of overall digitalization [4]. In the process of quality assurance, communication is based on intricate relations. This brings difficulties in communicating plans to others in a comprehensive way. Therefore, quality managers must provide the necessary resources to facilitate efforts towards improving quality [9]. Roles in quality assurance can include working on quality design and development and planning and developing the system architecture [6].

3.1.4 Quality improvement

Quality challenges that arise define where we are in the quality journey and how far traditional Quality management practices and methods have come to match demand and customer expectations of Industry 4.0. One of the fundamental roles of quality managers in the quality improvement process is creating an environment suitable for education of employees. This is crucial for them to understand the philosophy of quality and cooperation on a high level to create a synergy of all the company resources for achieving quality objectives [9].

3.2 Human aspect

Employee affective commitment to change positively affects QM implementation [10]. New technologies offer a variety of opportunities for work organization. Although interpersonal communication is now accompanied by interaction with networked and digitized machines, the role of people is the main force of Industry 4.0 [11]. The focus is on the human aspects of quality dimensions in meeting customer expectations, peer-driven target setting, grassroots autonomy, employee empowerment, good credibility, and accountability [10].

3.2.1 Quality responsibility

In Quality Control, Quality Assurance, and Quality Management, the narrow meaning of Quality responsibility (QR) was used to guarantee product/service quality. However, the purpose of QR in the 4th industrial revolution is extended, including the responsibility of ethics, the environment, community-involved contribution, and international norms of behavior [12]. In this stage of the industrial revolution, the brand quality and the service quality should focus on clarifying the responsibility (or accountability) of quality[13].

4. BARRIERS FOR QM IN INDUSTRY 4.0

Most enterprises are struggling to accept incorporating QMS in the Industry 4.0 era, despite QMS being a common paradigm [10]. The industry still relies more on conventional QMS procedures [14]. The organizational Barriers for QM (Table 1.), based on the literature review, are:

1. **Traditional QMS -** It's challenging to achieve customer satisfaction in the present industry, which is one of the aims of QMS [6]. Thus, modern quality management measures are necessary for digital transformation [15]. Perceived security of the Industry 4.0 concept may stimulate enterprises or constitute a barrier while moving from a traditional business system to a smart environment [16].
2. **Quality Culture** - The traditional organizational culture to Quality management must be addressed in line with the current industry era [5]. Most employees should understand and possess basic knowledge of processes, which means that employees are provided with adequate training to apply this knowledge in processes. Due to undeveloped organizational culture, the accumulated knowledge and organizational learning are not able to provide the desired effects [17].
3. **The problem of Time, Cost and Quality** - Issues related to time, cost, and quality affect QMS [18]. In particular, smaller and medium-sized manufacturing companies in high-wage countries struggle to be competitive at international markets. Differentiating due to unique selling propositions implies maximized process quality and minimized costs is essential to business continuity [18].
4. **Slow adoption of Industry 4.0** - Some enterprises still use the traditional method for Quality management [14]. This makes them slow to innovate in the current industrial era. Additionally, since machines are taking over the workplaces, the fear of job loss is common and plays a vital role in adoption [18].
5. **Inadequate application of QMS** - Inadequate application of quality management systems is, certainly, one of the biggest threats in implementing Industry 4.0 [19]. It aligns with previous similar studies [14, 20]. Shortcomings in ISO 9001 implementation lead to unclear specifications, instructions, and unspecified activities [18].

Table 1. Barriers for QM in Industry 4.0

Barriers	Literature
1	Odubiyi, T. B., Oke, A. E., Mustapha, Z., Polytechnic, C. C. and Thwala, W. D. Barriers to Implementing Quality Management System in the Industry 4.0 Era. (2019). Bihi, T., Luwes, N. and Kusakana, K. (2018) 'Innovative Quality Management System for Flexible Manufacturing Systems', in 2018 Open Innovations Conference (OI). IEEE, pp. 40–46.
2	Odubiyi, T. B., Oke, A. E., Mustapha, Z., Polytechnic, C. C. and Thwala, W. D. Barriers to Implementing Quality Management System in the Industry 4.0 Era. (2019). Durana, P. et al. (2019) 'Quality Culture of Manufacturing Enterprises: A Possible Way to Adaptation to Industry 4.0', Social Sciences. MDPI, Open Access Journal, 8(4), pp. 1–25.
3	Odubiyi, T. B., Oke, A. E., Mustapha, Z., Polytechnic, C. C. and Thwala, W. D. Barriers to Implementing Quality Management System in the Industry 4.0 Era. (2019). Buckhorst, A. and Schmitt, R. H. (2017) 'Quality Management 4.0-Potentials and requirements of a holistic cloud-based approach towards a digital reflected production system', in Industrial Engineering and Operations Management. Germany, pp. 24–25.
4	Odubiyi, T. B., Oke, A. E., Mustapha, Z., Polytechnic, C. C. and Thwala, W. D. Barriers to Implementing Quality Management System in the Industry 4.0 Era. (2019). Oesterreich, T. D. and Teuteberg, F. (2016) 'Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry', Computers in Industry. Elsevier B.V., 83, pp. 121–139.
5	Odubiyi, T. B., Oke, A. E., Mustapha, Z., Polytechnic, C. C. and Thwala, W. D. Barriers to Implementing Quality Management System in the Industry 4.0 Era. (2019). Nowotarski, P., Pasławski, Jerzy and Kadler, A. (2018) 'Quality Management Systems as a key element for company strategy selection - case study', MATEC Web of Conferences. Edited by J. Pasławski, 222, p. 01012.

5. RESEARCH FRAMEWORK

The proposed research framework is presented in Fig.1.

H1: Barriers for QM in Industry 4.0 have a negative influence on Industry 4.0.

Barriers could present a setback for achieving Industry 4.0 maturity [5, 15, 16, 19, 20, 21].

H2: Barriers for QM in Industry 4.0 have a negative influence on Quality 4.0.

Barriers for QM in Industry 4.0 could present a setback for the implementation of Quality 4.0, i.e., for improving Quality Management in accordance to Quality 4.0 [5, 15, 16, 19, 20, 21].

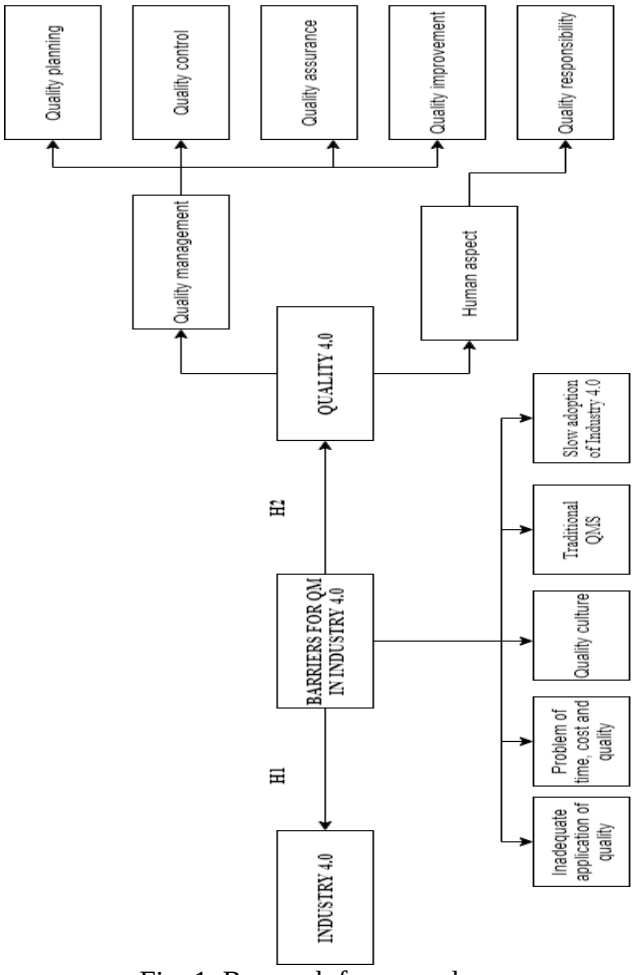


Fig. 1. Research framework

6. FINAL REMARKS

Quality Management is a key parameter that distinguishes the organization from the competition and ensures increasing revenue and productivity [21]. By overcoming the Barriers and improving Quality management based on Quality 4.0 innovations, there is a strong chance of achieving Industry 4.0 maturity. This is where the need for future research emerges. Quality 4.0 is a reference to Industry 4.0 and a crucial factor in the implementation and sustainability of this industry.

7. REFERENCES

[1] Schönreiter, I., *Significance of Quality 4.0 in Post-Merger Process Harmonization*, Lecture Notes in Business Information Processing, 285, 123–34 (2017).

[2] Gallo, T., Cagnetti, C., Silvestri, C., Ruggieri, A., *Industry 4.0 tools in lean production: A systematic literature review*, Procedia Computer Science, vol. 180, pp. 394-403, ISSN 1877-0509 (2021).

[3] Horváth, D., Szabó, R.Z., *Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal*

opportunities? Technological Forecasting and Social Change, vol. 146, pp. 119-132, ISSN 0040-1625 (2019).
[4] Aldag, M. C. and Eker, B. *What Is Quality 4.0 in the Era of Industry 4.0?* International Conference on Quality of Life, 31–34 (2018).
[5] Odubiyi, T. B., Oke, A. E., Mustapha, Z., Polytechnic, C. C. and Thwala, W. D., *Barriers to Implementing Quality Management System in the Industry 4.0 Era* (2019).
[6] Demartini, M., Tonelli, F., *Quality management in the Industry 4.0 era*, XXIII Summer School ―Francesco Turco‖ – Industrial Systems Engineering, 8-14 (2018).
[7] Rajnai, Z. and Kocsis, I., *Assessing Industry 4.0 readiness of enterprises*, IEEE 16th World Symposium on Applied Machine Intelligence and Informatics (SAMI), Kosice, pp. 000225-000230 (2018).
[8] Rashed, A. and Othman, M., *Quality Control in the Context of Industry 4.0*. International Conference, Industrial Engineering and Operations Management II vol. 281 (Springer International Publishing (2019).
[9] Djordjevic, P., Panic, M., Arsic, S. and Zivkovic, Z. *Total Quality Management & Business Excellence Impact of leadership on strategic planning of quality*. Total Quality Management. 0, 1–15 (2018).
[10] Gunasekaran, A. et al., *Quality Management in the 21st Century Enterprises: Research Pathway towards Industry 4.0*, International Journal of Production Economics, 207 (2019), 125–29 (2019).
[11] L. Adolph et al., *German Standardization Roadmap - Industry 4.0*, German Institute for Standardization and German Commission for Electrical, Electronic and Information Technologies of German Institute for Standardization and Association for Electrical, Electronic and Information Technologies, 1–76 (2016).
[12] Park, S., Shin, W. and Kim, K., *Assessing a social responsibility model for sustainable company growth in the Fourth Industrial Revolution*. Int. J. Qual. Serv. Sci. 11, 334–345 (2019).
[13] Park, S., Shin, W. and Park, Y. et al., *Building a new culture for quality management in the era of the Fourth Industrial Revolution*, Total Qual. Manag. Bus. Excell. 28, 934–945 (2017).
[14] Bihi, T., Luwes, N. and Kusakana, K. (2018) *Innovative Quality Management System for Flexible Manufacturing Systems*, Open Innovations Conference (OI). IEEE, pp. 40–46 (2018).
[15] Schlüter, N. and Sommerhoff, B., *Development of the DGQ role bundle model of the Q occupations*, International Journal of Quality and Service Sciences. Emerald Publishing Limited, 9(3/4), pp. 317–330 (2017).
[16] Gokalp, E., Şener, U. and Eren, P.E., *Development of an assessment model for Industry 4.0: Industry 4.0-MM*, International Conference on Software Process Improvement and Capability Determination, Springer, pp. 128-142 (2017).
[17] Delić, M., *Impact of management system application and application of information technologies on organizational performance, Faculty of technical sciences*, University of Novi Sad, Serbia (2013).
[18] Buckhorst, A. and Schmitt, R. H., *Quality Management 4.0-Potentials and requirements of a holistic cloud-based approach towards a digital reflected production system*, Industrial Engineering and Operations Management. Germany, pp. 24–25 (2017).
[19] Nowotarski, P., Pasławski, Jerzy and Kadler, A., *Quality Management Systems as a key element for company strategy selection - case study*, MATEC Web of Conferences. Edited by J. Pasławski, 222, p. 01012 (2018).
[20] Oesterreich, T. D. and Teuteberg, F., *Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry*, Computers in Industry. Elsevier B.V., 83, pp. 121–139 (2016).
[21] Porter, L. J., and Parker, A. J., *Total quality management—the critical success factors*. Total Quality Management, 4(1), 13–22 (1993).

Authors: **Assis. Master Stana Vasić, Assis. Master Marina Žižakov, Assoc. Prof. dr Milan Delić, Assoc. Prof. dr Srđan Vulanović,** University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Phone.: +381 21 485 2122.
E-mail: vasic.stana@uns.ac.rs
marinazizakov@uns.ac.rs
delic@uns.ac.rs
srdjanv@uns.ac.rs

ETIKUM 2021

INTERNATIONAL SCIENTIFIC CONFERENCE
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Walter, I., Tanasković, M.

OBJECT RECOGNITION IN THE DARK WITH IMAGE SEGMENTATION

Abstract: *Recent advances in machine learning development brought its wide application in surveillance and security systems. This research relates to machine learning-based surveillance methods that investigate detection and tracking mechanisms at night in low illumination. It proposes the economical and superior method for object detection in the night-time based on Mask R-CNN.*
Key words: *object recognition, image segmentation*

1. INTRODUCTION

At night, in conditions of reduced visibility, object recognition is research field in various areas such as surveillance systems, traffic, mobile robotics and autonomous vehicles. Multiple objects tracking enables the awareness of objects in the environment and provides information about their positions. On frames with low light sources, it is difficult to separate objects according to their specific characteristics and shapes, and this often requires special technologies e.g., infrared cameras and LIDAR.

With computer vision development various methods for object detection and tracking have been introduced, but these methods are generally reliable in normal visibility conditions and in daylight. Images taken at night have very low contrast and the pixels have the same gray levels on input images. [1] It is necessary to detect the attributes of objects that enable their differentiation, that is complex in low light conditions and in the absence of differentiation between objects and background. [2] Experiments show that common methods do not comply with the requirements for detection at night and in adverse visibility conditions.

RetinaNet is one-stage detector that consists of the backbone network that calculates feature maps across the image, and two subnetworks that provide object classification and bounding boxes generation. Yolo is one-stage detector that performs object detection by considering image segments and processes them with the neural network to determine bounding boxes and object classes. Mask R-CNN is popular method for detecting objects based on the CNN (Convolutional Neural Network) that can segment instances and predict their contours. Tracking results at night show that the first two algorithms are not reliable in detection during the night.

Fig. 1. Capture made at night

Fig. 2. Edge detection filter

To represent the low contrast boundaries in night scenes the edge detection image processing based on the CNN can be used. The video frames captured at night are affected by variable intensity, illumination and poor contrast and the color information is similar across the image. The image can be filtered utilizing the edge detection kernel that filters out the curves that are boundaries of image items. Image convolution applies the filter that adds each pixel specific values that are weighted according to the kernel matrix. The objective of this kind of image processing is to

extract low level features e.g., curves and shapes to represent the lack of color information and contrast issues in nighttime scenes. The filtered image on Fig.1 and 2 shows that the curves of the object on the right side couldn't be recognized due to the low illumination and contrast against the background.

2. RELATED WORK

In [3] the authors propose the Night Vision Detector and attempt to implement algorithms that improve lighting based on the RFB-Net detector. In [4] authors use thermal images combined with the association of data concerning object position.

3. METHODOLOGY

With recent development in computer vision numerous advanced algorithms for real time object tracking have been introduced. However, their accuracy depends on the environment conditions e.g., weather and light. In this research three different methods for real time object detection were evaluated. The real time object tracking was performed using RetinaNet and Yolo both in daylight and night conditions. The python library pixellib was applied for instance segmentation on the extracted video frames as the resolution to the challenge of object recognition at nighttime. The frames were extracted each half-second from the real time video sequences.

The features represent the characteristics that can distinguish different objects and based on them the feature match can be computed. Different approaches for the feature selection are based on the probabilistic distribution of features for different classes and they determine if those features can perform the classification. Three different kinds of features are relevant for object recognition. Global features are based on attributes of the corresponding image regions e.g., size and positions. The objective is to find characteristics given by examination of pixels, locations, color characteristics, and relations. Local features typically represent the curvature and boundaries that are characterized by the specific shape on the image region that is relevant for the object recognition. Relational features correspond to relative positions of regions, contours, or local features. They include distances between features and orientation relation. In this way the relative positions of items are determined for specific objects, and they can be used to verify if the specific object appears in the image. Every class of objects can be represented by specific features.[5] The matching of the object is calculated using specific features and for the given class it is represented in (1):

$$P = \sum_{i=1}^{N} w_i p_i \qquad (1)$$

where wi is the corresponding weight for the feature that is selected depending on the feature importance and pi is the computed matching value for the feature i. It can be calculated (2) as the absolute value of the difference between the unknown feature and the feature of the specified class:

$$p_i = |u_i - f_i| \qquad (2)$$

The intention is to examine if there are regions of the frame with the certain threshold level of matching.

4. RESULTS

The Retina Net and Yolo are very fast and accurate detectors that can process frames in real time. [5]

Fig. 3a. Object detection in daylight

Fig. 3b. Real-time tracking at night

Fig. 3 represents the precise bounding boxes prediction and classification of the RetinaNet during the day. Those methods however partly fail to detect objects at nighttime, above all in case of object motion. Fig. 4 shows this issue that was detected running object detector YOLOv3 on the real time video. By utilizing the Mask R-CNN detector on video frames captured in the nighttime, the object detection was successful with accurate classification that is represented on the Fig. 4.

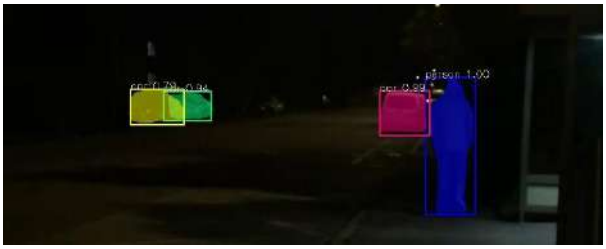


Fig. 4. Detection with segmentation

In the mentioned research, the recognized issue was that common detectors cannot differentiate objects in low light conditions and in case of objects' movement. The main reason for this occurrence is the very small color difference between the objects and the background. Therefore, deeper pixel-based analysis of frames is necessary for successful detection and the precise semantic segmentation. The tests were done on custom video sequences that were captured at nighttime at shorter distances. From video captures frames were extracted and then the image segmentation and object recognition were utilized using Mask R-CNN detector that was trained on the COCO dataset. Fig. 5 represents the architecture of the Mask R-CNN. This approach analyses images on the pixel level and objects can be detected even in low illuminated frames. Instance segmentation distinguishes foreground and background objects, and each pixel is labeled according to its class membership. The MaskRCNN detector provides pixel masks that distinguish pixels belonging to specific objects. The Mask R-CNN is the extension of the Faster R-CNN with the module for mask prediction for corresponding bounding boxes. The experiments show that the challenge of localizing objects due to the lack of color information in the nighttime and in unfavorable illumination conditions can be overcome by applying semantic segmentation. This method is fast and precise compared to other approaches and it can differentiate objects in dark scenes.

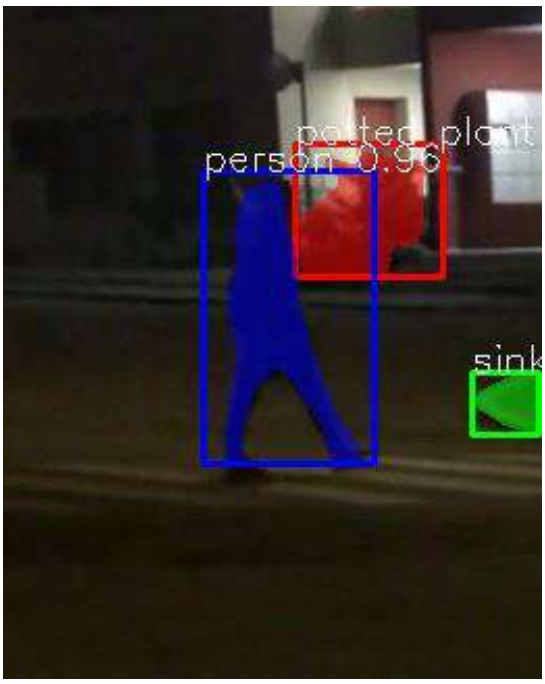


Fig. 5a. Mask R-CNN detection

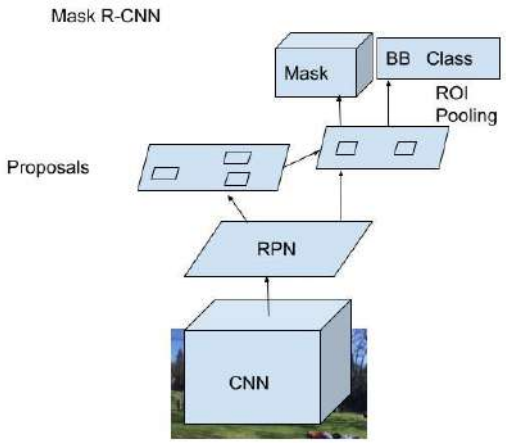


Fig. 5b. Mask R-CNN

5. CONCLUSION

The object recognition in reduced visibility and illumination can successfully be handled by applying the detector that is based on the Mask R-CNN and on the image segmentation. With its simple implementation and accurate performance this method can be implemented in surveillance systems for real-time object detection at night with weak light sources. Due to the precise calculating capability, it can distinguish items in low illuminated scenes and perform object recognition. The challenges of object recognition in low light conditions vary depending on light sources, viewpoint aspects and object classes and improvements are still required.

6. REFERENCES

[1] Ramesh Jain, Rangachar Kasturi, Brian G. Schunck, *Machine Vision book*, 1995

[2] Abdullah Nazib, Chi-Min Oh and Chil Woo Lee, *Object Detection and Tracking in Night Time Video Surveillance*, 2013

[3] Yuxuan Xiao, Aiwen Jiang, Jihua Ye, Ming-Wen Wang, *Making of Night Vision: Object Detection Under Low-Illumination*, 2020

[4] Usham Dias, Milind Rane, *Motion based object detection and classification for night surveillance*, 2012

[5] Ivana Walter, *Modelled Neural Networks for Multiple object Tracking*, Sinteza conference, 2021

Authors: **Ivana Walter, prof. dr Marko Tanasković**

Singidunum University, Danijelova 32, 11000 Belgrade, Serbia, Phone: 011/3094094

E-mail: ivana.walter.20@singimail.rs
mtanaskovic@singidunum.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE**
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Havrlišan, S., Šimunović, K., Šarić, T., Šimunović, G., Lujić, R., Svalina, I., Turinski, D., Klarić, Š.

REGRESIJSKO MODELIRANJE GUBITKA VOLUMENA PRI DULJEM TROŠENJU PLINSKI NAŠTRCANIH PREVLAKA

Sažetak: *Cilj ovog rada je statističkom analizom eksperimentalnih podataka dobiti regresijski model kojim će se uspešno predvideti ovisnost gubitka volumena usled abrazijskog trošenja o vrsti prevlake i udaljenosti plamenika i to pri duljem trošenju (2000 okretaja kotača, test "suhi pesak/gumeni kotač"). U radu je također provedena provera adekvatnosti dobivenog modela, analizom studentiziranih ostataka. Na osnovi statističke analize podataka te provere adekvatnosti modela, dobiven je adekvatan regresijski model s visokim koeficijentom determinacije* R^2.
Ključne reči: *abrazijsko trošenje, analiza varijanse, regresijski modeli, statistička analiza*

1. UVOD

Za planirane pokuse, dobivanje regresijskog modela predstavlja jedan od glavnih ciljeva. Upravo zbog toga mnogi autori su se u svojim istraživanjima bavili regresijskim modeliranjem [1, 2].

S ciljem dobivanja regresijskog modela, u radu [3] istražen je uticaj tri faktora (snaga lasera, brzina dodavanja praška i brzina skeniranja), na dimenzije nanesene prevlake od legure nikla (visina prevlake, širina prevlake i dubina penetracije prevlake u podlogu).

U radu [4] autori su za potrebe numeričkog modeliranja, s ciljem procene i uporedbe visine i penetracije prevlake od legure nikla i zone uticaja topline, proveli faktorski plan pokusa menjajući dva faktora (brzina skeniranja i snaga lasera) na četiri razine.

Autori su u radu [5] primenili centralno kompozitni plan pokusa za istraživanje brzine trošenja kod suhog kliznog trošenja legura nikla (uz leguru kobalta i nerđajući čelik) nanesenih plazma naštrcavanjem s prenesenim lukom na ugljični čelik. Statističkom obradom podataka dobiveni su regresijski modeli s visokim koeficijentima determinacije za brzinu trošenja materijala podloge te je zaključeno da tvrdoća valjčića imala značajan uticaj na odziv. Rezultati i zaključci istraživanja, ali samo za legure nikla prikazani su u radu autora [6].

Neki autori nisu primenili planirani pokus, ali su koristili statističku obradu podataka za dobivanje regresijskog modela i koeficijenta determinacije, kao na primer autori [7]. Ovisnost gubitka volumena o vremenu trošenja kod "valjčić po disku" kliznog testa za prevlaku od legure nikla dobivenu naštrcavanjem pomoću plinskog plamena, je prikazana linearnim regresijskim modelom s visokim koeficijentom determinacije R^2 (0,9968).

"Prizma po prstenu" testovi otpornosti na klizno trošenje su primenjeni u radu [8], na laserski nanesene prevlake od legura nikla na podlogu od sivog leva. Ovi autori su dobili statistički linearni model za procenu ovisnosti gubitka mase o potrošenom volumenu (koeficijent determinacije iznosi 0,9962); slično je učinjeno i u radu [9], ali za postupak naštrcavanja pomoću plinskog plamena i utaljivanja pomoću plamena (R^2 iznosi 0,9822) kao i za utaljivanje pomoću lasera (R^2 iznosi 0,9874). Autori [8] su statističkim linearnim modelom procenili prosečnu brzinu trošenja u ovisnosti o umnošku normalnog opterećenja i brzine klizanja (koeficijent determinacije iznosi 0,8638).

Linearni jednostruki i višestruki regresijski modeli (s visokim koeficijentima determinacije) ovisnosti brzine trošenja kod testa "suhi pesak/gumeni kotač" o parametrima vezanim za tvrde čestice (prosečna udaljenost među WC česticama, prosečni promer WC čestice i volumenski udeo WC čestica) razvijeni su u istraživanju prevlaka od legura nikla naštrcanih laserom, autora [10]. Dokazano je da tvrdoća matrice ne utiče na gubitak mase, dok je najveći uticaj imala prosečna udaljenost među WC česticama.

Na osnovi prethodnog pregleda primene planiranih pokusa i statističkih metoda u istraživanju toplinski naštrcanih legura nikla, može se zaključiti da su se planirani pokusi koristili i za proveru rezultata dobivenih numeričkim modeliranjem.

Stoga je cilj ovog rada dobiti regresijski model koji će uspešno predvideti gubitak volumena usled abrazijskog trošenja pri 2000 okretaja kotača (test "suhi pesak/gumeni kotač").

2. STATISTIČKA ANALIZA PODATAKA

Za statističku analizu podataka te za regresijsko modeliranje (tabela 3.49 [1], tabela 6 [2]) korišten je licencirani softver *Design Expert.*

U nastavku sledi regresijsko modeliranje (regresijska analiza) s ciljem dobivanja regresijskog modela kojim će se moći predvideti ovisnost gubitka volumena usled abrazijskog trošenja o vrsti prevlake i udaljenosti plamenika.

2.1 Regresijska analiza podataka abrazijskog trošenje prema B varijanti postupka (2000 okretaja kotača)

Izveštaj iz softvera *Design Expert* za analizu varijanse modela gubitka volumena usled abrazijskog trošenja za B varijantu postupka (2000 okretaja kotača) prikazan je u tabeli 1.

Standardna devijacija iznosi 1,27. Koeficijent determinacije R^2 iznosi 0,9902, a prilagođeni koeficijent determinacije iznosi 0,9866. Koeficijent varijacije iznosi 9,01%.

Tabela 1. Analiza varijanse modela gubitka volumena usled abrazijskog trošenja prema B varijanti postupka (2000 okretaja kotača)

Izvor varijabilnosti	**Suma kvadrata odstupanja**	**Stupnjevi slobode**	**Srednje kvadratno odstupanje**	F_0	**Verovatnost za F_0**
Model	1311,42	3	437,14	270,14	< 0,0001
A - Vrsta prevlake	1305,44	1	1305,44	806,74	< 0,0001
B - Udaljenost plamenika	3,83	1	3,83	2,37	0,1623
AB	2,14	1	2,14	1,32	0,2831
Pogreška	12,95	8	1,62		
Ukupno	1324,37	11			

Za navedene podatke prikazan je i regresijski model, izraz 1, s kodiranim vrednostima faktora, pri čemu su kodirane razine za faktor *A* (vrsta prevlake) –1 (NiCrBSi) i +1 (NiBSi), a za faktor *B* (udaljenost plamenika) –1 (mala) i +1 (velika).

$$\Delta V_{2000} = 14{,}12 + 10{,}43 \cdot A - 0{,}57 \cdot B - 0{,}42 \cdot A \cdot B \quad (1)$$

Ne uzimajući u obzir neznačajne članove (reduciranje modela) moguće je poboljšati model, no moguće ga je i pogoršati. Reduciranje modela provedeno je isključivanjem neznačajnih članova (udaljenost plamenika i interakcija), za koje je verovatnost za F_0 veća od 0,05 (verovatnost pogreške prve vrste α).

Analiza varijanse za reducirani model gubitka volumena usled abrazijskog trošenja za B varijantu postupka (2000 okretaja kotača) prikazana je u tabeli 2.

Tabela 2. Analiza varijanse reduciranog modela gubitka volumena usled abrazijskog trošenja prema B varijanti postupka (2000 okretaja kotača)

Izvor varijabilnosti	**Suma kvadrata odstupanja**	**Stupnjevi slobode**	**Srednje kvadratno odstupanje**	F_0	**Verovatnost za F_0**
Model	1305,44	1	1305,44	689,85	< 0,0001
A - Vrsta prevlake	1305,44	1	1305,44	689,85	< 0,0001
Ostatak	18,92	10	1,89		
Vrednost odstupanja od modela	5,98	2	2,99	1,85	0,2192
Pogreška	12,95	8	1,62		
Ukupno	1324,37	11			

Vrednost odstupanja od modela, nije značajna, što znači da je izabran odgovarajući model. Izrazom 2 prikazan je reducirani regresijski model s kodiranim vrednostima faktora, pri čemu su kodirane razine za faktor *A* (vrsta prevlake) –1 (NiCrBSi) i +1 (NiBSi).

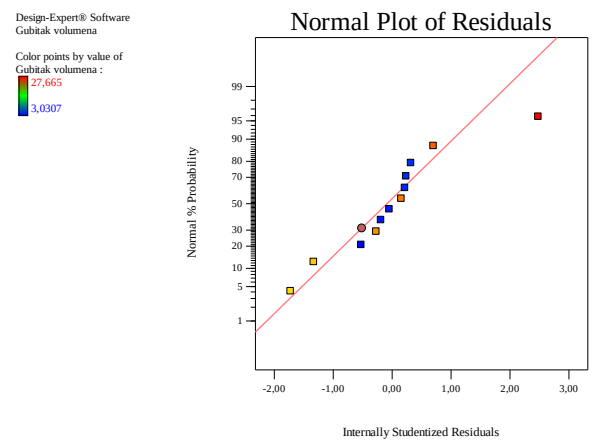
$$\Delta V_{2000} = 14{,}12 + 10{,}43 \cdot A \quad (2)$$

Za ovako dobiveni model standardna devijacija iznosi 1,38; koeficijent determinacije R^2 iznosi 0,9857, a prilagođeni koeficijent determinacije iznosi 0,9843. Koeficijent varijacije iznosi 9,74 %.

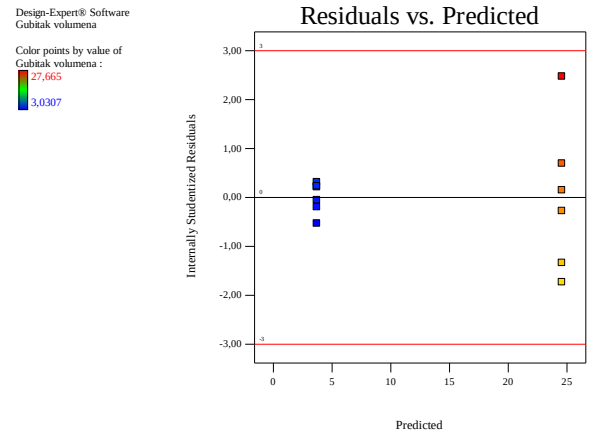
U nastavku sledi provera adekvatnosti modela, analizom studentiziranih ostataka.

Na slici 1 je vidljivo da su interno studentizirani ostatci raspodeljeni normalno. Ne

postoje značajna odstupanja od pravca, osim za šesti uzorak (NiBSi prevlaka - mala udaljenost plamenika).

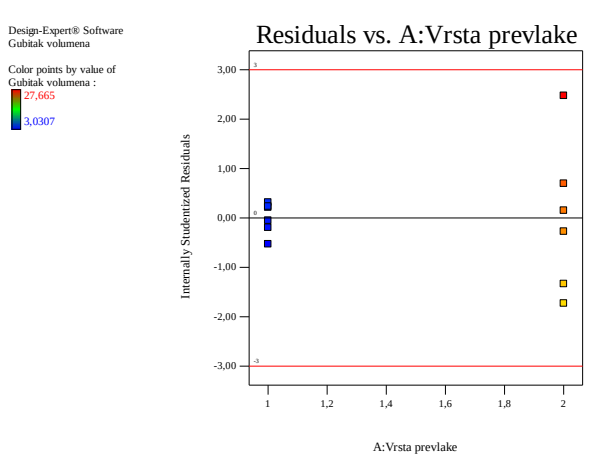


Sl. 1. Provera pretpostavke o normalnoj raspodeli ostataka za gubitak volumena usled abrazijskog trošenja prema B varijanti postupka (2000 okretaja kotača)

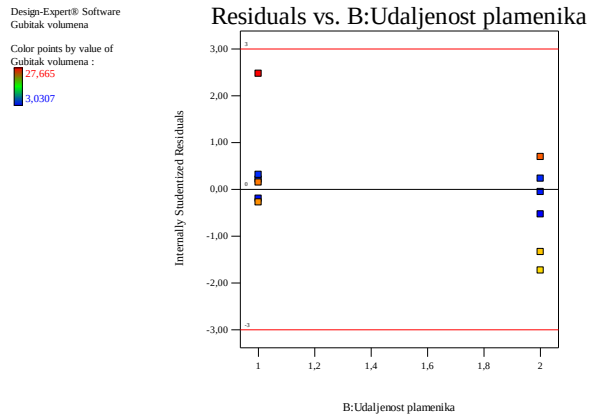


Sl. 2. Ovisnost ostataka o predviđanim vrednostima za gubitak volumena usled abrazijskog trošenja prema B varijanti postupka (2000 okretaja kotača)

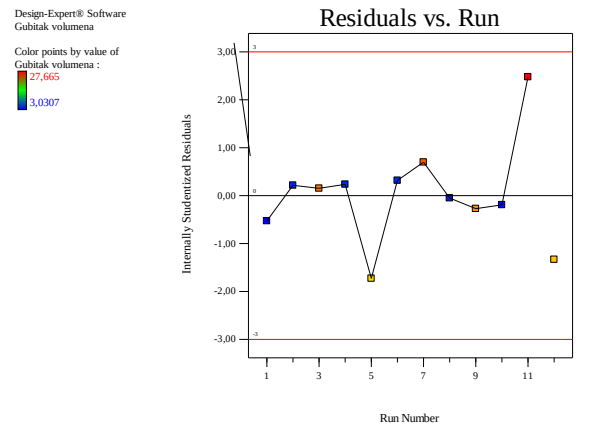
Za ovaj podatak, na slikama koje prikazuju ovisnost studentiziranih ostataka o predviđanim vrednostima (slika 2) te o razini faktora (slika 3, slika 4), vidljivo je da se nalazi u granicama $\pm 3\sigma$ i ne smatra se potencijalnim outlierom. Određena odstupanja od normalnosti i ne utiču toliko na analizu varijanse, barem za model fiksnih efekata te se može tvrditi da je analiza varijanse robusna na pretpostavku o normalnoj raspodeli [11]. Također, često se u malim uzorcima pojavljuju značajna odstupanja, tako da odstupanje od normalne raspodele i ne znači da je to značajno odstupanje od pretpostavke za analizu varijanse [11].



Sl. 3. Ovisnost ostataka o razinama faktora A za gubitak volumena usled abrazijskog trošenja prema B varijanti postupka (2000 okretaja kotača)



Sl. 4. Ovisnost ostataka o razinama faktora B za gubitak volumena usled abrazijskog trošenja prema B varijanti postupka (2000 okretaja kotača)



Sl. 5. Ovisnost ostataka o redosledu izvođenja pokusa za gubitak volumena usled abrazijskog trošenja prema B varijanti postupka (2000 okretaja kotača)

Iz već ranije spomenutih slika 2 do 5, vidljivo je, osim što studentizirani ostatci ne izlaze iz intervala $\pm 3\sigma$, da se malo razlikuju po varijansama. Varijanse su najveće za najveće

predviđene vrednosti (slika 2). Rasipanje ostataka je veće za NiBSi prevlaku (slika 3) i za malu udaljenost plamenika (slika 4). Kako je već ranije navedeno, nejednakost varijansi može uticati na *F* test, ali ne značajno kada postoji isti broj podataka u svakom uzorku (razini) [11], a što je u ovome pokusu ispunjeno.

3. ZAKLJUČAK

U radu su eksperimentalni podatci statistički analizirani s ciljem dobivanja regresijskog modela.

Na osnovi statističke analize podataka, dobiven je značajni regresijski modeli s visokim koeficijentima determinacije (R^2 iznosi 0,9857), iz kojih se može zaključiti da vrsta prevlake ima značajan uticaj na gubitak volumena usled abrazijskog trošenja pri 2000 okretaja kotača (dulje trošenje).

4. REFERENCE

[1] Havrlišan, S.: *Stohastički pristup modeliranju i optimiranju procesa naštrcavanja pomoću plinskog plamena*, doktorska disertacija, Slavonski Brod, Strojarski fakultet u Slavonskom Brodu, 2017.

[2] Havrlišan, S., Šimunović, K., Vukelić, D.: *Modelling of abrasive wear of Ni-based self-fluxing alloy coatings by the application of experimental design*, Tehnički vjesnik, 23, 6, 1687-1693, 2016.

[3] Davim, J. P., Oliveira, C., Cardoso, A.: *Predicting the Geometric Form of Clad in Laser Cladding by Powder using Multiple Regression Analysis (MRA)*, Materials and Design, 29, 2, 554-557, 2008.

[4] Felde, I., Bergant, Z., Grum, J.: *Simulation of Laser Alloying Process*, Critical Infrastructure Protection Research: Results of the First Critical Infrastructure Protection Research Project in Hungary, Book Series: Topics in Intelligent Engineering and Informatics, Nadai, L., Padányi, J. (ur.), Springer International Publishing, 12, 59-67, 2016.

[5] Ramachandran, C. S., Balasubramanian, V., Varahamoorthy, R.: *Comparative Evaluation of Dry Sliding Wear Behaviour of Plasma Transferred Arc Hardfaced Surfaces by the Pin-on-Roller Method*, Proceedings of the Institution of Mechanical Engineers Part J - Journal of Engineering Tribology, 224, 91-106, 2010.

[6] Ramachandran, C. S., Balasubramanian, V., Varahamoorthy, R., Babu, S.: *Dry Sliding Wear Behaviour of Plasma Transferred Arc Hardfaced Colmonoy Surface*, Surface Engineering, 25, 6, 440-448, 2009.

[7] Stanford, M. K., Jain, V. K.: *Friction and Wear Characteristics of Hard Coatings*, Wear, 251, 1-12, 990-996, 2001.

[8] Fernandez, E., Cadenas, M., Gonzalez, R., Navas, C., Fernandez, R., de Damborenea, J.: *Wear Behaviour of Laser Clad NiCrBSi Coating*, Wear, 259, 870-875, 2005.

[9] Gonzalez, R., Cadenas, M., Fernandez, R., Cortizo, J. L., Rodriguez, E.: *Wear Behaviour of Flame Sprayed NiCrBSi Coating Remelted by Flame or by Laser*, Wear, 262, 3-4, 301-307, 2007.

[10] Polak, R., Ilo, S., Badisch, E.: *Relation Between Inter-Particle Distance (LIPD) and Abrasion in Multiphase Matrix-Carbide Materials*, Tribology Letters, 33, 1, 29-35, 2009.

[11] Montgomery, D. C.: *Design and Analysis of Experiments*, Hoboken, John Wiley & Sons, 2013.

Autori: **doc. dr. sc. Sara Havrlišan, prof. dr. sc. Katica Šimunović, prof. dr. sc. Tomislav Šarić, prof. dr. sc. Goran Šimunović, prof. dr. sc. Roberto Lujić, doc. dr. sc. Ilija Svalina, Dražen Turinski mag. ing. mech.,** Sveučilište u Slavonskom Brodu, Strojarski fakultet u Slavonskom Brodu, Trg Ivane Brlić Mažuranić 2, 35000 Slavonski Brod, Hrvatska, Tel.: +385 35 493 439, Fax: +385 35 446 446.

E-mail: shavrlisan@unisb.hr
ksimunovic@unisb.hr
tsaric@unisb.hr
gsimunovic@unisb.hr
rlujic@unisb.hr
isvalina@unisb.hr
dturinski@unisb.hr

Dr. Štefanija Klarić, Charles Darwin University, Red 1.3.15, Ellengowan Drive, Casuarina 0810, Darwin, Australia, Tel: +61889466416
E-mail: stefanija.klaric@cdu.edu.au

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Nedeljković, D., Stanojević, S., Puzović, R., Jakovljević, Ž.

INTEGRACIJA PROIZVODNIH RESURSA U SISTEM ZA IZVRŠAVANJE PROIZVODNJE KORIŠĆENJEM OPC-UA

Rezime: *Kompletna digitalizacija svih proizvodnih procesa u okviru Industrije 4.0 i povezivanje realnog sveta i njegove kibernetske (virtuelne) reprezentacije u realnom vremenu zahteva neometani protok informacija između i unutar svih nivoa piramide automatizacije. Jedan od ograničavajućih faktora u tom kontekstu predstavlja razmena podataka između uređaja i softverskih sistema različitih proizvođača koji po pravilu za komunikaciju koriste namenski kreirane protokole. Rešenje ovog problema se pronalazi u postizanju interoperabilnosti kroz primenu OPC-UA (engl. Open Platform Communication - Unified Architecture) standarda. U okviru ovog rada sprovedena je integracija resursa zasnovanih na servo motorima i sistema za izvršavanje proizvodnje korišćenjem OPC-UA.*
Ključne reči: *Upravljanje proizvodnim resursima, Sistem za izvršavanje proizvodnje, OPC-UA*

1. UVOD

Savremeni proizvodni procesi projektuju se po principima paradigme poznate pod nazivom Industrija 4.0 [1]. Između ostalog, to podrazumeva kompletnu digitalizaciju protoka informacija unutar piramide automatizacije počevši od najnižeg sloja gde se nalaze senzori i aktuatori, sve do sloja kojim je definisan sistem za planiranje proizvodnje. Tok podataka i informacija izvodi se u realnom vremenu kako bi se obezbedilo planiranje i upravljanje procesom proizvodnje. OPC-UA (engl. *Open Platform Communication - Unified Architecture* - Otvorena platforma za komunikaciju – jedinstvena arhitektura) standard pokazao se kao pogodan za ostvarivanje pouzdane i sigurne razmene podataka i postizanje visoke interoperabilnosti između uređaja različitih proizvođača [2,3].

Kao jezgro proizvodnog sistema, sistemi za izvršavanje proizvodnje (MES - engl. *Manufacturing Execution System*) upravljaju radom proizvodnih procesa koji uključuju fizički povezana sredstva/opremu [4]. Pored toga, MES omogućava automatsku razmenu podataka između informacionih sistema i upravljačkih podsistema proizvodnih resursa u realnom vremenu.

S druge strane, automatizacija proizvodnih procesa dovodi do sve veće potražnje za servo sistemima, koji postaju neizbežan deo u aplikacijama gde se zahteva visoka fleksibilnost u ostvarivanju zadatih trajektorija [5]. Iako je funkcionisanje servo sistema moguće ostvariti upotrebom samo motora i servo drajvera, najčešće se za upravljanje radom motora koristi i nadređeni kontroler, npr. programabilni logički kontroler (PLC - engl. *Programmable Logic Controller*).

U ovom radu izvršena je integracija servo motora (koji simulira njime pogonjeni proizvodni resurs) i sistema za izvršavanje proizvodnje. Automatsko izvršavanje trajektorije servo motora (koja odgovara proizvodnji željenog proizvoda) izvodi se na osnovu lansiranog radnog naloga definisanog planom proizvodnje u okviru MES.

Nastavak rada biće struktuiran na sledeći način. Drugo poglavlje prikazuje sistem za upravljanje radom servo motora, dok je u trećem poglavlju opisana njegova integracija sa sistemom za izvršavanje proizvodnje. Zaključne napomene i pravci daljih istraživanja dati su u poglavlju 4.

2. UPRAVLJANJE RADOM SERVO MOTORA

Servo motor je sastavni deo demonstracionog panela koji se nalazi u okviru Laboratorije za automatizaciju proizvodnih procesa na Mašinskom fakultetu u Beogradu i u ovom slučaju će simulirati odgovarajući proizvodni resurs. Komponente demonstracionog panela korišćene za ovu aplikaciju su: 1) PLC *Mitsubishi iQ-F FX5UC*, 2) servo motor *Mitsubishi HG-KN13J*, 3) servo drajver *Mitsubishi MR-JE-10C*, 4) induktivni senzor.

Međusobna veza između računara, PLC-a i servo drajvera ostvarena je pomoću *Ethernet* protokola, gde su svi uređaji povezani na jedan *switch*. Svakom umreženom uređaju dodeljena je jedinstvena IP adresa iz prethodno definisanog opsega. Pored toga, za komunikaciju između PLC-a i servo drajvera koristi se *CC-Link IE Field Network Basic* protokol kojim se postiže velika

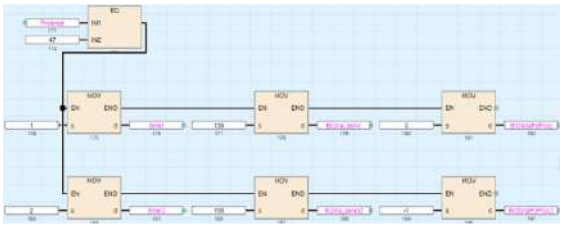
brzina komunikacije i prenosa podataka. Za programiranje PLC-a korišćen je softverski paket *MELSOFT GX Works3*, gde se uz pomoć jezika *FBD/LD* generišu programi na bazi funkcijskih blokova i lestvičastih dijagrama.

Servo motor simulira rad proizvodnog resursa koji se koristi za proizvodnju četiri različite vrste proizvoda. Informaciju o proizvodu koji treba izraditi kao i o potrebnoj količini, PLC dobija od *Opera MES* preko OPC-UA; za to se koriste promenljive *Kolicina* (PLC adresa D200) i *Proizvod* (PLC adresa D202). Pored toga, *Opera MES* preko OPC-UA dostavlja PLC-u i promenljivu *Servo_on* (PLC adresa D201) koja se koristi za pokretanje ciklusa. Proizvodi se razlikuju po sekvencama koje servo motor ostvaruje, a koje su definisane smerom, brzinom i brojem punih obrta (Tabela 1).

Tabela 1. Parametri zadatih trajektorija [6]

Pr. (Kod)	Sekvenca 1			Sekvenca 2		
	Smer	Brz.	Br. o.	Smer	Brz.	Br. o.
1 (47)	poz.	150	3	neg.	100	1
2 (48)	poz.	1000	10	neg.	800	3
3 (49)	neg.	200	3	poz.	120	2
4 (50)	neg.	700	4	poz.	900	7

Na osnovu primljenih podataka, PLC postavlja odgovarajuće vrednosti parametara servo motoru u cilju izvršavanja zadate trajektorije za taj proizvod; na Slici 1 dat je primer postavljanja željenih parametara za proizvod 1.



Sl. 1. PLC kod za definisanje proizvoda [6]

PLC kod za izvršavanje jednog ciklusa proizvoda prikazan je na Slici 2. U osnovi ovog dela koda su funkcijski blokovi *MC_MoveAbsolute_JEC* koji upravljaju brzinom i pozicijom ose koju pogoni servo motor, u ovom slučaju ose *axis1*. Po jedan funkcijski blok se koristi za svaku od sekvenci iz Tabele 1. Na ulaze *Position*, *Velocity* i *Direction* blokova unose se vrednosti za željenu poziciju (*BrObrtaPoProiz*/*BrObrtaPoProiz*2*100), brzinu (*Brzina_servo*/*Brzina_servo*2) i smer (*Smer*/*Smer*2) dobijeni korišćenjem kodova poput onog prikazanog na Slici 1. Vremena ubrzanja i usporenja (ulazi *Acceleration* i *Decelaration*) su unapred definisana i ista za svaki proizvod. Funkcijski blokovi koji odgovaraju dvema sekvencama izvršavaju se jedan za drugim, s tim što se nakon svakog od njih servo motor vraća u početnu poziciju definisanu induktivnim senzorom korišćenjem funkcijskih blokova *MCv_Home_JEC*. Željeni broj ciklusa se ostvaruje korišćenjem standardnog funkcijskog bloka brojača unapred (*CTU*). Ciklus proizvodnje dela otpočinje kada se promenljivoj *Servo_on* preko OPC-UA pošalje vrednost 1.

3. INTEGRACIJA U SISTEM ZA IZVRŠAVANJE PROIZVODNJE

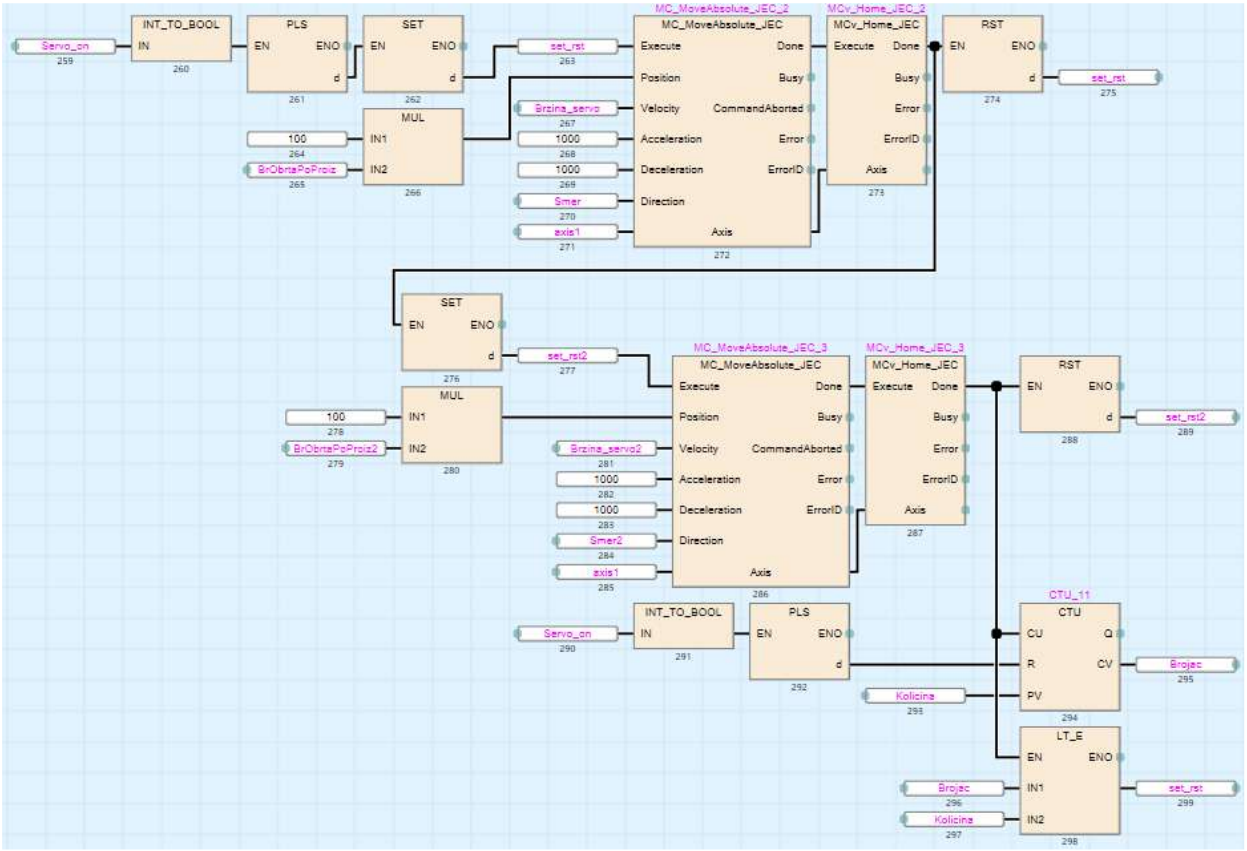
U ovom poglavlju ukratko je prikazana procedura informacione integracije PLC-a i nadređenog sistema za izvršavanje proizvodnje. Integracija između PLC-a i MES-a će se ostvariti korišćenjem OPC-UA standarada. Na osnovu plana proizvodnje definisanog u okviru MES, potrebno je nakon lansiranja radnog naloga omogućiti automatsko izvršavanje trajektorije servo motora koja odgovara proizvodnji željenog proizvoda.

Opera MES se sastoji od dva osnovna funkcionalna dela: *Opera Plant Manager* i *Opera Work Flow Manager*. *Opera Workflow Manager* omogućava upravljanje svim radnim stanicama i ostalim procedurama vezanim za radne stanice, dok se *Opera Plant Manager* koristi za upravljanje radnim nalogom i analizu dobijenih podataka u realnom vremenu.

Kako bi se u okviru *Opera Plant Manager*-a [7] kreirao i lansirao radni nalog potrebno je definisati elemente poput postrojenja, mašina, operacija, radnih naloga itd. koji su prikazani u Tabeli 2. Postupak počinje kreiranjem postrojenja *Mašinski fakultet*, kojem se dodeljuje određeni departman – u ovom slučaju *Proizvodno mašinstvo*. Departman sadrži skup operatera, kao i radni centar i troškovni centar za koje je vezana mašina *Servo Motor*. Za potrebe ovog rada, dodato je ukupno pet proizvoda, od kojih se proizvod *Deo 1* kupuje, dok se ostali proizvodi smatraju finalnim. Postupak izrade proizvoda definisan je izvršavanjem jedne ili više operacija.

Tabela 2. Elementi u okviru *Opera Plant Manager*

Element	**Naziv**
Plants	Mašinski fakultet
Departments	Proizvodno mašinstvo
Cost Center, Work Center	Automatizacija proizvodnje
Machines	Servo Motor
Operators	Servo Operator 1 Servo Operator 2
Products	Deo 1 Proizvod *i*, (*i*=1,...,4)
Operations	Moment
Workflow	Start servo Stop servo
Work Order	za proizvod *i*, (*i*=1,…,4)



Sl. 2. PLC program za izvršavanje odgovarajućeg ciklusa [6]

Za puštanje radnih naloga koji su kreirani u okviru *Opera Plant Manager*-a u proizvodnju koriste se radni tokovi koji se definišu u okviru *Opera Workflow Manager*-a. U skladu sa tim, za povezivanje PLC-a koji upravlja radom motora sa softverom *Opera MES* potrebno je kreirati odgovarajući radni tok. U ovom slučaju, generisana su dva radna toka od kojih je jedan namenjen za pokretanje rada servo motora, a drugi za informisanje MES-a da je završena proizvodnja željene količine proizvoda. Prilikom kreiranja radnih tokova neophodno je kreirati tri SQL procedure kojima se odgovarajuće informacije razmenjuju između radnog toka i *Opera Plant Manager*-a. Prva od njih je procedura *OnWfCreate* koja se aktivira pri pokretanju radnog toka i služi za odabir mogućih operatera na mašini i njihovo prebacivanje u radni tok. Pored toga, procedura *OnChangeValue* služi za automatski unos odgovarajućih vrednosti pri prebacivanju između tabova u okviru radnog toka nakon odabira ili popunjavanja polja u trenutnom tabu; u ovom slučaju u sukcesivnim tabovima se biraju mašina, radni nalog i sa njim vezani vrsta i količina proizvoda. Unutar pomenutih procedura figurišu određene promenljive: *di_badge* (ID radnika), *ma_codice* (broj mašine), *pb_codice* (broj radnog naloga), *dp_qtavrs* (količina) i *ar_codice* (ID broj proizvoda). Procedure se kreiraju u okviru okruženja *Microsoft SQL Server Management Studio*. Kreiranje narudžbenice svodi se na odabir proizvoda, kao i na potrebnu količinu. Po prispeću narudžbenice, za svaki proizvod se u okviru *Opera Plant Manager*-a generiše radni nalog na osnovu koga se informacija automatski prosleđuje kreiranom radnom toku.

Za prosleđivanje informacije o vrsti proizvoda (*ar_codice*) i njegovoj količini (*dp_qtavrs*) PLC-u preko OPC-UA koristi se procedura *Commit* koja se pokreće prilikom prihvatanja podataka definisanih u radnom toku. U okviru ove procedure korišćenjem XML koda čija je struktura definisana od strane proizvođača softvera traženi podaci se predaju za komunikaciju preko OPC-UA. OPC-UA komunikacija je bazirana na klijent/server arhitekturi, gde *Opera MES* predstavlja OPC-UA klijenta koji šalje podatke, dok OPC server *KEPServerEX 6* [8] prima podatke i shodno tome ažurira vrednosti na *PLC*-u (Slika 3).

Sl. 3. OPC-UA konfiguracija [6]

Kako *KEPServerEX 6* koji se koristi za pristupanje odgovarajućim registrima PLC-a *Mitsubishi iQ-F FX5UC* predstavlja klasičan

OPC-DA server za pristup podacima (DA - engl. *Data Access*), za komunikaciju sa *Opera MES* OPC-UA klijentom neophodna je njegova konverzija u OPC-UA model. Konverzija se izvodi upotrebom OPC-UA *wrapper*-a i u ovom slučaju je korišćen *OPC Expert*. Adresa OPC-UA servera nakon konvertovanja korišćenjem *OPC Expert*-a je *opc.tcp://desktop-7nifbm3:57888/opcexpert*, gde je *desktop-7nifbm3* naziv lokalnog računara. Funkcionalnost *OPC Expert*-a proverava se pomoću *UAExpert*-a. Takođe, ovim softverom izvršeno je očitavanje čvorova (*NodeID*) koji su namenjeni za komunikaciju između PLC-a i *Opera MES*-a. Konkretno u ovoj aplikaciji kreirani su čvorovi sa sledećim identifikacionim brojevima:

1. ns=3;s=DESKTOP-7NIFBM3-> Kepware.KEPServerEX.V6-> PLC.Device1.Servo_on
2. ns=3;s=DESKTOP-7NIFBM3-> Kepware.KEPServerEX.V6-> PLC.Device1.Kolicina
3. ns=3;s=DESKTOP-7NIFBM3-> Kepware.KEPServerEX.V6-> PLC.Device1.Proizvod

koji se koriste za pristup adresama D201, D200 i D202, respektivno i prenos podataka od *Opera MES* ka PLC-u.

Konfigurisanje *Opera MES* kao OPC-UA klijenta vrši se korišćenjem *json* fajla čiju strukturu je definisao proizvođač softvera, a koji sadrži podatke potrebne za uspostavljanje komunikacije između klijenta i servera. Neki od najznačajnijih podataka su adresa OPC-UA servera (*discoveryURL*), IP adresa računara na kome je instaliran MES (*monitorAddress*), identifikacioni brojevi čvorova u okviru OPC-UA servera (*nodeID*) kao i nazivi promenljivih (*alias*) definisanih u okviru procedure *Commit* čije vrednosti treba smestiti u odgovarajuće čvorove na OPC-UA serveru i dalje ih proslediti na PLC.

4. ZAKLJUČAK

U okviru ovog rada predstavljen je sistem za upravljanje radom servo motora koji obezbeđuje automatsko pokretanje motora iz sistema za izvršavanje proizvodnje. Sistem je zasnovan na OPC-UA komunikaciji baziranoj na klijent/server arhitekturi pri čemu OPC server *KEPServerEX* 6 ima pristup PLC-u koji upravlja radom motora, dok je *Opera MES* OPC-UA klijent. Servo motor je upotrebljen kao simulator proizvodnog resursa koji može proizvoditi različite vrste delova. Nakon lansiranja radnog naloga iz radnog toka sistema za izvršavanje proizvodnje, PLC koji upravlja radom motora automatski dobija informacije o željenoj vrsti i količini proizvoda i automatski pokreće izvršavanje potrebne trajektorije motora bez potrebe za papirnom dokumentacijom. Sistem je implementiran i eksperimentalno testiran na instalaciji u Laboratoriji za automatizaciju proizvodnih procesa. U daljem radu planirana je integracija složenijih proizvodnih resursa kao što su roboti i mašine alatke sa sistemom za izvršavanje proizvodnje.

5. REFERENCE

[1] Kagermann, H., Helbig, J., Hellinger, A., Wahlster, W.: *Recommendations for implementing the strategic initiative INDUSTRIE 4.0*, Forschungsunion, 2013.

[2] OPC foundation, OPC UA Online Reference, https://reference.opcfoundation.org, datum pristupa: 02.11.2021.

[3] Jakovljević, Ž., Nedeljković, D., Ševarlić, F., Puzović, R.: *Komunikacija između proizvodnih resursa korišćenjem OPC-UA standarda*, Zbornik radova 42. Jupiter konferencije, pp. 211-222, Beograd, 2020.

[4] Kletti, J.: *Manufacturing execution system-MES*, Springer Science & Business Media, 2007.

[5] Younkin, G. W.: *Industrial Servo Control Systems: Fundamentals and Applications, Revised and Expanded*, CRC press, 2002.

[6] Stanojević, S.: *Integracija resursa zasnovanih na AC servo motorima i sistema za izvršavanje proizvodnje*, master rad, Univerzitet u Beogradu – Mašinski fakultet, 2021.

[7] Opera MES: https://www.operames.it/index.php/en/, datum pristupa: 02.11.2021.

[8] Kepware: https://www.kepware.com/en-us/, datum pristupa: 02.11.2021.

ZAHVALNICA: Rad je nastao u okviru istraživanja sprovedenog uz podršku Fonda za nauku Republike Srbije, evidencioni broj: 6523109, VI-MISSION4.0, 2020-2022, kao i u okviru projekta ev. broj: 451-03-9/2021-14/200105 finansijski podržanog od strane MPNTR Republike Srbije. Autori se zahvaljuju kompaniji Key IT d.o.o., Beograd na donaciji Opera MES softvera.

Autori: **Dušan Nedeljković, Stefan Stanojević, prof. dr Radovan Puzović, prof. dr Živana Jakovljević,** Univerzitet u Beogradu, Mašinski fakultet, Kraljice Marije 16, 11120 Beograd.
E-mail: dnedeljkovic@mas.bg.ac.rs
stefan.st97sd@gmail.com
rpuzovic@mas.bg.ac.rs
zjakovljevic@mas.bg.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER2-4, 2021**

Košarac, A., Mlađenović, C., Zeljković, M.

PREDICTION OF SURFACE ROUGHNESS IN END MILLING USING ARTIFICIAL NEURAL NETWORK

Abstract:*Artificial neural networks (ANNs), as one of the techniques of artificial intelligence, can be used to monitor, or predict, different phenomenon related to the cutting process such as cutting resistance, vibration, toolwear, surface roughness, etc. This paper presents the application of artificial neural networks in order to predict influence of the machining parameters, i.e. cutting speed, feed per tooth, depth of cut and the effect of coolant to surface roughness. For this purpose, 108 different architectures of artificial neural networks as well as different training algorithms, were tested.Dataset used for ANNs development was obtained experimentally.*
Key words:*Artificial neural networks, surface roughness, design of experiment*

1. INTRODUCTION

Surface quality is one of the most important indicators of the machined parts quality. Average surface roughness (Ra) represents a measure of the surface quality. Average surface roughness is influenced by machining parameters and tool geometry. The analytical method of defining the average surface roughness is not applied in practice due to the its complexity and the empirical models are applied only for certain values of machining parameters.

This paper shows design and development of artificial neural networks (ANNs) for prediction of average surface roughness, as one of the most common surface roughness parameters. Dataset used for ANNs development was obtained experimentally, by machining Al7075 aluminum alloy under various machining conditions.

Benardos [1] uses artificial neural networks to determine the arithmetic average surface roughness and the cutting forces in the process of milling. The factors considered in the experiment are depth of cut, feed per tooth, cutting speed, and wear of tool, cutting fluid and components of the cutting forces. The workpiece material is a series 2 aluminum alloy. Data set for ANNs development was provided experimentally. Experiment was designed using Taguchi methodology.Benardos [1] assumes that there is an interaction between cutting speed and displacement, as well as cutting speed and tool wear, while there is no interaction between the remaining factors. There arethree levels for all factors except tool wear, which has two levels.The neural network architecture consists of one input layer with five neurons, two hidden layers with four and three neurons, and one output layer with two neurons. The Levenberg - Marke training algorithm was used for training.

Al Hazza [2] studies the influence of high-speed machining on the average surface roughness using artificial neural networks. Dataset was provided experimentally, in the end milling machining operation of AISI H13 tool steel (EN ISO 4957 X40CrMoV5-1). The neural network dataset was obtained experimentally, by 20 runs, whereby factors were cutting speed, feed per tooth, and depth of cut.Vrabel [3] uses artificial neural networks to develop an online system for monitoring and controlling tool wear and estimate average surface roughness in drilling nickel-based alloy Udimet 720. Vrabel uses two neural networks, one to monitor the wear 3-5-1 and second one to estimate average surface roughness 4-6-4-1.Alharthi [4] developed ANNs model to predict the surface roughness for different cutting speed, depth of cut, and feed per tooth in face milling of AZ61 magnesium alloy. The experiment was conducted on the basis of a full factorial plan. The dataset contains 64 samples, classified into the following groups: 80% samples were used as a training set and 20% as a testing set. The results obtained using the artificial neural network are compared with the results obtained by regression analysis.Fang [5] investigates the possibility of predicting average surface roughness on turning a series 2 aluminum alloy using artificial neural networks. Fang analyzes Multy-Layer Perceptron (MLP) and the Radial Basis Function (RBF) neural networks. Datasetobtained experimentally has 45 samples. Out of this number 84% samples were used as a training set, 16% as a testing set. Comparing output data from neural networks and experimentally obtained results of measurement average surface roughness shows that MLP neural network has better performance comparing to RBF

ANNs.Šarić[6] investigates different architecture of neural networks for predicting average surface roughness in milling process of S235JRG2 steel. Šarić considers the influence of cutting speed, feed rate per tooth, dept of cut and cooling/lubricating technique on average surface roughness. Several different ANNs was used: Radial Basis Function NN, Feed Forward NN, Bayesian NN and Neuro-Fuzzy networks.Beatrice [7] uses ANNs to predict average surface roughness in turning hardened steel H13. Cooling/lubricating technique was Minimum Quantity Lubricant (MQL). Dataset was provided experimentally and has 27 samples, where 85% of dataset was used for training and15% for testing. Totally 60 different architectures of ANNswere developed and simulated. On the base of minimum square error (MSE) optimal architecture of ANNs 3-7-7-1 was selected.Zain [8] uses artificial neural networks to predict average surface roughness in milling. He investigates the influence of cutting speed, feed per tooth and rake angle on the surface roughness. Dataset was obtained experimentally and has 24 samples. Out of this number 16 samples were used as a training dataset and 8 for testing. It was developed and tested 8 ANNs with different architecture. The best prediction of average surface roughness was obtained using 3-1-1 network structure.

2. EXPERIMENTAL PROCEDURE

Dataset was formed experimenally based on a full factorial plan. There were 81 samples, all corresponding to full factorial DOE at 4 factors and 3 levels. Average surface roughness was measured after machining using portable measuring instrument Mitutoyo SJ210. Machining experiments were conducted on Emco Concept Mill 250 milling center, with spindle range 150-12000 rpm. The factors and levels are assigned in Table 1 according to finishing conditions. Semi-synthetic metalworking fluids BIOL MIN-E, quality level ISO 6743/7 was used for wet machining.

Table 1. Experimental factors and their levels (axial depth of cut is keptconstant at 15 mm)

Factor	Level		
	1	2	3
Spindle speed (m/min)	120	160	200
Dept of cut (mm)	0,6	0,8	1
Feed per tooth (mm/tooth)	0,05	0,1	0,15
Cooling / lubricating technique	Emu ls-ion	Dry cut	Air

3. ARTIFITIAL NEURAL NETWORKS

Artificial neural network is acomputing system inspired by human biological neural networks.ANNs uses dataset obtained experimentally or analytically to model the behavior of a system with a number of influencing factors.ANNs consists of a number of elementary units called neurons. A neuron can be viewed as a processor that has one or more inputs and one output.The number of neurons in the input and output layers is defined by the number of factors and the number of outputs. The number of neurons in the hidden layer can be determined based on the recommendations given in [9] according to equations 1-3.

$$n = \frac{2(N_x + N_y)}{3} \quad (1)$$

$$n < 2N_x \quad (2)$$

$$n = \sqrt{N_x \cdot N_y} \quad (3)$$

A desirable approach in defining neural network architecture is to create several different architectures (topologies) of artificial neural networks and apply different training algorithms followed by evaluating the performance on the basis of different criterion.Out of the multiple training methods of the neural networks, this paper covers only supervised learning.Supervised learning involves a mechanism of providing correct outputs with the inputs.The network processes the inputs and compares resulting outputs with desired outputs.Errors (difference between desired and network output) are back propagated through the system, causing adjusting the weights which control the network. Figure 1. illustrates the concept of supervised learning.Dataset used for developing of ANNs contains 27 samples belonging to initial set of 81 samples.The NN model trained with 27 samples will then be presented (simulated) with experimentally obtained input set containing 81 samples. The aim is to measure the accuracy of the network trained using small dataset. Machining conditions and resulting surface roughness, usedas a dataset for ANN development are assigned in Table 2. For the development of neural networks, the Matlab software is used, i.e., its graphical environment NNToolbox.Samples are divided into three sets: 70% of dataset (19samples) was used for training, 15% of dataset (4samples) was used for validation and 15% of dataset (5samples) was used for testing.

Table 2. Machining conditions and surface roughnes

Experime-ntal run	Cutting speed (m/min)	Axial dept of cut (mm)	Feed per tooth (mm/z)	Cooling / lubricating techniques	Ra 1 (µm)	Ra 2 (µm)	Ra 3 (µm)	Average Ra(µm)
1	120	0,6	0,05	Emulsion	0.348	0.361	0.345	0.3513
2	120	0,6	0,1	Dry machining	0.477	0.476	0.476	0.476
3	120	0,6	0,15	Air cooling	0.936	0.925	0.926	0.929
4	120	0,8	0,05	Dry machining	0.264	0.262	0.259	0.261
5	120	0,8	0,1	Air cooling	0.515	0.514	0.516	0.515
6	120	0,8	0,15	Emulsion	0.973	0.971	0.973	0.972
7	120	1	0,05	Air cooling	0.261	0.259	0.259	0.260
8	120	1	0,1	Emulsion	0.574	0.689	0,633	0.632
9	120	1	0,15	Dry machining	0.868	0.865	0.87	0.868
10	160	0,6	0,05	Emulsion	0.327	0.39	0.40	0.369
11	160	0,6	0,1	Dry machining	0.529	0.499	0.501	0.510
12	160	0,6	0,15	Air cooling	0.939	0.929	0.935	0.934
13	160	0,8	0,05	Dry machining	0.319	0.319	0.315	0.318
14	160	0,8	0,1	Air cooling	0.566	0.569	0.563	0.566
15	160	0,8	0,15	Emulsion	1.082	1.088	1.083	1.084
16	160	1	0,05	Air cooling	0.309	0.301	0.306	0.305
17	160	1	0,1	Emulsion	0.825	0.809	0.809	0.814
18	160	1	0,15	Dry machining	0.978	0.973	0.975	0.975
19	200	0,6	0,05	Emulsion	0.434	0.419	0.413	0.422
20	200	0,6	0,1	Dry machining	0.558	0.598	0.575	0.577
21	200	0,6	0,15	Air cooling	0.923	0.93	0.919	0.924
22	200	0,8	0,05	Dry machining	0.3	0.306	0.296	0.300
23	200	0,8	0,1	Air cooling	0.53	0.514	0.519	0.521
24	200	0,8	0,15	Emulsion	1.088	1.095	1.088	1.090
25	200	1	0,05	Air cooling	0.284	0.282	0.287	0.284
26	200	1	0,1	Emulsion	0.723	0.732	0.725	0.727
27	200	1	0,15	Dry machining	0.938	0.938	0.943	0.940

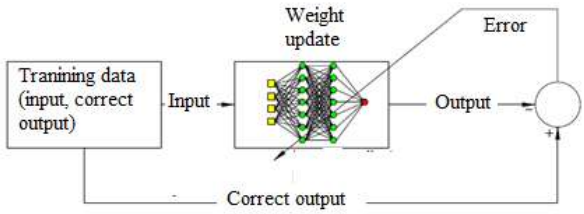


Fig. 1. Concept of supervised learning

Matlab function *dividend* ensures that network performs the same kind of data division when it is trained: training dataset contains samples 1:19, validation dataset samples 20:23 and testing dataset samples 24:27.

In total 108 different neural models were developed, using 18 different network architectures. Each of the selected network architectures is trained using 6 learning algorithms: Levenberg-Marquardt (LM), Bayesian Regulation (BR), Resilient Backpropagation (RP), Gradient Descent (GDX), Quasi-Newton backpropagation (BFG) and Scaled conjugate gradient backpropagation (SCG). Sigmoid and linear function were used as a transfer function. Sigmoid transfer function is used between the input and hidden layer, sigmoid or linear between the hidden layers and linear transfer function between the hidden and output layer.The results for all tested networks are shown in Table 3.

3.1 Data preprocessing

There are several preprocessing techniques which can be performed on numerical dataset. Linear scalig is one of them, where variables are linearly scaled for easier adjustment of weight ratios, usually in the interval from 0 to 1. In this paper, linear scaling of input and target variables is in the range 0.1 - 0.9 according to the following formulas:

$$x_{scal} = \frac{x_{tren} - x_{min}}{x_{max} - x_{min}} (\bar{x}_{max} - \bar{x}_{min}) \quad (4)$$

$$y_{scal} = \frac{y_{tren} - y_{min}}{y_{max} - y_{min}} (\bar{y}_{max} - \bar{y}_{min}) \quad (5)$$

In this case $\bar{x}_{max}$ and $\bar{y}_{max}$represent the minimum or maximum value of the range in which the data is scaled, x_{max}, x_{min}, y_{max} and y_{min} the largest and smallest values in the input and output data set, respectively.

Table 3. Results for all NN models

	NN architecture	R	Number of epochs	MSE		NN architecture	R	Number of epochs	MSE
	Levenberg-Marquardt (LM) algorithm					Bayesian Regulation (BR) algorithm			
1	4x1x1	0.91322	6	0.0020	1	4x1x1	0,98901	41	0,00189
2	4x2x1	0,9556	11	0,0019	2	4x2x1	0,99467	44	0,00096
3	4x3x1	0,97698	6	0,0027	3	4x3x1	0,99430	97	0,00027
4	4x4x1	0,983	9	0,0047	4	4x4x1	-0.9837	58	0,056499
5	4x8x1	0,979	7	0,006	5	4x8x1	0,98222	125	$2{,}14\cdot10^{-14}$
6	4x10x1	0,799	6	0,014	6	4x10x1	0,98051	173	$1{,}75\cdot10^{-14}$
7	4x1x1x 1	0,976	7	0,0012	7	4x1x1x 1	0,98909	1000	0,00189
8	4x2x2x 1	0,975	8	0,0057	8	4x2x2x 1	0,98356	37	0,0577
9	4x3x2x 1	0,943	6	0,0012	9	4x3x2x 1	0,9838	37	0,0577
10	4x5x2x 1	0,9964	9	0,00074	10	4x5x2x 1	0,9838	38	0,0577
11	4x8x4x 1	0,846	8	0,027	11	4x8x4x 1	0,98402	38	0,0577
12	4x10x4x 1	0,890	8	0,019	12	4x10x4x 1	0,9838	38	0,0577
13	4x2x2x2x1	0,960	19	0,032	13	4x2x2x2x1	-0,78219	86	0,0577
14	4x3x2x2x1	0,965	17	0,0018	14	4x3x2x2x1	0	21	0,0667
15	4x4x3x2x1	0,9837	15	0,0013	15	4x4x3x2x1	0	35	0,0643
16	4x5x3x2x1	0,960	8	0,013	16	4x5x3x2x1	0,91736	32	0,0662
17	4x7x4x2x1	0,950	12	0,006	17	4x7x4x2x1	0	31	0,0664
18	4x10x4x2x1	0,99713	4	0,00020	18	4x10x4x2x1	0,90476	41	0,0658
	Resilient Backpropagation (RP) algorithm					Gradient Descent (GDX) algorithm			
1	4x1x1	0,97513	6	$3{,}16\cdot10^{-5}$	1	4x1x1	0,97565	141	0,00058136
2	4x2x1	0,9436	6	0,010833	2	4x2x1	-0,9199	56	0,006586
3	4x3x1	0,9633	6	0,0024626	3	4x3x1	0,94019	140	0,0042864
4	4x4x1	0,82739	6	0,0044551	4	4x4x1	0,5879	88	0,0028835
5	4x8x1	0,97874	6	0,012403	5	4x8x1	0,7549	186	0,0060558
6	4x10x1	0,99259	11	0,021152	6	4x10x1	-0,91372	6	0,031521
7	4x1x1x 1	0,9148907	16	0,0011574	7	4x1x1x 1	0,82356	74	0,0037192
8	4x2x2x 1	0,29668	7	0,019677	8	4x2x2x 1	0,27105	81	0,033783
9	4x3x2x 1	0,053017	8	0,039857	9	4x3x2x 1	0,89452	77	0,042865
10	4x5x2x 1	0,95375	17	0,010477	10	4x5x2x 1	0,91328	117	0,012526
11	4x8x4x 1	0,99162	19	0,012794	11	4x8x4x 1	0,76334	74	0,0075099
12	4x10x4x 1	0,96849	6	0,0019671	12	4x10x4x 1	0,30189	54	0,020986
13	4x2x2x2x1	0,96881	30	0,0028199	13	4x2x2x2x1	-0,903229	77	0,03963
14	4x3x2x2x1	-0,055383	9	0,019247	14	4x3x2x2x1	-0,24808	77	0,03962
15	4x4x3x2x1	0,40091	10	0,034651	15	4x4x3x2x1	0,92829	116	0,023847
16	4x5x3x2x1	0,96214	18	0,0026711	16	4x5x3x2x1	0,93969	64	0,037863
17	4x7x4x2x1	0,93932	15	0,002873	17	4x7x4x2x1	0,9381	6	0,034819
18	4x10x4x2x1	0,93649	15	0,0023631	18	4x10x4x2x1	0,95615	124	0,025836
	Quasi-Newton backpropagation (BFG) algorithm					Scaled conjugate gradient backpropagation (SCG) algorithm			
1	4x1x1	0,97722	13	0,002691	1	4x1x1	0,97859	15	0,0017497
2	4x2x1	0,92073	32	0,0044498	2	4x2x1	0,92591	17	0.012217
3	4x3x1	0,9232	16	0,007515	3	4x3x1	0.88958	12	0,0026530
4	4x4x1	0,97149	14	0,0024259	4	4x4x1	0,96801	15	0,00099602
5	4x8x1	0,78725	25	0.0044701	5	4x8x1	0,77885	24	0,0061669
6	4x10x1	0,89511	42	0,0075095	6	4x10x1	0,9683	75	0,0030131
7	4x1x1x 1	0,9739	16	0,0023739	7	4x1x1x 1	0,98276	21	0,0005
8	4x2x2x 1	0,94194	45	0,0025083	8	4x2x2x 1	0,9474	13	0,0070227
9	4x3x2x 1	0,89233	7	0,042685	9	4x3x2x 1	-0.727	7	0.04
10	4x5x2x 1	0,96475	27	0,004755	10	4x5x2x 1	0.97979	27	0,0015945
11	4x8x4x 1	0,93033	18	0,022565	11	4x8x4x 1	0.91423	14	0.01604
12	4x10x4x 1	0,90857	14	0,00099236	12	4x10x4x 1	0,81501	6	0,04416
13	4x2x2x2x1	0,84936	13	0,026458	13	4x2x2x2x1	0.055	12	0.047
14	4x3x2x2x1	0,96006	14	0,013682	14	4x3x2x2x1	-0,0726	7	0,040627
15	4x4x3x2x1	0,057505	12	0,040046	15	4x4x3x2x1	0,899	11	0,0083887
16	4x5x3x2x1	0,90791	9	0,017959	16	4x5x3x2x1	0,97423	28	0,0096273
17	4x7x4x2x1	0,78003	9	0,032067	17	4x7x4x2x1	0,463	10	0,025448
18	4x10x4x2x1	0.96165	20	0,0037442	18	4x10x4x2x1	0,67	14	0,014792

4. RESULTS AND DISCUSSIONS

In total, 108 ANNswere developed in this paper, all with different architecture and training algorithms, in order to predict average surface roughness under different machining conditions.

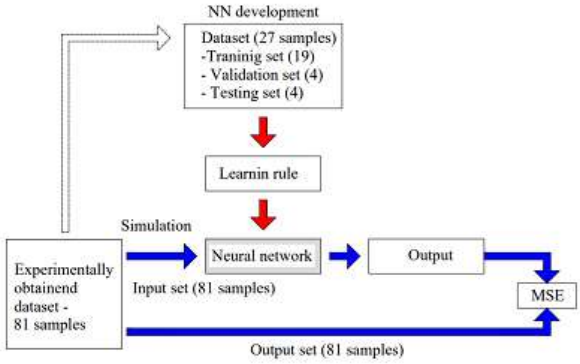


Fig. 2. Simulation of developed NNs by experimentally obtained dataset

Table 4. MSE between actualvalues (output set obtained experimentaly) and estimated values (output of NN simulated by input set)

No.	Training algorithm	ANNs architecture	MSE
1	SCG	4[1]1	0.0053
2	SCG	4[3]1	0.0305
3	SCG	4[4]1	0.00997
4	SCG	4[2-2]1	0.0225
5	SCG	4[5-2]1	0.0063
6	SCG	4[5-2-3]1	0.0102
7	BFG	4[1]1	0.0127
8	BFG	4[10-4]1	0.0172
9	BFG	4[10-4-2]1	0.015
10	GDX	4[1]1	0.0043
11	GDX	4[3]1	0.0194
12	GDX	4[8]1	0.0680
13	RP	4[1]1	0.00348
14	RP	4[8-4]1	0.01593
15	BR	4[10]1	0.0025
16	BR	4[1-1]1	0.0028
17	LM	4[5-2]1	0.00823
18	LM	4[10-4-2]1	0.01287

Out of that number, 18 networks with the best characteristics,have been selected.Estimation of characteristics has been done based on the value of the mean square error (MSE) in relation to the validation dataset and correlation coefficient (R) in relation to the test dataset, Table 3.Next, each of the selected 18 models weresimulated with input data set containing 81 samplesderived from the experiment. Out of that number, 54 sets are completely unknown to the network, while 27 are known.The outputs from the simulation of neural networks were then compared with the output set obtained experimentally, Figure 2. Table 4. shows differece between actual value, i.e. output set obtained experimentally and estimated values, i.e. output of NN simulated by input set obtained experimentaly.

The lowest value of the MSE 0.0025 had the neural network architecture 4[10]1 trained by Bayesian Regulation (BR) algorithm, Figure 3.

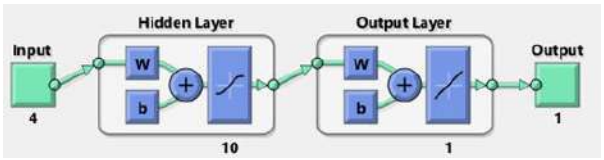


Fig. 3. ANN architecture 4[10]1

Figure 4. shows average surface roughness obtained experimentally (blue line), simulated neural networks architectures 4[10]1 (red line) and 4[1-1]1 (green line), whereby training algorithm was Bayesian Regulation (BR).

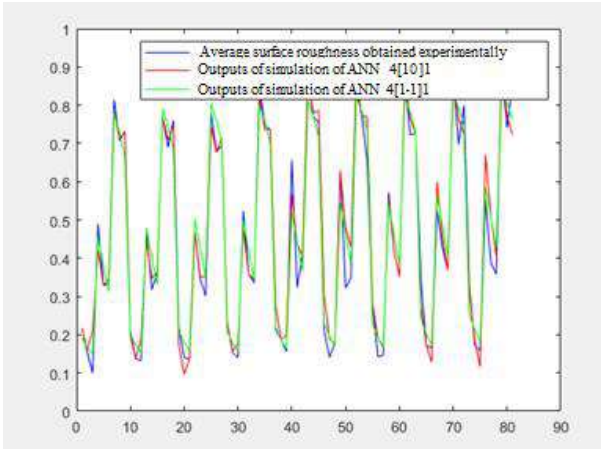


Fig. 4. Average surface roughness obtained experimentally and simulated ANNs

5. FINAL REMARKS

The possibility to predict surface roughness parameter under given machining parameters is important from the economic aspect as well as from the aspect of assessing mechanical properties of the part and its function. Surface roughness plays an important role in many areas. Surface roughness parameters are classified into groups according to its functionality: amplitude parameters, spacing parameters, and hybrid parameters. In this paper, the prediction of average surface roughness (Ra), as one of the most important parameters belonging to the category of amplitude parameters, is considered.

The most significant milling parameters on surface roughness are cutting speed, feed rate, and depth of cut. Besides, different cooling/lubrication techniques has an impact on surface roughness. Increasing the cutting depth increases the cutting

resistance but also the amplitude of vibrations, which results in poorer surface quality. Higher cutting speeds and lower speeds of auxiliary movement e.g., feed per tooth result in increasing in surface quality. The application of different cooling and lubricating techniques has a favorable effect on the surface quality, since it reduces the friction between rake face and chip, also flank face and workpiece. Also, the coolant and lubricant remove pieces of chip from the cutting zonewhich also has a favorable effect on the surface quality. The influence of the coolant and lubricant is particularly influential in machining of difficult-to-cut materials, while it is less significant in soft materials such as aluminum.

Artificial neural networks can be used as a tool for predicting average surface roughness for defined machining parameters in a short time and without costs. The reliability of the obtained results depends mostly on the design of the experiment, involved factors and their interaction. Also, this tool enables determination of the optimal values of machining parameters based on the desired value of the average surface roughness.

When designing and conducting an experiment using DOE technique like Taguchi method number of samples is smaller compared to the full factor plan. In such a case neural network handle small dataset of experimental data. Having in mind that the set of available data is small, it is necessary to carefully plan the architecture and algorithms for training networks. This paper shows that neural network can be designed using small dataset with satisfactory accuracy.

6. REFERENCES

[1] Benardos, P. G., Vosniakos, G. C.:*Prediction of surface roughness in CNC face milling using neural networks and Taguchi's design of experiments*, Robotics and Computer-Integrated Manufacturing 18(5), 343-354.DOI: 10.1016/S0736-5845(02)00005-4, 2002.

[2] Al Hazza M., H., F., Adesta E., Y., T.: *Investigation of the effect of cutting speed on the Surface Roughness parameters in CNC End Milling using Artificial Neural Network*, IOP Conference Series: Materials Science and Engineering 53(1), 2013.

[3] Vrabel, M., Mankova, I. Beno, J. Tuharskýa: *Surface roughness prediction using artificial neural networks when drilling Udimet 720*, Procedia Engineering 48, 693 – 700, 2012.

[4] Alharthi,N.,H., Bingol,S., Abbas,A.T., Ragab,A.E., El-Danaf, E. ,A., Alharbi, H., F.:*Optimizing Cutting Conditions and Prediction of Surface Roughness in Face Milling of AZ61 Using Regression Analysis and Artificial Neural Network*, Advances in Materials Science and Engineering, 2017.

[5] Fang,N., Srinivasa Pai,P.Edwards,N.:*Neural Network Modeling and Prediction of Surface Roughness in Machining Aluminum Alloys*,Journal of Computer and Communications, 2016.

[6] Šarić, T.; Šimunović, G., Šimunović, K.:*Use of neural networks in prediction and simulation of steel surface roughness*,International Journal of Simulation Modelling, 2013.

[7] Beatrice, B. A., Kirubakaran, E. ,Thangaiah, P.R.J., Wins,K.L. D.:*Surface Roughness Prediction using Artificial Neural Network in Hard Turning of AISI H13 Steel with Minimal Cutting Fluid Application*, 12th global congress on manufacturing and management, 2014.

[8] Zain, A. M. ,Haron, H., Sharif, S.:*Prediction of surface roughness in the end milling machining using Artificial Neural Network*, Expert Systems with Applications 37, 2010.

[9] Miljković, Z., Aleksendrić, D.:*Veštačke neuronske mreže, zbirka zadataka sa izvodima iz teorije*, Mašinski fakultet Beograd, 2009.

Authors: **Associate professor Aleksandar Košarac,** University of East Sarajevo, Faculty of Mechanical Engineerign, Vuka Karadžića 30,71123Istočno Sarajevo, Republika Srpska, BiH, Phone.: +387 57 340 847, Fax: +387 57 340 847

Full professor Milan Zeljković, Assistant Cvijetin Mlađenović, PhD, University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Phone.: +381 21 485 2320, Fax: +381 21 454 495

E-mail: aleksandar.kosarac@ues.rs.ba
mladja@uns.ac.rs
milanz@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Kovač, P., Savković, B., Ješić, D., Dudić, B.

ODREĐIVANJE FUNKCIJE ODZIVA U ZAVISNOSTI OD VIŠE PROMENLJIVIH NA OSNOVU JEDNOFAKTORNOG EKSPERIMENTA

Rezime: *Kao najpouzdanije empirijske zavisnosti se smatraju zavisnosti određene pomoću klasičnog jednofaktornog eksperimenta. Ako se primene jednofaktorni planovi eksperimenta kako je to prikazano u ovom radu moguće je odrediti i zavisnosti od više promenljivih. Za ovakav eksperimentalni plan osim regresione analize prikazana je i disperziona analiza sa ocenom signifikantnosti, ocena adekvatnosti i tačnosti modela. Dosada se ocena tadekvtnonosti modela mogla raditi samo preko koeficijenta korelacije. predložena metodologija je pokazana određivanju funkcije postojanosti alata u zavisnosti od brzine rezanja i pomaka.*

Ključne reči: *jednofaktorni plan, signifikantnost, adekvatnost, tačnosti modela.*

1. UVOD

Model izražava bitna svojstva objekta, procesa ili sistema. Sam matematički model se sastoji od sistema jednačina, stanja i algoritamskih pravila [1,2]. Ovo uključuje odgovarajuće algebarske tehnike koje se koriste u razmatranju tačnih rešenja u jednačinama [3]. Prilikom postavljanja matematičkog modela koriste se osnovni izvori informacija.

Osnovni cilj matematičkog modeliranja je: • proračun i analiza objekta, procesa ili sistema u cilju dobijanja novih i potpunijih znanja i zakonitosti proučavanog procesa; • otkrivanje mehanizama interakcije u okviru proučavanog procesa; • testiranje postavljenih hipoteza o ispravnosti mehanizama unutrašnjih interakcija i sistema; • predviđanje stanja i ponašanja procesa, sistema i pojava; • optimizacija na osnovu postavljenih kriterijuma optimizacije; • upravljanje objektima, procesima ili sistemima u prostoru i vremenu [4]. Oblast primene matematičkog modeliranja je veoma rasprostranjena i široka. Postoje neki važni matematički modeli koji se koriste za objašnjenje računskih svojstava problema u stvarnom svetu i oni su opisani u literaturi, kao što su [5,6]. Matematičkim modelima obrađeni su frakcioni derivati sa nerazličitim jezgrom, kao i nelinearni oblici kristala. Primena složenih dinamičkih alata za rešavanje nelinearnih jednačina je sve veća oblast istraživanja u radovima [5,7]. Tako u literaturnim radovima sreće se primena faktorskih planova u složenim sistemima koji se bave distribucijom nabavke odgovarajućih proizvoda na različite lokacije od strane različitih dobavljača i nivoa kvaliteta sirovina [8]. Kao i specifične aktivnosti, kao što je implementacija digitalnog marketinga sa analizom uticajnih faktora na njegovu profitabilnost u odnosu na već postojeći tradicionalni print marketing [9].

Takođe, moguća je i primena faktorskih planova u određivanju investicija pojedinih kompanija u zemljama u razvoju, a sve u odnosu na faktore koji utiču na nivo i visinu ovih investicija. To se, na primer, odnosi na faktore kao što su stepen obrazovanja stanovništva u regionima gde industrijski gigant želi da se implementira, starost stanovništva, visina poreza na zarade, priliv stranih direktnih investicija, ulaganja u infrastrukturni projekti [10]. Svi ovi faktori mogu se matematički opisati jezikom brojeva. Da ovakvi modeli nisu primenljivi samo u oblasti ekonomije pokazuju i druge oblasti primene. Tako nalazimo primenu u sektoru transporta kako bismo predstavili matematički model za prelaz plana saobraćajne signalizacije [12]. Takođe je razvijen matematički model za predviđanje redukcije kristala vustita tokom procesa livenja [13]. Takođe, u literaturi nalazimo primenu faktorskog plana za određivanje optimalnog nivoa adsorpcije ugljenika u cilju uklanjanja boja iz vodenih rastvora [14]. Veoma interesantan rad nalazimo sa aspekta kompleksnosti uticajnih faktora u istraživanju „elegancije kao karakteristike dobrog sistema [15]. Autori analiziraju eleganciju u kontekstu sistemskog inženjeringa sa aspekta osam različitih faktora, među kojima se izdvajaju vizuelne umetnosti, geštalt psihologija, neuronauka i teorija složenosti. Osim toga, može se konstatovati da jednačine dobijene na osnovu DoE mogu poslužiti kao osnova za primenu modeliranja putem veštačke inteligencije. Tako imamo primere da se granične vrednosti u modeliranju uz pomoć genetskih algoritama određuju na osnovu već

postojećih vrednosti u jednačinama, koje su prethodno dobijene na osnovu DoE [19,]. Autori u radu [23,24] na osnovu regresionih vrednosti dobijenih na osnovu DoE analize formiraju model za predviđanje temperture i hrpavosti obrađene površine. Prilikom optimizacije parametara obrade teško obradivih kompozitnih cevi u vidu pronalaženja optimalne sile rezanja primenjeni su genetski algoritmi koji su svoje koeficijente regresije zasnivali na modelima dobijenim uz pomoć DoE [20].

Na osnovu pregleda literature može se konstatovati da su osnovne karakteristike višefaktornih (višestruko niži troškovi i kraće trajanje skupih eksperimentalnih ispitivanja), kao i maksimalni skup eksperimentalnih tačaka. informacije o efektima matematičkog modela procesa formiranog zahvaljujući istraživanju prema kibernetičkom pristupu-crne kutije.

Prva faza eksperimentalnog istraživanja je prikupljanje, proučavanje i analiza svih dostupnih i relevantnih informacija o objektu istraživanja. Rezultati prve etape su: lista uticajnih faktora (poželjno rangiranih prema stepenu uticaja), granica rasejanja i druge karakteristike faktora, kriterijumi i parametri optimizacije u skladu sa postavljenim ciljem i sl. Ukoliko je broj uticajnih faktora veliki, potrebno je, primenom odgovarajućih metoda, odvojiti manji broj značajnih od većeg broja manje uticajnih [2].

U okviru eksperimentalnih metoda, istoriski gledano, postoje dva različita koncepta planiranja eksperimenta i eksperimentalnih ispitivanja. To su metode jednofaktornih i višefaktornih planova eksperimenta a kasnije su se pojavile metode višefaktornih planova eksperimenta [1,2,4,], ove metode su se razvile na osnovu kibernetskog pristups modeliranju. Kada se objekat modeliranja posmatra kao crna kutija, sa uticajnim ulaznim veličinama i interesantnom izlaznom veličinom ili funkcijom odziva.

Kod jednofaktornog plana eksperimenta pri ispitivanju se menja samo jedan faktor dok se vrednosti ostalih faktora zadržavaju na nekom konstantnom nivou i meri se funkcija odziva. Ove procedure se uzastopno ponavljaju nad svim obuhvaćenim faktorima. Jednofaktorni planovi se vrlo često koriste u naučnoj i tehničkoj praksi pri ispitivanju različitih pojava, stanja i sistama, a ranije, pre pojave više faktornih planova su bili i jedini.

Ocena jednofaktornog modela se najčešće vrši na osnovu izračunavanja koeficijenta korelacije a ocena signifikantnosti parametara i ocena tačnosti se i ne vrši.

U radu će biti prikazan način planiranja jednofaktornog eksperimenta, koji može da se analizira samostalno ili zajedno sa više jednofaktornih eksperimenata. Na osnovu više takvih jednofaktornih eksperimenata može se odrediti i zavisnost od više faktora. Takođe je prikazana regresiona analiza, disperziona analiza i dekodiranje ovakvog planiranog jednofaktornog i višefaktornog [18] eksperimenta.

2. MATERIJAL I METOD RADA

2.1 Regresion anliza

Zavisnost između nezavisno promenljivih F_i i zavisno promenljive R se predstavlja u oblikustepene funkcije:

$$R = C \cdot F_1^{p_1},$$

koji se može predstaviti linearnim matematičkim modelom uz grešku eksperimenta:

$$y - \varepsilon = b_0 x_0 + b_1 x_1$$

gde je: $x_0 = 1$

x_i - logaritmovane vrednosti F_i

b_i - koeficijenti koji se određuju

y - logaritmovana vrednost merene veličine sa greškom merenja ε.

Za određivanje ovih parametara se koristi metoda najmanjih kvadratnih odstupanja u matričnom obliku [1,2,7,8]:

$$B = (X'X)^{-1} X'Y \qquad (1)$$

gde je : B - matrica parametara koji se određuju

X - matrica plana eksperimenta

X' - transponovana matrica matrice X

$(X'X)^{-1}$ - inverzna matrica matrice (X'X)

Y - matrica logaritmovanih vrednosti merene veličine.

2.2 Kodiranje parametara

Da bi se pojednostavila obrada podataka pomoću jednačine (1) vrši se kodiranje parametara pomoću sledeće jednačine:

$$x_i = 1 + 2\left(\frac{\ln F_{iu} - \ln F_{i1}}{\ln F_{i1} - F_{i2}}\right), \quad i = 1,2,...,k; \quad u = 1,2,3; \qquad (2)$$

gde je:

F_{i1} kodirano $x_i = +1$ gornji nivo faktora

F_{i3} kodirano $x_i = 0$ srednja vrednost faktora (3)

F_{i2} kodirano $x_i = -1$ donji nivo faktora.

Ponavljanje se vrši u svakoj tački eksperimenta po dva puta. Broj eksperimenata je N. Na osnovu toga, dobija se plan matrica X za jednofaktorni plan:

$$X = \begin{bmatrix} 1 & -1 \\ 1 & 0 \\ 1 & 1 \\ 1 & -1 \\ 1 & 0 \\ 1 & 1 \end{bmatrix} \qquad (4)$$

$$X' \cdot X = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & 0 & 1 & -1 & 0 & -1 \end{bmatrix} \cdot \begin{bmatrix} 1 & -1 \\ 1 & 0 \\ 1 & 1 \\ 1 & -1 \\ 1 & 0 \\ 1 & 1 \end{bmatrix} = \begin{bmatrix} 6 & 0 \\ 0 & 4 \end{bmatrix} \quad (5)$$

$$(X \cdot X)^{-1} = \begin{bmatrix} 1/6 & 0 \\ 0 & 1/4 \end{bmatrix},$$

pa su na osnovu jednačine (1) koeficijenti regresije su:

$$b_0 = 1/6 \sum y_i$$
$$b_1 = 1/4\left(-y_1 + y_3 - y_4 + y_6\right). \quad (6)$$

Za dvofaktorni plan koji se dobija kombinovanjem dva jednofaktorna plana plan matrica X sa ponavljanjem po dva puta u svakoj tački eksperimenta ima sledeći oblik:

$$X = \begin{bmatrix} 1 & -1 & 0 \\ 1 & 1 & 0 \\ 1 & 0 & -1 \\ 1 & 0 & 1 \\ 1 & 0 & 0 \\ 1 & -1 & 0 \\ 1 & 1 & 0 \\ 1 & 0 & -1 \\ 1 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix} \quad (7)$$

$$X' \cdot X = \begin{bmatrix} 10 & 0 & 0 \\ 0 & 4 & 0 \\ 0 & 0 & 4 \end{bmatrix} \quad (8)$$

$$(X' \cdot X)^{-1} = \begin{bmatrix} 1/10 & 0 & 0 \\ 0 & 1/4 & 0 \\ 0 & 0 & 1/4 \end{bmatrix},$$

pa su na osnovu jednačine (1) koeficijenti:

$$b_0 = 1/10 \sum y_i$$
$$b_1 = 1/4\left(-y_1 + y_2 - y_6 + y_7\right) \quad (9)$$
$$b_2 = 1/4\left(-y_3 + y_4 - y_8 + y_9\right).$$

2.3. Dekodiranje parametara

Dekodiranje matematičkog modela se vrši tako što se vrednosti za faktore eksperimenta zamene vrednostima za kodirane faktore x_i , prema jednačini (2) uz uvođenje oznaka:

$$A_i = 2 / \ln(F_{i1} / F_{i2}) \quad (10)$$
$$a_i = 1 - A_i \ln F_{i1} \quad (11)$$

Posle množenja i grupisanja pojedinih članova dobijaju se koeficijenti u kodiranim kordinatama:

$$p_0 = b_0 + \sum_{i=1}^{k} b_i a_i \quad (12)$$
$$p_i = A_i b_i \quad (13)$$
$$C = exp(p_0) \quad (14)$$
$$R = exp(\hat{y})$$

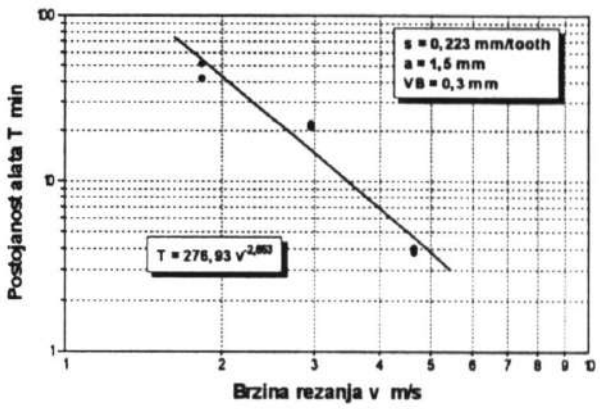
2.4 Disperziona analiza

Način izračunavanja disperzionih odnosa potrebnih za ocenu signifikantnosti parametara modela, adekvatnosti i tačnosti modela je razrađen.

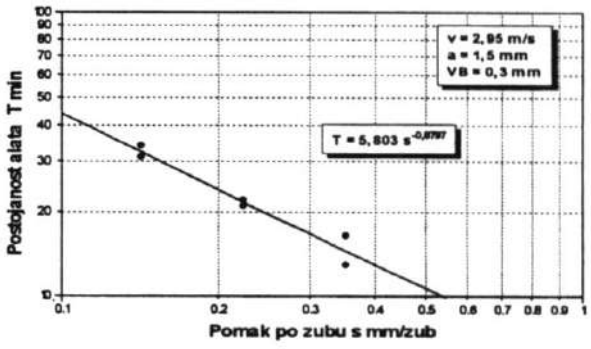
2.5 Uslovi pri ispitivnju

Eksperimentalna ispitivanja su vršena na čeliku za poboljšanje Č 1730, na vertikalnoj glodalici snage pogonskog motora 14 kW. Pri ispitivanju je korišćena glava za glodanje Ø125 mm sa mehanički pričvršćenim pločicama SPAN 1203 ER, kvaliteta P25. Obrada je vršena sa jednim zubom (pločicom), bez upotrebe sredstva za hlađenje i podmazivanje. Merenje srednje vrednosti širine pojasa habanja na leđnoj površini je vršeno na alatnom mikroskopu. U toku eksperimenta varirani su brzina rezanja v i pomak po zubu s_z. Kriterijum postojanosti je bio Širina pojasa habanja na leđnoj površini VB = 0,3 mm.

Na slici 1 je prikazana zavisnosti postojanosti alata od brzine rezanja v, a na slici 2 zavisnost postojanosti alata od pomaka po zubu s_z.



Sl. 1. postojnost u funkciji brzine rezanja



Sl. 2. Postojanost alata u funkciji od pomaka po zubu

Tabela 2. Kodirane, stvarne i računske vrednosti za jednofaktorni dvofaktorni eksperiment

Broj eks.	Kod X_0	Kod X_1	Brzina v [m/s] X_1	Mereno T [min]	Računato T [min]	Pomak s [mm/o] X_2	Mereno T[min]	Računato T[min]
1	1	-1	1,83	51	55,7	0,142	31	32,3
2	1	0	2,95	25	15,7	0,223	22	21,7
3	1	1	4,65	3,8	4,7	0,351	13	14,6
4	1	-1	1,83	42	55,7	0,142	34	32,3
5	1	0	2,95	22	15,7	0,223	21	21,7
6	1	1	4,65	4	4,7	0,351	16,5	14,6

Na osnovu prikazane metodologije dobijene su sledeće vrednosti koeficijenata b_i u kodiranim koordinatama za zavisnost postojanosti alata od brzine rezanja:

$$b_0 = 1/6 \sum y_i = 2,78345 \quad (15)$$

$$b_1 = 1/4\left(-y_1 + y_3 - y_4 + y_6\right) = -1,23705 \quad (16)$$

Stvarne (dekodirane) vrednosti koeficijenta su:

$$\begin{aligned} A_1 &= 2 / \ln(F_{max}/F_{min}) = 2,144654 \\ a_1 &= 1 - A_1 \ln F_{max} = -2,29605 \\ p_0 &= b_0 + b_1 a_1 = 5,62378 \\ p_1 &= A_1 b_1 = -2,6530 \\ C &= exp(p_0) = 276,93, \end{aligned} \quad (17)$$

tako da je zavisnost postojanosti alata od brzine rezanja:

$$T = C \cdot v^{p_1} = 276,93 v^{-2,653}. \quad (18)$$

Analogno prethodnom za zavisnost postojanosti alata od pomaka određene su vrednosti koeficijenata b_i:

$$b_0 = 1/6 \sum y_i = 3,07737$$

$$b_1 = 1/4\left(-y_1 + y_3 - y_4 + y_6\right) = -0,39801. \quad (19)$$

Stvarne vrednosti koeficijenta su:

$$\begin{aligned} A_1 &= 2 / \ln(F_{max}/F_{min}) = 2,21004 \\ a_1 &= 1 - A_1 \ln F_{max} = 3,31384 \\ p_0 &= b_0 + b_1 a_1 = 1,75842 \\ p_1 &= A_1 b_1 = -0,87962 \\ C &= exp(p_0) = 5,80330, \end{aligned} \quad (20)$$

tako da je dobijena zavisnost postojanosti alata od pomaka po zubu:

$$T = 5,809 \cdot s^{-0,8797}. \quad (21)$$

Ocena signifikantnosti parametara i ocena adekvatnosti jednofaktornog modela je prikazana u tabeli 2 a na osnovu sledećih jednačina:

$$S_R = \sum_{i=1}^{N} (y_i - \hat{y}_i)^2 = 0,48891$$

$$s_a^2 = \frac{S_R - S_E}{f_R - f_E} = \frac{0,48891 - 0,02835}{4-3} = 0,4605$$

$$S_E = \sum \left[y_1 - \left(\frac{y_1 + y_4}{2} \right) \right]^2 + \left[y_2 - \left(\frac{y_2 + y_5}{2} \right) \right]^2 + \left[y_3 - \left(\frac{y_3 + y_6}{2} \right) \right]^2$$

$$S_E = \frac{1}{2}\left[(y_1 - y_4)^2 + (y_2 - y_5)^2 + (y_3 - y_6)^2 \right] = 0,02835$$

$$s_E^2 = \frac{S_E}{f_E} = \frac{0,02835}{3} = 0,00945 \quad (22)$$

Tabela 3. Ocena signifikantnosti i adekvatnosti jednofaktornih modela

	$T = 276,93\ v^{-2,653}$	$T = 5,809\ s^{-0,8797}$
F_{ro}	4922,16	5044,61
F_{ri}	648,14	56,26
$F_a = s_a^2 / s_E^2$	48,71	0,028

Parametri su signifikantni za obe jednačine. Model nije adekvatan za jednačinu u zavisnosti od brzine, dok za jednačinu u zavisnosti od pomk jeste.

Na osnovu plana matrice (tabela 4) i izračunatih vrednosti za jednofaktorne planove, komponuje se tabela 3 za dvofaktorni plan sa ponavljanjem u svakoj tački plana.

Tabela 4. Vrednosti eksperimenta za dvofaktorni plan

Broj eksp	Kod X_0	Kod X_1	Kod X_2	Brzina v [m/s]	Pomak s [mm/o]	Mereno T [min]	Računato T [min]
1	1	-1	0	1,83	0,223	51	61,8
2	1	1	0	4,65	0,223	3,8	5,2
3	1	0	-1	2,95	0,142	31	25,8
4	1	0	1	2,95	0,351	13	11,7
5	1	0	0	2,95	0,223	22	17,4
6	1	-1	0	1,83	0,223	42	61,8
7	1	1	0	4,65	0,223	4	5,2
8	1	0	-1	2,95	0,142	34	25,8
9	1	0	1	2,95	0,351	16,5	11,7
10	1	0	0	2,95	0,223	21	17,4

Obradom podataka prema dvofaktornom planu dobijaju se koeficijenti u kodiranim koordinatama:

$$\begin{aligned} b_0 &= \frac{1}{10} \sum y_i = 2,88550 \\ b_1 &= \frac{1}{4}\left(-y_1 + y_2 - y_6 + y_7\right) = -1,2370 \\ b_2 &= \frac{1}{4}\left(-y_3 + y_4 - y_8 + y_9\right) = -0,3980 \end{aligned} \quad . \quad (23)$$

Stvarne vrednosti koeficijenta su:

$$\begin{aligned} p_0 &= b_0 + b_1 a_1 + b_2 a_2 = 4,40677 \\ p_1 &= A_1 b_1 = -2,6530 \\ p_2 &= A_2 b_2 = -0,8796 \\ C &= exp(p_0) = 82,004, \end{aligned} \quad (24)$$

tako da sada zavisnost postojanosti alata od brzine rezanja i pomaka glasi:

$$T = 82,004 \cdot v^{-2,653} \cdot s^{-0,8796}. \quad (25)$$

3. ZAKLJUČAK

Prikazana metodologija omogućuje određivanje potrebnih regresionih jednačina na osnovu jednofaktornog planiranog eksperimenta a po potrebi i određivanje višefaktornih zavisnosti. Takođe prema predloženoj metodologiji može da se izvrši ocena signifikantnosti i adekvatnosti ovih modela.

4. REFERENCE

[1] Stanić J.: *Metod inženjerskih merenja, Mašinski fakultet*, Beograd, 1990.

[2] Stankov J.: *Osnovi merne tehnike - metode planiranja eksperimenta*. IPM, FTN, Novi Sad, 1982.

[3] Pantelić I.: *Primena statističkih metoda u istraživanjima procesa proizvodnje*, FTN, Novi Sad, 1984.

[4] Box G. E. P, Hunter J. S.: *Multi Factor Experimental designs for exploring Response surfaces*. Analls of Mathemat Statist. 28, 1957, 195-241.

[5] O. Kienzle, *Die bestimmung von kräften und leistungen an spanenden werzeugen und werkzeugmaschinen, gekürtze wiedergabe eines vortrages in der fachsitzung Betriebstechnik der 81*. In: VDIHauptversammlung, Hannover, Zeitschrift des Vereines Deutscher Ingenieure. Düsseldorf. 1951.

[6] H. F. Ismael, H. Bulut and H. M. Baskonus, *W-shaped surfaces to the nematic liquid crystals with three nonlinearity laws*, Soft Computing, vol. 25, no. 6, pp. 4513–4524, 2021.

[7] J. Losada and J. Nieto, *Fractional integral associted to fractional derivatives with nonsingular kernels*, Progress in Fractional Differentiation and Applications, vol. 7, no. 3, pp. 137–143, 2021

[8] A. Cordero Barbero, J. P. Jaiswal and J. R. Torregrosa Sánchez, *Stability analysis of fourth-order iterative method for finding multiple roots of nonlinear equations*, Applied Mathematics and Nonlinear Sciences, vol. 4, no. 1, pp. 43–56, 2019.

[9] D. A. Olivares Vera, E. Olivares-Benitez, E. Puente Rivera, M. López-Campos and P. A. Miranda, *Combined use of mathematical optimization and design of experiments for the maximization of profit in a four-echelon supply chain*, Complexity, vol. 2018, pp. 1–25, 2018.

[10] B. Melovic, M. Jocović, M. Dabić, T. B. Vulić, B. Dudić, *The impact of digital transformation and ´ digital marketing on the brand promotion, positioning and electronic business in Montenegro*, Technology in Society, vol. 63, no. 2, pp. 101425, 2020

[11] B. Dudić, Z. Dudić, J. Smolen and V. Mirković, *Support for foreign direct investment inflows in Serbia*, ´ Economic Annals-XXI, vol. 169, no. 169, pp. 4–11, 2018.

[12] R. Peñabaena-Niebles, V. Cantillo, J. L. Moura and A. Ibeas, *Design and evaluation of a mathematical optimization model for traffic signal plan transition based on social cost function*, Journal of Advanced Transportation, vol. 2017, no. 1867, pp. 1–12, 2017.

[13] [12] E. Mousa, *Mathematical analysis of the reduction of wüstite at different basicity using factorial design*, Journal of Metallurgy, vol. 2014, no. 6, pp. 1–8, 2014

[14] N. Özbay, A. Yargıç, R. Yarbay- ¸Sahin and E. Önal, *Full factorial experimental design analysis of reactive dye removal by carbon adsorption*, Journal of Chemistry, vol. 2013, pp. 1–13, 2013.

[15] L. Iandoli, L. Piantedosi, A. Salado and G. Zollo, *Elegance as complexity reduction in systems design*, Complexity, vol. 2018, pp. 1–10, 2018.

[16] P. Kardar, M. Ebrahimi, S. Bastani and M. Jalili, *Using mixture experimental design to study the effect of multifunctional acrylate monomers on UV cured epoxy acrylate resins*, Progress in Organic coatings, vol. 64, no. 1, pp. 74–80, 2009.

[17] [27] H. Yin, Z. Chen, Z. Gu and Y. Han, *Optimization of natural fermentative medium for selenium-enriched yeast by D-optimal mixture design*, LWT-Food Science and Technology, vol. 42, no. 1, pp. 327–331, 2009.

[18] B. Savkovic, P. Kovac, D. Rodic, B. Strbac and S. Klančnik, *Comparison of artificial neural network, fuzzy logic and genetic algorithm for cutting temperature and surface roughness prediction during the face milling process*, Advances in Production Engineering & Management, vol. 15, no. 2, pp. 137–150, 2020.

[19] S. S. Lin, J. C. Lin and Y. K. Yang, *Optimization of mechanical characteristics of short glass fiber and polytetrafluoroethylene reinforced polycarbonate composites via D-optimal mixture design*, Polymer Plastics Technology and Engineering, vol. 49, no. 2, pp. 195–203, 2010

[20] P. Kovac, V. Pucovsky, M. Gostimirovic, B. Savkovic and D. Rodic, *Influence of data quantity on accuracy of predictions in modeling tool life by the use of genetic algorithms*, International Journal of Industrial Engineering, vol. 21, no. 2, pp. 14–21, 2014

[21] K. V. Kumar and A. N. Sait, *Modelling and optimisation of machining parameters for composite pipes using artificial neural network and genetic algorithm*, International

Journal on Interactive Design and Manufacturing (IJIDeM), vol. 11, no. 2, pp. 435–443, 2017.
[22] J. A. Cornell, *Experiments with Mixtures: Designs*, Models, and the Analysis of Mixture Data. UK: John Wiley & Sons, 2011.
[23] P. Kovac, B. Savković and M. Vrabel, *Modeling of contact temperature during surface grinding*, in ´ X Int. Scientific Conf. on Mechanical Engineering, COMEC 2019, Santa Clara, Cuba, pp. 1–11, 2019.
[24] B. Savkovic, P. Kovac, I. Mankova, M. Gostimirovic, K. Rokosz et al., *Surface roughness modeling of semi solid aluminum milling by fuzzy logic*, Journal of Advances in Technology and Engineering Studies, vol. 3, no. 2, pp. 51–63, 2017

Autori: **[1]Prof. dr Pavel Kovač, [2]Vanr. prof. dr Borislav Savković, [3]dr Dušan Ješić, [4]dr Branislav Dudić,** [1,2]Univerzitet Novi Sad, Fakultet Tehničkih Nauka, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2329, Fax: +381 21 454-495, [3]Technology Menagement Academy, Trg D Obradovica 7, 21000 Novi Sad, Serbia, [4]Comenius University in Bratislava, Faculty of Management, Bratislava, 820054 Slovakia
E-mail: pkovac@uns.ac.rs
savkovic@uns.ac.rs
dusanjesic@hotmail.com
branislav.dudic@fm.uniba.sk

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Krstanović, L., Antić, A., Janev, M., Popović, B.

SISTEM ZA NADGLEDANJE STANJA ALATA PRIMENOM OBELEŽJA TEKSTURE SPEKTROGRAMA

Rezime: *Mnoge savremene metode za nadgledanje stanja alata korišćenjem vibracionih senzora zasnovane su na primeni vektora obeležja dobijenih na osnovu signala koje prikuplja senzor, te opisuju stepen pohabanosti alata. U ovom radu su opisane i implementirane metode koje koriste vektore obeležja tekstura dobijene primenom kratkoročne diskretne Furijeove transformacije spektra (STDFT). Posmatramo STDFT spektra u predefinisanom vremenskom intervalu kao 2D sliku teksture u vremensko-frekvencijskom domenu, koja se nakon toga deli na odgovarajuće 2D uzorke.*

Ključne reči: *nadgledanje stanja alata, vektor obeležja tekstura, neuralna mreža*

1. UVOD

Nadgledanje stanja alata, u smislu njegovog habanja, grebanja ili lomljenja [1], je veoma važan deo procesa proizvodnje. Cilj tog nadgledanja je da se preduprede štete koje bi nastale u jednom takvom procesu. Te štete mogu nastati na samom alatu koji se koristi ili na samom proizvodu koji taj alat obrađuje [2]. Jako je važno da se eventualna šteta na vreme predvidi i da se onemogući nastajanje bilo kakve greške pri izradi. To se može uraditi upotrebom adekvatnih senzora, kao i obradom signala koji ti senzori detektuju. Ima više načina za tako nešto. Direktnim metodama se putem različitih senzora određuje šteta koja je nastala [3], dok indirektne metode pomoću senzora pokušavaju da odrede silu rezanja, temperaturu koja nastaje prilikom obrade, potrošnju struje i slično, sve sa ciljem da se uoči stanje alata. Direktne metode su vrlo komplikovane i skupe i o njima u ovom radu neće biti reči. Pokazalo se da metode kojima se analizira signal koje registruje vibracioni senzor daju dosta dobre rezultate (videti [4], [5]).Ove metode spadaju u indirektne metode kojima se analizira spektrogram koji nastaje na osnovu signala koji detektuje vibracioni senzor. Kod ovakvih metoda je jako bitno dobro odrediti vektor obeležja koji opisuje sam signal koji se analizira, jer u suprotnom taj signal neće biti adekvatno predstavljen i sama metoda neće dati dovoljno dobre rezultate. Nadgledanje stanja alata na osnovu signala iz vibracionog senzora, kao i odabir adekvatnih vektora obeležja u ovom slučaju je tema ovog rada.

U [6] i [7] su prvi put iskorišćeni vektori obeležja spektrograma sa ciljem nadgledanja stanja alata. U [5] je analizirano kako izbor vektor obeležja signala koji je detektovan vibracionim senzorom utiče na detekciju habanja rezanog alata. U [1] autori predlažu vektor obeležja koji je dobijen iz signala koji su detektovani od strane više senzora u vremenskom i frekvencijskom domenu sa ciljem nadgledanja stanja alata. Autori u [8] su jedni od prvih koji koriste vejvlete i momente nižeg reda kao što je srednja vrednost, standardna devijacija i slično.

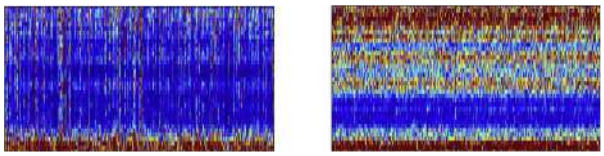
U ovom radu se u procesu nadgledanja alata koristi vektor obeležja baziran na teksturi. Dakle, na osnovu signala koji je detektovan od strane vibracionog senzora se dobija spektrogram koji se zatim posmatra kao tekstura i formira se vektor obeležja te teksture. Biće opisane i implementirane metode koje koriste vektore obeležja tekstura dobijene primenom kratkoročne diskretne Furijeove transformacije spektra (eng. *Short Term Discrete Fourier Transform*-STDFT). Posmatramo STDFT spektra u predefinisanom vremenskom intervalu kao 2D sliku teksture u vremensko-frekvencijskom domenu, koja se nakon toga deli na odgovarajuće 2D uzorke [9]. Kao klasifikatori kojima se klasifikuje stanje alata će se koristiti: multivarijabilna regresija (MV), Lasso klasifikator, Lasso klasifikator baziran na selekciji vektora obeležja (vidi [9]), i feed forward neuralna mreža sa dva skrivena sloja od po deset neurona.

2. STDFT SPEKTROGRAM I FORMIRANJE VEKTORA OBELEŽJA

2.1 Spektrogram

Spektrogram je vizuelna reprezentacija spektra frekvencije signala u zavisnosti od vremena. Spektrogram se može posmatrati kao 2D slika teksture koja reprezentuje neki signal u vremensko-frekvencijkom domenu. U našem radu se koristi STDFT spektrogram koji na x osi ima k diskretnih podeoka koji predstavljaju vremensku komponentu ovog spektra, a na y osi ima ω diskretnih podeoka

koji predstavljaju frekvencijsku komponentu ovog spektrograma.



Sl. 1. Spektrogrami novog i korišćenog alata

Na slici 1. su prikazani STDFT spektrogrami dobijeni na osnovu signala koji je detektovan vibracionim senzorom. Levi spektrogram odgovara novom alatu, dok desni spektrogram odgovara alatu koji je već korišćen. Mogu se uočiti razlike u samoj strukturi spektrograma, pre svega u vertikalnim linijama koje se pojavljuju. Pokazuje se da su ove linije u bliskoj korelaciji sa stanjem alata [9]. One predstavljaju iznenadan skok u frekvenciji signala koji je detektovan vibracionim senzorom.

2.2 STDFT spektrogram i MR8 banka filtara

STDFT spektrogram je podeljen na uzorke teksture. Nakon toga je korišćena banka filtara da bi se dobili vektori obeležja bazirani na teksturi. Podatak o vertikalnim linijama koje smo uočili na slici 1. se mora uzeti u obzir prilikom izbora odgovarajuće banke filtara. Jako je bitno odabrati odgovarajuću banku filtara za svaki opseg frekvencije. Banka filtara MR8 iz [10] je takva da daje deskriptore kao vektore obeležja koji su invarijantni na rotaciju i skaliranje. Iz tog razloga je ova banka filtara pogodna za primenu u problemima klasifikacije uopšte, pa prema tome i za klasifikaciju stanja alata na osnovu slike spektrograma koji se posmatra kao 2D slika teksture.

STDFT signala s je reprezentovana na sledeći način

$$F(k,\omega) = \sum_{n=-\frac{K}{2}}^{\frac{K}{2}} s_n w_{k-n} e^{-ikn} \quad (1)$$

gde je w *Hamming*-ov prozor koji je fiksne dimezije K, $\mathrm{k} = 0, \dots, \mathrm{k}_{\max}$, $\omega = 0, \dots, \omega_{\max}$. Važi da je STDFT spekrogram je kvadrat modula $\mathrm{F}(\mathrm{k},\omega)$, tj. $|\mathrm{F}(\mathrm{k},\omega)|^2$. Označimo sa $\mathrm{I}(\mathrm{x},\mathrm{y})$ 2D teksturnu sliku koja odgovara STDFT spektrogramu koji je dobijen na osnovu signala detektovanog vibracionim senzirim. Tada važi $\mathrm{I}(\mathrm{x},\mathrm{y}) = |\mathrm{F}(\mathrm{k},\omega)|^2$, za $\mathrm{x} = 0, \dots, \mathrm{x}_{\max}$, $\mathrm{y} = 0, \dots, \mathrm{y}_{\max}$ i naravno za $\mathrm{k} = 0, \dots, \mathrm{k}_{\max}$, $\omega = 0, \dots, \omega_{\max}$. U daljoj analizi slike $\mathrm{I}(\mathrm{x},\mathrm{y})$ ćemo bez umanjenja opštosti razmatrati neprekidan slučaj za $x \in [0, x_{max}]$, $y \in [0, y_{max}]$.

Banka filtara MR8 koja se korisiti u ovom radu sadrži osamnaest varijanti Gausovog filtara $G(\sigma_x, \sigma_y, \theta, x, y)$ sa šest različitih orijentacija za $\theta \in \left\{0, \frac{\pi}{6}, \frac{2\pi}{6}, \dots, \frac{5\pi}{6}\right\}$ i tri različite skale za $(\sigma_x, \sigma_y) \in \{(1,3), (2,6), (4,12)\}$, kao i osamnaest LoG (eng. *Laplacians of Gaussians*) $\Delta\, G(\sigma_x, \sigma_y, \theta, x, y)$. Oznaka Δ predstavlja Laplasov operator $\Delta = \partial_x^2 + \partial_y^2$. Na kraju se za izlaz nakon filtriranja uzimaju samo maksimalne vrednosti po svim orijentacijama, što bi značilo da u stvari dobijamo šest različitih odziva [11,12].

2.3 Formiranje vektora obeležja baziranih na teksturi

U ovom odeljku će biti opisano kako se formiraju vektori obeležja 2D slike teksture koja predstavlja STDFT spektrogram [9]. Deli se interval $[0, y_{max}]$ na N podintervala, $y_0 = 0, y_N = y_{max}$. Takođe se za svako $\mathrm{x} = 0, \dots, \mathrm{x}_{\max}$ uzorak slike $\mathrm{I}(\mathrm{x},\mathrm{y})$ dobija kao matrica piksela koja odgovara svakom podintervalu intervala $[0, y_{max}]$, tako što se uzimaju u obzir pikseli po x osi u intervalu $[x, x + M]$. Vrednost M je širina jednog uzorka slike. Treba napomenuti da jedan podinterval intervala $[0, y_{max}]$ odgovara podintevalu intervala $[0, \omega_{max}]$. Označimo taj jedan delić slike, odnosno uzorak sa $P_{x,q}$, gde q odgovara jednom podintevalu intervala $[0, y_{max}]$. Dakle, važi $q = 1, \dots, N$. Za svako x i svako q se formira vektor obeležja $v_{x,q}$ koji zavisi od šest komponenti koje odgovaraju rezličitim odzivima filtara iz banke filtara MR8. Nakon filtriranja za relevantne vrednosti vektora obeležja uzimaju samo maksimalne vrednosti po svim orijentacijama, tj.

$$v_{x,q}^{l,(1)} = max_\theta G\left(\sigma_x, \sigma_y, \theta, x, y\right) * P_{x,q}$$
$$v_{x,q}^{l,(2)} = max_\theta \Delta G\left(\sigma_x, \sigma_y, \theta, x, y\right) * P_{x,q}$$
$$\theta \in \left\{0, \frac{\pi}{6}, \frac{2\pi}{6}, \dots, \frac{5\pi}{6}\right\}.$$

Ovde treba uočiti da se u $v_{x,q}^{l,(1)}$ koristi Gausov filtar, dok se u $v_{x,q}^{l,(2)}$ koristi LoG za taj delić slike, odnosno taj uzorak slike, pri čemu l označava jednu od tri različite skale, tj. $l \in L = \left\{(\sigma_x, \sigma_y) | (1,3), (2,6), (4,12)\right\}$. Dakle, dobijamo

$$v_{x,q} = \left[v_{x,q}^{l,(1)} | v_{x,q}^{l,(2)} | l \in L\right]. \quad (2)$$

2.4 Konačan vektor obeležja

Vektori obeležja $v_{x,q}$ koji su pojašnjeni u prethodnoj sekciji se sada posmatraju kao opservacije slučajne promenljive V_q^u sa rapodelom $p_{V_q^u}$. Ovde u označava predefinisani vremenski interval za koji se formira STDFT spektrogram kao 2D slika teksture u vremensko-frekvencijskom domenu. Cilj je da se dobije konačna forma jednog robustnog vektora obeležja koji će se koristi u problemu klasifikacije stanja alata [9].

Neka su sve komponente V_q^u međusobno nezavisne. To znaci da su $v_{x,q}$ međusobno nezavisne. Važi

$$E\left[e^{iV_q^u t}\right] = \sum_{j=0}^{\infty} \frac{(it)^j}{j!} E\left(\left(V_q^u\right)^j\right).$$

Treba primetiti da ovaj izraz zavisi pre svega od $m_q^{u,j} = E\left(\left(V_q^u\right)^j\right),\ j = 1,2,\ldots$, pri čemu su $m_q^{u,j}$ u stvari momenti j-tog reda. S obzirom da su opservacije $v_{x,q}$ međusobno nezavisne ovo su vektori dimenzije šest. Uzeće se u obzir samo prvih P momenata da bi se dobila gruba aproksimacija raspodele $p_{V_q^u}$. Konačan vektor obeležja koji koristimo u problemu klasifikacije stanja alata se dobija na sledeći način:

- odrede se momenti $m_q^{u,j}$ za svako $j = 1,2,\ldots,P$
- poređaju se u jedan vektor za svaku komponentu
- kako je svako to $m_q^{u,j}$ vektor dimenzije šest, dobija šest nezavisnih PN dimenzionalnih vektora za svako u
- vektori po komponentama se onda mogu zapisati na sledeći način

$$v_i^u = \left[m_1^{u,1,(i)} \ldots m_1^{u,P,(i)} | \ldots | m_N^{u,1,(i)} \ldots m_N^{u,P,(i)}\right]$$

$i = 1,\ldots,6$, $m_q^{u,1,(i)}$ su komponente $m_q^{u,j}$ (3)

- u procesu klasifikacije koristimo šest različitih klasifikatora, čije rezultate usrednjavamo.

3. EKSPERIMENTALNI REZULTATI

Za potrebe eksperimenata je korišćena CNC GU 600 glodalica od proizvođača INDEX iz laboratorije Fakulteta tehničkih nauka u Novom Sadu. Kao vibracioni senzor je korišćen akcelerometar Kistler 8002. Signal koji je detektovan je uzorkovan na 625 kHz, pomoću A/D konveretera NI 625 USB. Korišćene su pločice 42CrMo4, 310HB, 950MPa. Prilikom klasifikacije stanja alata se posmatrao nivo pohabanosti alata.

3.1 Eksperimenti sa četiri klase

U ovim eksperimentima je korišćeno 100 fajlova vibracionih signala. Signali su podeljeni u četiri klase prema nivou pohabanosti (u svakoj klasi ima 25 fajlova). Treba imati u vidu da se stanje alata menja kontinulano, što bi značilo da granice između klasa nisu striktne. Iz tog razloga za tačnu klasifikaciju potrebno je da razlika između rezultata klasifikacije i tačne klasifikacije ne bude veća od 1. Označimo sa c rezultat klasifikacije, c_t tačnu klasifikaciju i sa C oznaku klase. Važi $c - 1 \leq c_t \leq c + 1$. Kako su u ovoj grupi eksperimenata signali podeljeni na četiri klase, to znači da je C=1, ..., 4. Veći broj klase označava veći stepen pohabanosti alata.

Prilikom formiranja vektora obeležja iz (2) koji je baziran na teksturi korišćene su tri skale, dok je za potrebe dobijanja konačnog vektora obeležja korišćeno četiri momenta (P=4 u (3)).

Korišćene su četiri vrste klasifikatora: multivarijabilna regresija (MV), Lasso klasifikator, Lasso klasifikator baziran na selekciji vektora obeležja (Lasso SF, vidi [9]), i neuralna mreža sa propagacijom unapred, sa dva skrivena sloja od po deset neurona (FFNN).

U Tabeli 1. su prikazani procenti prepoznavanja za svaku klasu za sva četiri klasifikatora. U poslednjoj vrsti ove tabele KV je prikazana srednja vrednost prepoznavanja iz pet iteracija kros-validacije.

Tabela 1. Četiri klase

	MV	Lasso	Lasso SF	FFNN
Klasa 1	80,00	75,00	80,00	65,00
Klasa 2	90,00	100,00	100,00	90,00
Klasa 3	100,00	100,00	100,00	100,00
Klasa 4	75,00	85,00	85,00	95,00
KV	86,25	90,00	91,25	87,50

3.2 Eksperimenti sa dve klase

U ovim eksperimentima je korišćeno 600 fajlova vibracionih signala. Signali su podeljeni u dve klase prema nivou pohabanosti (u svakoj klasi ima 300 fajlova). Stanje alata se naravno i ovde menja kontinualno, ali kako imam samo dve klase u ovom slučaju su granice između klasa oštrije. Unutar klasa su promene u stanju alata kontinualne. Prepoznavanje se vrši metodom kros-validacije, po principu jedan na jedan.

Prilikom formiranja vektora obeležja su korišćene tri skale i četiri momenta. Korišćene su četiri vrste klasifikatora kao i u prethodnom slučaju.

U Tabeli 2. su prikazani procenti prepoznavanja za svaku klasu za sva četiri klasifikatora, kao i srednja vrednost nakon 5 iteracija procesa kros-validacije.

Tabela 2. Dve klase

	MV	Lasso	Lasso SF	FFNN
Klasa 1	82,67	98,00	83,33	93,33
Klasa 2	52,67	26,00	50,67	84,00
KV	67,67	62,00	67,00	88,67

4. ZAKLJUČAK

U ovom radu je razmatrana indirektna metoda

za nadgledanje stanja alata koja je zasnovana na signalu koji je detektovan od strane vibracionog senzora. Na osnovu detektovanog signala u predefinisanom vremenskom intervalu je forimaran STDFT spektrogram, koji se nadalje posmatra kao 2D slika teksture u vremensko-frekvencijskom domenu. Zatim su formirani vektori obeležja za potrebe klasifikacije stanja alata kao u [9], sa dodatkom nove metode klasifikacije FFNN.

U eksperimentima sa četiri klase se pokazuje da klasifikacija pomoću FFNN nije baš u potpunosti opravdana,. Lasso i Lasso MV daju bolje rezultate, dok MV daje lošije.

Iz tog razloga su urađeni dodatni novi eksperimenti sa dve klase. Iz Tabele 2. se može videti da se metoda FFNN pokazala znatno dominantnijom u odnosu na druge metode klasifikacije.

Kako je ova druga grupa eksperimenata urađena na mnogo većem polaznom skupu, u daljem istraživanju bi se na tom skupu mogla uraditi klasifikacija na četiri klase sa ciljem poređenja i unapređenja trenutnog algoritma.

Zahvalnica

¶ Istraživanje sprovedeno uz podršku Fonda za nauku Republike Srbije #6524560, VI-S-ADAPT, i Ministarstva prosvete, nauke i tehnološkog razvoja projekat br. 451 03-68/2020-14/200156: "Inovativna naučna i umetnička istraživanja iz domena delatnosti Fakulteta tehničkih nauka"

5. REFERENCE

[1] S. Cho, S. Binsaeid, S. Asfour, *Design of multisensor fusion-based tool condition monitoring system in end milling*, Int. J. Adv. Manuf. Technol. 46 (2010) 681–694.

[2] A. Siddhpura, R. Paurobally, *A review of flank wear prediction methods for tool condition monitoring in a turning process*, Int. J. Adv. Manuf. Technol.65 (2013) 371–393.

[3] B. Sick, *On-line and indirect tool wear monitoring in turning with artificial neural networks: a review of more than a decade of research*, Mech. Syst.Sign. Process. 16 (2002) 487–546.

[4] G.L. Goïc, M. Bigerelle, S. Samper, H. Favrelière, M. Pillet, *Multiscale roughness analysis of engineering surfaces: a comparison of methods for the investigation of functional correlations*, Mech. Syst. Sign. Process. 66–67 (2016) 437–457.

[5] D. Dimla, *The correlation of vibration signal features to cutting tool wear in a metal turning operation*, Int. J. Adv. Manuf. Technol. 19 (2002) 705–713.

[6] B. Bahr, S. Motavalli, T. Arfi, *Sensor fusion for monitoring machine tool conditions*, Int. J. Comput. Integr. Manuf. 10 (1997) 314–323.

[7] Y.-H. Tsai, J.C. Chen, S.-J. Lou, *An in-process surface recognition system based on neural networks in end milling cutting operations*, Int. J. Mach. Tools Manuf 39 (1999) 583–605.

[8] A. Al-Habaibeh, N. Gindy, *A new approach for systematic design of condition monitoring systems for milling processes*, J. Mater. Process. Technol. 107 (2000) 243–251.

[9] Antić, A., Popović, B., Krstanović, L., Obradović, R., Milošević, M.: *Novel texture-based descriptors for tool wear condition monitoring*, Mechanical Systems and Signal Processing 98 (2018) 1–15

[10] T. Leung, J. Malik, *Representing and recognizing the visual appearance of materials using three-dimensional textons*, Int. J. Comput. Vis. 43 (2001) 29–44.

[11] M. Varma, A. Zisserman, *A statistical approach to material classification using image patch exemplars*, IEEE Trans. Pattern Anal. Mach. Intell. 31 (2009) 2032–2047.

[12] J. Hays, M. Leordeanu, A.A. Efros, Y. Liu, *Discovering texture regularity as a higher-order correspondence problem, in: A. Leonardis, H. Bischof*, A. Pinz (Eds.), Computer Vision – ECCV 2006, ECCV 2006, Lecture Notes in Computer Science, vol. 3952, Springer, Berlin, Heidelberg, 2006, pp. 522–535.

Autori: **Doc. dr Lidija Krstanović, Prof. dr Aco Antić, Dr Marko Janev, Dr Branislav Popović,** Univerzitet Novi Sad, Fakultet Tehničkih Nauka, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2350, Fax: +381 21 454-495.

E-mail: lidijakrstanovic@uns.ac.rs
antica@uns.ac.rs
janev.marko@gmail.com
bpopovic@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Đurđev, M., Desnica, E., Novaković, B., Đorđević, L., Palinkaš, I.

ANALIZA STANJA I PRIMENE METAHEURISTIČKIH ALGORITAMA ZA REŠAVANJE PROBLEMA INŽENJERSKE OPTIMIZACIJE

Rezime: *Metaheuristički algoritmi smatraju se vrlo efikasnim metodama koje omogućavaju pronalaženje veoma dobrih rešenja u relativno zadovoljavajućem vremenskom periodu. Njihova primena dosegla je široke razmere u različitim poljima inženjerskih nauka. Naročito se ističe uspeh u rešavanju problema nelinearne optimizacije u okviru koje se mogu pronaći problemi sa ili bez zadatih ograničenja. Rad ima za cilj da, pored osnovnih prednosti i klasifikacije metaheurističkih algoritama, pruži kratak pregled stanja u oblastima optimizacije inženjerskog dizajna i mašinske obrade kao interesantnim primerima iz područja nelinearne optimizacije.*

Ključne reči: *metaheurisitike, algoritmi, optimizacija, inženjerski dizajn, mašinska obrada*

1. UVOD

Nelinearna optimizacija kao deo operacionih istraživanja podrazumeva pronalaženje minimuma ili maksimuma određene funkcije cilja koja je nelinearne prirode. Pored toga, rešenja u okvirima dopustivih skupova mogu podleći ograničenjima koja su definisana nelinearnim jednačinama i/ili nejednačinama [1]. Rešavanje ovakvih problema ne može se rešavati primenom univerzalnih metoda kao što je npr. simpleks metoda kod linearnog programiranja. Veliku primenu u rešavanju raznih problema nelinearne optimizacije pronašli su metaheuristički algoritmi. U ovom radu biće data sažeta analiza i klasifikacija metaheurističkih algoritama i njihov potencijal primene u reševanju nelinearnih problema kao što su problemi optimizacije u oblastima inženjerskog dizajna i mašinske obrade koji pripadaju klasi problema uslovne i bezuslovne optimizacije.

Metaheuristike predstavljaju napredne heuristike, odnosno algoritme opšte namene koji se mogu primeniti za rešavanje raznih optimizacionih problema. Koriste se sa ciljem dobijanja odgovora, odnosno rešenja za probleme o kojima ne posedujemo dovoljno znanja. Iscrpna pretraživanja nisu odgovarajuća iz razloga što je prostor raspoloživih rešenja koja treba pretražiti veoma obiman. Sasvim je dovoljno da postoje kandidati rešenja koji se mogu testirati u skladu sa prethodno definisanim kriterijumom i na osnovu kojeg se može ustanoviti njihov kvalitet.

Postoji niz prednosti koje karakterišu metaheurističke algoritme, a najvažnije među njima su sledeće [2]:

- Jednostavnost, koja se, pre svega, odnosi na izvore inspiracije imajući u vidu da su metaheuristike inspirisane različitim fizičkim pojavama, ponašanjem individualnih i kolektivnih organizama iz prirode, procesima na bazi evolucije itd. Autori na osnovu toga vrše simulacije, razvijaju nove i modifikuju postojeće algoritme.
- Fleksibilnost, koja podrazumeva mogućnost implementacije metaheuristika u odgovarajućim programskim okruženjima za rešavanje problema različitih tipova i dimenzija.
- Stohastičnost, u skladu sa kojom metaheuristike ne zahtevaju izračunavanje izvoda funkcija, za razliku od gradijentnih metoda. Polaženjem od slučajnih rešenja mogu se rešavati problemi iz realnih okruženja.
- Izbegavanje lokalnih optimuma, kao veoma važnom karakteristikom koja otvara vrata za primenu metaheuristika u rešavanju problema globalne optimizacije. Često se prostor pretraživanja smatra nepoznatim, ili veoma kompleksnim, sa vrlo velikim brojem lokalnih optimuma, pri čemu se metaheuristički algoritmi pokazuju veoma dobrim tehnikama koje uspešno sprečavaju zarobljavanje u lokalnim rešenjima, i vrše pretraživanje većeg broja regiona.

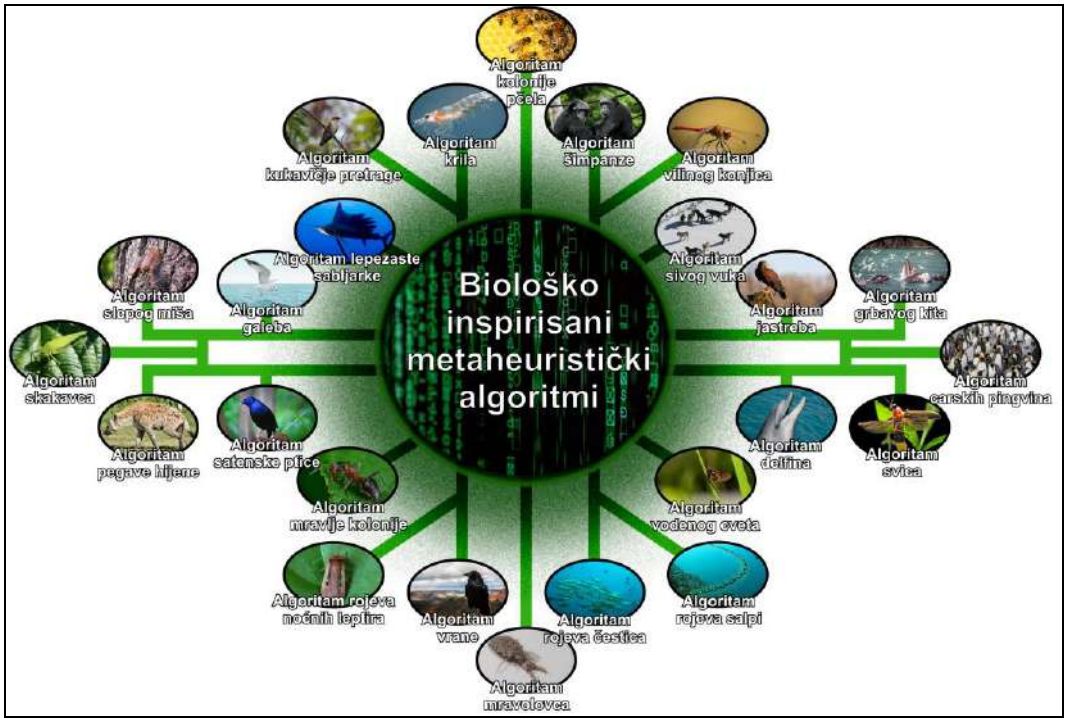
1.2 Klasifikacija metaheuristika

Klasifikacija metaheurističkih algoritama može se izvršiti prema različitim kriterijumima. Autori u [3] izdvajaju sledeće podele:

1) Algoritmi inspirisani prirodom, i algoritmi koji nisu inspirisani prirodom;
2) Algoritmi koji koriste memoriju i pamte prethodno pronađena rešenja, i algoritmi koji ne koriste memoriju;
3) Algoritmi bazirani na populaciji rešenja, i algoritmi na bazi jednog rešenja;

4) Iterativni algoritmi koji rade sa potpunim početnim rešenjem, i „pohlepni“ algoritmi koji polaze od „praznog“ rešenja koje grade sve do kompletnog.

Pored pomenutih kriterijuma jedan od takođe popularnih načina klasifikovanja metaheuristika je prema nivou njihove inspiracije. U literaturi posebno preovladavaju algoritmi koji inspiraciju pronalaze u ponašanjima raznih organizama iz prirode. Radi se o biološki inspirisanim populacionim algoritmima zasnovanim na inteligentnim mehanizmima koje koriste organizmi zasebno ili kao pripadnici veće grupe (populacije, roja, jata, i slično). Na slici 1 može se videti ilustrovani prikaz metaheurističkih algoritama koji su inspirisani raznim životinjama i organizmima iz sveta prirode.



Sl. 1. Ilustrativni prikaz biološki-inspirisanih metaheuristika [4]

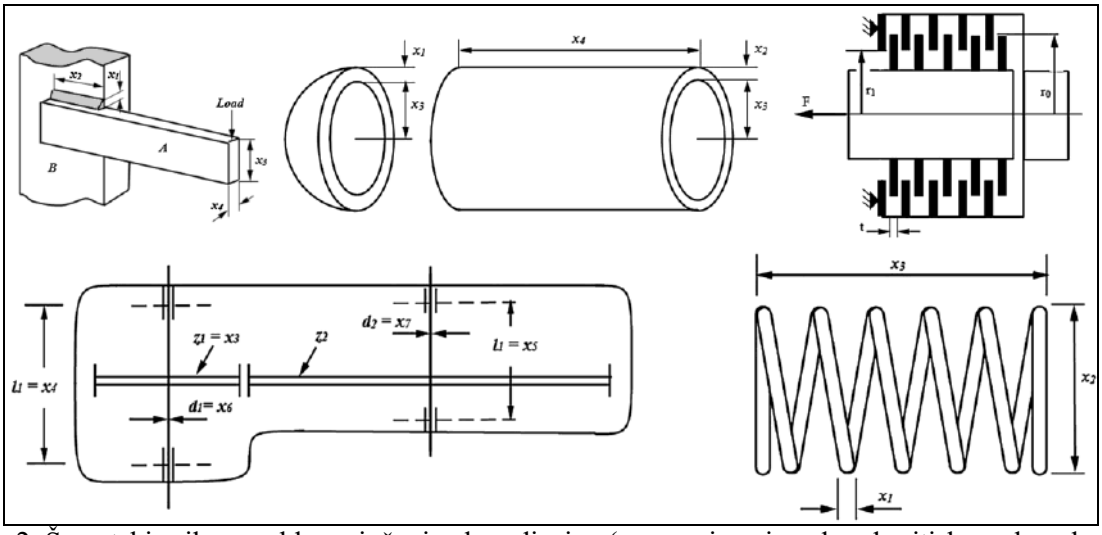
2. PRIMENA METAHEURISTIKA U INŽENJERSKOM DIZAJNU

Kada se vrši testiranje performansi metaheurističkih algoritama, a naročito pri razvoju novih ili unapređenih rešenja, od esencijalne je važnosti da se evaluacija izvrši koristeći relevantne funkcije i primere, kao i da se uporede ostvareni rezultati sa ostalim popularnim algoritmima. U literaturi se može pronaći veliki broj benčmark funkcija predstavljenim u matematičkim oblicima [5]. Radi se o primerima različitih dimenzija koji ne razmatraju ograničenja i imaju jedan ili više ekstrema, odnosno optimuma. Pored ovih funkcija, bliže realnim inženjerskim uslovima, u eksperimentalnim studijama autori razmatraju probleme iz oblasti inženjerskog dizajna. Pored činjenice da pripadaju klasi nelinearnih problema optimizacije, karakteriše ih skup odgovarajućih ograničenja, pa se otuda nazivaju i problemima uslovne optimizacije. Sa ciljem da se dođe do efikasnog metaheurističkog algoritma, autori vrše modifikacije algoritama i kao rezlutat dobijaju metode koja će demonstrirati svoje istraživačke kapacitete na različitim problemima optimizacije. Autori [6] su u svojoj temeljno izvršenoj studiji predstavili skup od ukupno 57 primera iz inženjerske optimizacije među kojima se izdvaja 19 primera optimizacije iz područja inženjerskog dizajna. Pojedini primeri iz ove grupe su sledeći optimizacioni zadaci:

- Minimizacija težine reduktora,
- Optimizacija težine opruge.
- Optimizacija troškova zavarivanja, materijala i izrade suda pod pritiskom,
- Minimizacija troškova dizajna zavarenog nosača,
- Minimizacija težine grednih nosača,
- Minimizacija težine lamelaste kočnice sa više diskova,
- Minimizacija grešaka u prenosnom odnosu planetarnih prenosnika,
- Minimizacija težine menjača,
- Optimizacija nosivosti kotrljajnih ležajeva,

- Optimizacija zapremine čelične žice za izradu pritisnih opruga i dr.

Na slici 2 šematski su predstavljeni neki od navedenih primera. Autor [7] je u svom istraživanju izvršio modifikaciju i hibridizaciju algoritma svica, algoritma kukavičje pretrage, algoritma slepog miša i algoritma arktičkog krila, sa ciljem rešavanja ovih problema uslovne optimizacije, kao i određene primere iz oblasti primenjene mehanike. Komparativnom analizom funkcija cilja verifikovana je ispravnost i efikasnost predloženih metoda. Slično, u publikaciji [8] je izvršena primena savremenog algoritma inspirisanog sivim vukovima koji je testiran za rešavanje inženjerskih problema. Ostvareni su optimalni i približno optimalni rezultati u pet različitih studija, pri čemu je naglašen cilj postizanja boljih rezultata u odnosu na postojeće rezultate u literaturi.



Sl. 2. Šematski prikaz problema inženjerskog dizajna (zavareni spoj, sud pod pritiskom, lamelasta kočnica, reduktor i opruga) [9]

3. PRIMENA METAHEURISTIKA ZA OPTIMIZACIJU PARAMETARA MAŠINSKE OBRADE

Druga oblast primene metaheurističkih algoritama u ovoj studiji odnosi se na područje optimizacije parametara mašinske obrade. Pronalaženje optimalnih parametara obrade smatra se vrlo važnim zadatkom koji ima direktan uticaj na troškove obrade, kvalitet proizvoda, ekonomičnost, a i sam finalni kvalitet proizvoda. Reč je o optimizacionim problemima koji, za razliku od problema inženjerskog dizajna, ne uključuju ograničenja, i proces optimizovanja zavisi isključivo od funkcije cilja.

Da bi se ovaj zadatak izvršio, neophodno je poći od matematičkog modela za proračun optimalnih torškova obrade. Parametri procesa obrade se prema zavisnosti mogu grupisati u nezavisne parametre koji su uticajni na proces rezanja (materijal alata, materijal obratka, režimi rezanja, SHP; geometrija alata i dr.), i na zavisne parametre koji su promenljive prirode (vrsta i oblik strugotine, habanje alata, kvalitet obrađene površine, tačnost obrade, ekonomičnost obrade, temperatura rezanja, sila i snaga rezanja i dr.) [10].

Planiranjem i izvođenjem eksperimenata dobijaju se odgovarajući izlazni rezultati nakon kojih sledi faza modelovanja izlaznih performansi. Često se u literaturi mogu pronaći centralni kompozicioni dizajni eksperimenata [10] i Tagučijevi ortogonalni nizovi [11,12] na bazi kojih se prikupljaju eksperimentalni podaci. Jedan od načina za predikciju izlaznih performansi procesa obrade je pomoću metode odzivnih površina [13,14].

Primena metaheurističkih algoritama za optimizaciju hrapavosti obrađene površine pri obradi glodanjem može se pronaći u radu [14] gde su optimalne vrednosti brzine vretena, pomaka po zubu, aksijalne i radijalne dubine rezanja dobijene pomoću metode odzivnih površina, genetskog algoritma i algoritma sivog vuka koje su upoređene se izmerenim rezultatima. Autori su u [12] optimizovali ulazne parametre procesa bušenja uzorak od nerđajućeg čelika pomoću abrazivnog vodenog mlaza pri čemu su za optimizaciju primenjeni algoritam krila, i algoritam sivog vuka. Na osnovu regresionih jednačina, autori su u [15] primenom algoritma inspirisanog rojevima čestica optimizovali parametre obrade završnim glodanjem za minimizaciju hrapavosti obrađene površine.

Pored navedenih primera, mogu se pronaći i

uporedne analize rezultata različitih algoritama kao što je izvršeno u radu [16] za pet različitih studija slučaja.

4. ZAKLJUČAK

U radu je izvršena kratka analiza metaheurističkih algoritama i njihov potencijal primene za rešavanje problema nelinearne optimizacije. Izvršena je klasifikacija pri čemu je naglasak stavljen na biološki inspirisane algoritme. Potom je izvršena analiza primene u rešavanju problema uslovne optimizacije u oblasti inženjerskog dizajna, kao i problema bezuslovne optimizacije za određivanje optimalnih parametara mašinske obrade.

5. REFERENCE

[1] Milovanović, G.V., Stanimirović, P.S.: *Simbolička implementacija nelinearne optimizacije*, Edicija monografije, Elektronski fakultet u Nišu, Niš, 2002.

[2] Mirjalili, S., Mirjalili, S.M., Lewis, A.: *Grey wolf optimizer*, Advances in engineering software, Vol. 69, p.p. 46-61, 2014.

[3] Talbi, E-G.: *Metaheuristics: from design to implementation*, John Wiley & Sons, Vol. 74, 2009.

[4] Đurđev, M.: *Primena savremenih metaheurističkih algoritama u optimizaciji tehnoloških procesa obrade proizvoda*, Doktorska disertacija, Fakultet tehničkih nauka, Novi Sad, 2021.

[5] Hussain, K., Saleh, M.N.M., Cheng, S., Naseem, R.: *Common Benchmark Functions for Metaheuristic Evaluation: A Review*, International Journal on Informatics Visualization, Vol. 1, No. 4-2, p.p. 218-223, 2017.

[6] Kumar, A., Wu, G., Ali, M.Z., Mallipeddi, R., Suganthan, P.N., Das, S.: *A test-suite of non-convex constrained optimization problems from the real-world and some baseline results*, Swarm and Evolutionary Computation, Vol. 56, p.p. 1-47, 2020.

[7] Miodragović, R. G.: *Razvoj naprednih biološki inspirisanih algoritama za rešavanje optimizacionih problema primenjene mehanike*, Doktorska disertacija, Fakultet za mašinstvo i građevinarstvo u Kraljevu, Kraljevo, 2015.

[8] Milenković, B., Krstić, M., Jovanović, Đ.: *Primena algoritma sivog vuka za rešavanje inženjerskih optimizacionih problema*, Tehnika, Vol. 1/2021, p.p. 50-57, 2021.

[9] Guedria, N.B.: *Improved accelerated PSO algorithm optimization for mechanical engineering problems*, Applied Soft Computing, Vol. 40, p.p. 455-467, 2016.

[10] Kovač, P.: *Metode planiranja i obrade eksperimenta*, FTN izdavaštvo, Novi Sad, 2015.

[11] Thamizhmanii, S., Saparudin, S., Hasan, S.: *Analyses of surface roughness by turning process using Taguchi method*, Journal of Achievements in Materials and Manufacturing Engineering, Vol. 20, p.p. 503-506, 2007.

[12] Balaji, K., Kumar, S., Yuvaraj, N.: *Multi objective taguchi-grey relational analysis and krill herd algorithm approaches to investigate the parametric optimization in abrasive water jet drilling of stainless steel*, Applied Soft Computing Journal, Vol. 102, p.p. 1-25, 2021.

[13] Killickap, E., Huseyinoglu, M., Yardimeden, A.: *Optimization of drilling parameters on surface roughness in drilling of AISI 1045 using response surface methodology and genetic algorithm*, Int J Adv Manuf Technol, Vol.52, p.p. 79-88, 2011.

[14] Sekulic, M., Pejic, V., Brezocnik, M., Gostimirovic, M., Hadzistevic, M.: *Prediction of surface roughness in the ball-end milling process using response surface methodology, genetic algorithms, and grey wolf optimizer algorithm*, Advances in Production Engineering & Management, Vol. 13, No. 1, p.p. 18-30, 2018.

[15] Pare, V., Agnihotri, G., Krishna, C.M.: *Optimization of Cutting Conditions in End Milling Process with the Approach of Particle Swarm Optimization*, International Journal of Mechanical and Industrial Engineering, Vol. 1, p.p. 21-25, 2011.

[16] Madić, M., Marković, D., Radovanović, M.: *Comparison of Meta-Heuristic Algorithms for Solving Machining Optimization Problems*, Facta Universitatis, Vol. 11, No. 1, p.p. 29-44, 2013.

Autori: **Dr Mića Đurđev, Prof. dr Eleonora Desnica, MSc Borivoj Novaković, MSc Luka Đorđević, MSc Ivan Palinkaš,** Univerzitet u Novom Sadu, Tehnički fakultet "Mihajlo Pupin" Zrenjanin, Đure Đakovića bb, 23000 Zrenjanin, Serbia, Tel: +381 23 550 515, Fax: +381 23 550 520.

E-mail: mica.djurdjev@tfzr.rs
eleonora.desnica@tfzr.rs
borivoj.novakovic@tfzr.rs
luka.djordjevic@tfzr.rs
ivan.palinkas@tfzr.rs

ETIKUM 2021

INTERNATIONAL SCIENTIFIC CONFERENCE
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Aleksić, A., Rodić, D., Gostimirović, M., Sekulić, M., Savković, B., Kulundžić, N.

MODELOVANJE HRAPAVOSTI OBRAĐENE POVRŠINE PRI SEČENJU PLAZMOM

Rezime: *Obrada plazmom se koristi za sečenje raznih vrsta materijala, pre svega teško obradivih metalnih i nemetalnih materijala. U radu je predstavljeno sečenje dve vrste materijala, a to su EN 16MnCr5 i EN X5CrNi18-10. Tokom eksperimenta variran je jedan parametar (brzina rezanja), dok su parametri struja pražnjenja, pritisak i debljina materijala bili konstantni. Za potrebe eksperimenta korišćen je delimični plan eksperimenta urađen u programu Design Expert 7. Korišćenje ANOVA analize izvršena je analiza rezultata, gde je pokazan uticaj parametara rezanja i izvršeno modelovanje matematičkog modela srednje aritmetičke hrapavosti. Daljom analizom utvrđeno je da je model adekvatan i da može da se koristi za optimizacuju procesa rezanja plazmom.*

Ključne reči: *Sečenje plazmom, srednja aritmetička hrapavost, brzina rezanja, ANOVA, modelovanje.*

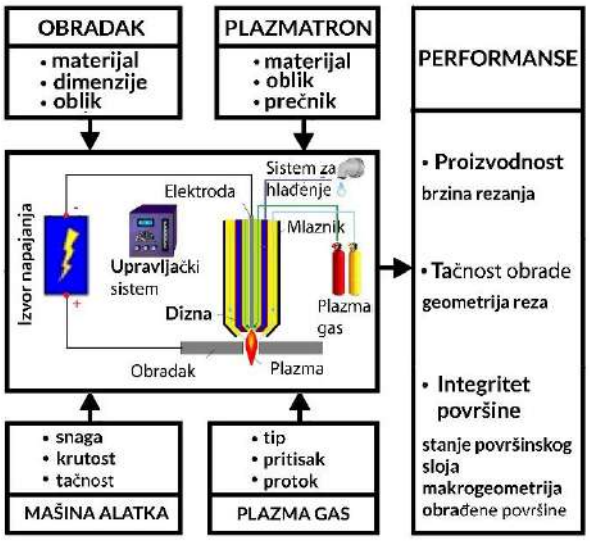
1. UVOD

Obrada plazmom spada u relativno novije nekonvencionalne postupke obrade materijala. Uglavnom se koristi za sečenje teškoobradljivih metalnih i nemetalnih materijala, koji se veoma teško mogu seći nekim drugim postupcima. Klasično sečenje plazmom metalnih i nemetalnih materijala, koji se drugim postupcima obrade teško mogu obrađivati, jedna je od najčešćih proizvodnih operacija plazmom [1]. Primena je uglavnom opravdana kod obrade visokolegiranih čeličnih materijala, teškoobradljivih Ti-Ta-W-Mo legura i teškotopivih legura obojenih metala. Kod obrade nemetalnih materijala (keramika, staklo, oksidi, karbidi i sl.) pogodnost plazme se ogleda u mogućnosti obrade i elektro-neprovodljivih materijala, jer nije neophodna električna veza materijala sa izvorom napajanja [2].

Proces obrade materijala plazmom bazira na visokoj toplotnoj i kinetičkoj energiji struje plazme usmerene na površinu materijala obratka. Delovanjem ovih energija dolazi do razvoja vrlo visokih temperatura u zoni udara plazme o površinu obratka. Temperature na mestu obrade dostižu vrednosti 4.000÷10.000 °C. Visoka i široka koncentracija toplotne energije dovodi do niza fizičko-hemijskih procesa i promena u široj zoni materijala obratka. Visoka i neujednačena temperatura luka plazme, dovodi do neizbežnih mikrogeometrijskih neravnina i mikrostrukturnih promena u površinskom sloju materijala obratka. Promene strukture i tvrdoće osnovnog materijala i pojava pukotina, prslina ili nagorelih površina, zbog širokog i dugotrajnog dejstva toplotnog opterećenja obratka, javljaju se u dubokom površinskom sloju materijala obratka [1].

Prema tome obrada plazmom je zahtevan proces čiji je mehanizam uklanjanja materijala veoma složen. Stoga je teško uspostaviti adekvatan matematički model i njegovo optimalno podešavanje koje može precizno predvideti izlazne performanse obrade, pogotovo hrapavost obrađene površine [3]. Uglavnom se za ispitivanje odnosa i parametarskih interakcija između ulaznih parametara i izlaznih performansi koriste klasične metode modelovanja [4,5].

Na proces obrade plazmom utiče mnogo ulaznih faktora od čijih specifikacija zavise tehnološke karakteristike plazma procesa, kao što su: izvor napajanja (struja i napon), plazma gas (vrsta i pritisak), plazmatron (dimenzije i položaj), brzina rezanja, materijal obratka (vrsta i debljina) i proizvodna operacija (topljenje ili zagrevanje), slika 1.



Sl. 1. Osnove obrade plazmom

Pošto je i dalje jedan od glavnih zadataka sečenja plazmom postizanje što boljeg kvaliteta

obrađene površine, posebna pažnja usmerena je na uticaj brzine rezanja na hrapavost obrađene površine. Dobro je poznato da sečenje plazmom nudi veoma visoku produktivnost ali nizak kvalitet obrađene površine. Stoga je glavi cilj ovog rada ispitivanje uticaja brzine rezanja na hrapavost obrađene površine pri plazma sečenju dve vrste materijala EN 16MnCr5 i EN X5CrNi18-10. Ovi legirani materijali imaju širok spektar primene u mašinogradnji. Da bi se ostvario postavljeni cilj prvo je potrebno generisati adekvatne matematičke modele. Za ocenu adekvatnosti matematičkih modela korišćena je analiza varijansi ANOVA.

2. EKSPERIMENTALNI POSTUPAK

2.1 Postavka eksperimenta

Eksperimentalna istraživanja su sprovedena u firmi d.o.o. Velpan iz Kikinde. Uslovi u kojima je izvedeno eksperimentalno ispitivanje je predstavljeno u narednom delu poglavlja. Uslovi se odnose na:

- mašinu alatku
- materijal obratka
- izabrane režime obrade

Mašina alatka: Eksperimenti su odrađeni na CNC plazma mašini sa radnim prostorom 2000x1600x160, maksimalnom brzinom kretanja gorionika 12000 mm/min. Agregat koji pokreće mašinu je firme „Miller“, oznake „Spectrum 1251“, dok je gorionik takođe istog proizvođača oznake „ICE-100TM“ [8].

Materijal obratka: Za potrebe istraživanja korišćene su dve vrste materijala debljine 6 mm. U prvom slučaju korišćen je čelik EN 16MnCr5 koji spada u Cr-Mn čelike za cementaciju. Karakteristika ovog materijala je dobra prokaljivost. Koristi se za delove vozila i reduktore kao što su zupčanici, osovine, puževi, lančanici i bregaste osovine. Dok u drugom slučaju koristio se čelik EN X5CrNi18-10 koji po kvalitetu spada u grupu plemenitih čelika. Koristi se u raznim oblastima mašinstva, kao što su ventili, vodene turbine, delovi, pumpe, delovi u hemijskoj i tekstilnoj industriji, takođe je otporan na koroziju.

Režim obrade: Za potrebe eksperimenta varirana je brzina rezanja i materijal obradka, dok su struja (I=70 A), pritisak gasa (P=5 bar) i debljina materijala (h=4 mm) bile konstantne. Brzina rezanja i materijal obradka su varirani na osnovu dobro poznatog plana eksperimenta, koji je prikazan u tabeli 1.

Kao izlazna funkcija posmatrana je minimalna srednja aritmetička hrapavost (Ra_{min}). Hrapavost obrađene površine merena je pomoću uređaja „Mitotoyo Surftest SJ-210“. Svako merenje je izvršeno sa tri ponavljanja na referentnu dužinu L=5,6 mm, gde je kao konačna mera uzeta srednja aritmetička sredina.

Tabela 1. Postavka i rezultat eksperimenta

Red. br.	Brzina rezanja [mm/min]	Materijal obratka	Srednja aritmetička hrapavost [μm]
1	500	čelik 1	2,11
2	700	čelik 1	2,47
3	900	čelik 1	3,33
4	1100	čelik 1	4,37
5	1300	čelik 1	5,13
6	1500	čelik 1	4,75
7	1700	čelik 1	3,41
8	1900	čelik 1	4,92
9	500	čelik 2	2,28
10	700	čelik 2	2,87
11	900	čelik 2	3,64
12	1100	čelik 2	6,91
13	1300	čelik 2	7,93
14	1500	čelik 2	8,43
15	1700	čelik 2	9,81
16	1900	čelik 2	11,08

3. REZULTATI

3.1 Anova analiza

Za proveru eksperimenta je korišćena analiza varijansi, kojom je utvrđen uticaj ulaznih parametara na izlaznu karakteristiku. Test značajnosti regresivnog modela pojedinačnih koeficijenata i R^2 izračunati su pomoću programskog paketa Design Expert 7. Na osnovu osnovnih statističkih parametara predložen je model sa međusobnim uticajem **2FI** (tabela 3.1.1).

Tabela 2. Izbor adekvatnog modela

Model Summary Statistics						
	Std.		Adjusted	Predicted		
Source	Dev.	R-Squared	R-Squared	R-Squared	PRESS	
Linear	1,44	0,7712	0,736	0,6302	43,53	
2FI	**0,75**	**0,9424**	**0,928**	**0,9071**	**10,93**	**Suggested**
Quadratic	0,71	0,9534	0,9365	0,8989	11,90	
Cubic	0,74	0,9581	0,9302	0,7866	25,11	

Pomoću ANOVA analize izvršena je analiza modela i njegovih članova. U tabeli 2 izvršena je provera značajnosti predloženog modela. Zaključeno je da je predloženi model adekvatan, zato što je vrednost F<0,05.

U tabeli 3. prikazana je podešena vrednost (engl. Adjust R^2) i vrednost R^2 za predviđanje (engl. Predict R^2). Na osnovu dobijenih rezultata zaključuje se da je model adekvatan i da može da se koristi za optimizaciju procesa rezanja.

Tabela 3. Provera adekvatnosti predloženog modela

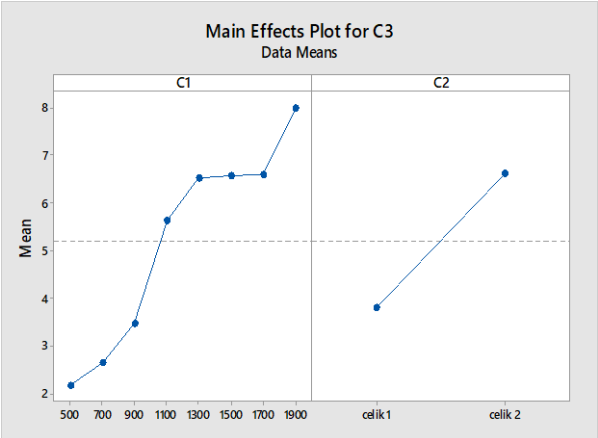
Source	Sum of Squares	df	Mean Square	F	p-value Prob > F	
Model	**110,92**	**3**	**36,97**	**65,49**	**< 0,0001**	**significant**
A-Brzina	59,24	1	59,24	104,92	< 0,0001	
B-B	31,53	1	31,53	55,85	< 0,0001	
AB	20,16	1	20,16	35,71	< 0,0001	
Residual	6,77	12	0,56	65,49	< 0,0001	
Cor Total	117,70	15	36,97	104,92	< 0,0001	

Tabela 4. Naziv tabele

Std. Dev.	0,75	R-Squared	**0,9424**
Mean	5,21	Adj R-Squared	**0,928**
C.V. %	14,41	Pred R-Squared	**0,9071**
PRESS	10,93	Adeq Precision	24,775

3.2 Uticaj parametara obrade na hrapavost obrađene površine

Uticaj parametara na hrapavost obrađene površine predstavljen je preko Main Effects Plot dijagrama (slika 4). Na dijagramu C1 može se uočiti da sa povećanjem brzine rezanja povećava se i hrapavost. Takođe se uočava stagnacija hrapavosti pri brzinama rezanja 1300-1700 mm/s hrapavost obrađene površine je približno jednaka. Na dijagramu C2 može se uočiti da izborom materijala obratka (čelik 1) postiže se manja hrapavost nego korišćenjem čelik 2, pri istim režimima obrade.



Sl. 2. Odzivni ANOVA dijagram

3.3 Matematički model

Na osnovu prethodne analize dobijen je kodirani matematički model srednje aritmetičke hrapavosti obrađene površine.

$$R_a = +5{,}22 + 2{,}94 * A + 1{,}40 * B + 1{,}71 * A * B \quad (1)$$

Pošto gore navedena jednačina obuhvata i vrstu materijala, mora se uraditi dekodiranje jednačine 1 i samim tim dobiti nove dve jednačine (2 i 3) koje posebno opisuju prvi materijal (čelik 1), a posebno drugi (čelik 2).

$$R_{a1} = +1{,}71196 + 1{,}74940 * 10^{-3} * Brzina\ rezanja\ (v) \quad (2)$$

$$R_{a2} = -1{,}35911 + 6{,}64821 * 10^{-3} * Brzina\ rezanja\ (v) \quad (3)$$

4. ZAKLjUČAK

Sečenje pomoću plazmom je visokoproduktivna tehnologija koja pripada grupi nekonvencionalnih postupaka obrade rezanjem i najveću primenu ima u rezanju ploča napravljenih od teško obradljivih materijala.

U poređenju sa drugim nekonvencionalnim tehnologijama, sečenje plazmom se postižu najveće brzine sečenja sa zadovoljavajućim kvalitetom i tačnošću obrađene površine. Međutim, sečenje plazmom dovodi do intezivnog zagrevanja u zoni obrade, što dovodi do neželjene promene strukture u oblasti sečenja.

Na osnovu prethodne analize rezultata dolazi se do sledećih zaključaka:

1. Pri malom broju eksperimenatalnih rezultata moguće je izvršiti obradu podataka pomoću programa Design expert 7.
2. Na osnovu plana eksperimenta koristeći ANOVA analizu uspešno je izvršena analiza rezultata i dobijen je matematički model.
3. Dobijeni matematički model je proveren na adekvatnost, gde je ANOVA analizom potvrđena adekvatnost matematičkog modela, koji dalje može da se koristi za optimizaciju procesa obrade.
4. Odzivni ANOVA dijagram je dokazao unapred predpostavljenu hipotezu, da pri porastu brzine rezanja dolazi do porasta hrapavosti obrađene površine. Takođe je pokazao da se materijal obratka (čelik 1), mnogo bolje pokazao sa aspekta površinske hrapavosti od materijala obratka (čelik 2).

Optimizacija procesa obrade sečenjem plazmom je jedan od narednih koraka u istraživanju.

5. REFERENCE

[1] Gostimirovic, M.: *Nekonvencionalni postupci obrade*, Fakultet tehničkih nauk, Novi Sad, 2012.

[2] Gostimirović, M., Rodoć, D., Sekulić, M., Aleksić, A.: *An Experimental Analysis of Cutting Quality in Plasma Arc Machining,* Advanced Technologies and Materials, Vol. 45, No. 1, p.p. 1-8, 2020.

[3] Ramakrishnan, H., Balasundaram, R., Ganesh, N., Karthikeyan, N.: *Experimental investigation of cut quality characteristics on SS321 using plasma arc cutting,* Journal of the Brazilian society of Mechanical Sciences and Engineering, Vol. 40, No. 2, p.p. 1-11, 2018.

[4] Aleksić, A., Sekulić, M., Savković, B., Gostimirović, M., Kamenko, I.: *Optimization of cutting parameters by nature-inspired algorithms,* Acta tehnica corviniensis – Bulletin of engineering, Vol. 13, No. 4, p.p. 41-41, 2020.

[5] Radovanovic, M., Madic, M.: *Modeling the plasma arc cutting process using ANN,* Nonconventional Technologies Review, Vol. 4, p.p. 43-48, 2011.

[6] Kumar, D., Maity, K.P.: *An optimization and experimental analysis of plasma arc cutting of Hardox-400 using Taguchi based desirability analysis,* Proceedings, Vol. 5, p.p. 13157-13165, 2018.

[7] Bhowmick, S., Basu, J., Majumdar, G., Bandyopadhyay, A.: *Experimental study of plasma arc cutting of AISI 304 stainless steel,* Proceedings, Vol. 5, p.p. 4541-4550, 2018.

[8] Subbarao, C., N.Sinivasa, R., Manoj, K. E., Ramana D. V. R.: *Investigation Analysis of Plasma arc cutting Parameters on the Unevenness surface of Hardox-400 material,* Procedia Engineering, Vol. 64, p.p. 854-861, 2013.

[9] Internet: www.millerwelds.com, Download: 07.11.2021. From: https://www.millerwelds.com/files/owners-manuals/o201872c_mil.pdf

ACKNOWLEDGEMENT

This paper has been supported by the Ministry of Education, Science and Technological Development through the project no. 451-03-68/2020-14/200156: "Innovative scientific and artistic research from the FTN (activity) domain".

Autori: **MSc Anđelko Aleksić, Doc. dr Dragan Rodić, Prof. dr Marin Gostimirović, Prof. dr Borislav Savković, MSc Nenad Kulundžić,** Univerzitet Novi Sad, Fakultet Tehničkih Nauka, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2350, Fax: +381 21 454-495.

E-mail: andjelkoa94@uns.ac.rs
rodicdr@uns.ac.rs
maring@uns.ac.rs
milenkos@uns.ac.rs
savkovic@uns.ac.rs
kulundzic@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE**
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Bojanić Šejat, M., Knežević, I., Živković, A., Rackov, M., Ilić,V.

MODELOVANJE STATIČKOG PONAŠANJA RADIJALNIH LEŽAJA

Rezime: *U okviru ovog rada opisan je analitički model za analizu kvazistatičke raspodele opterećenja u kotrljajnim ležajima. Kvazistatički model je razvijen na bazi statičkog modela, primenom Hertz-ove teorije kontakta i John-Harris-ove raspodele opterećenja na kotrljajna tela. Verifikacija statičkog ponašanja razmatranog ležaja je izvršena poređenjem rezultata dobijenih kvazistatičkim modelovanjem i rezultata dobijenih primenom metode konačnih elemenata.*
Ključne reči: *kotrljajni ležaj, kvazistatički model, elastične deformacije, kontaktni naponi*

1. UVOD

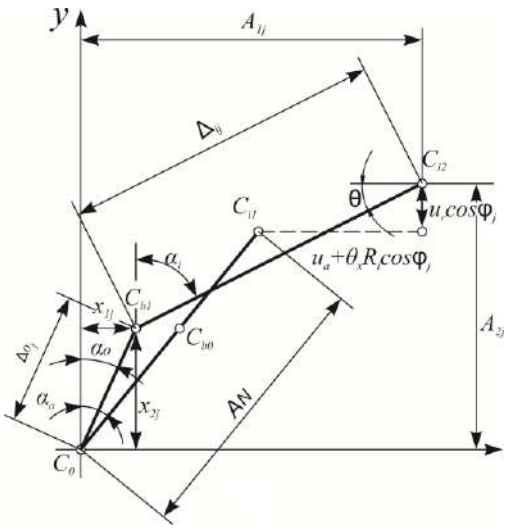
Gotovo da ne postoji ni jedan mašinski element kod koga se sreću tako teški uslovi eksploatacije, kao kod kotrljajnog ležaja. Celokupno opterećenje se prenosi preko nekoliko kotrljajnih elemenata, koji sa prstenovima ostvaruju kontakt u tački ili duž linije. Čak i kod umerenih opterećenja, ovakva koncentracija izaziva ekstremno velike kontaktne sile/napone. Tačka kontakta se neprekidno pomera sa obrtanjem prstenova, tako da je materijal izložen i sa te strane ekstremnim uslovima koji imaju izraziti dinamički karakter opterećenja.

Na bazi *Hertz-ove* teorije kontakta i teorije kontrole staza kotrljanja, *Jones* [1] i *Harris* [2] predložili su klasičan model za analizu kotrljajnog ležaja, koji se i dalje koristi u simulaciji ležaja. Pri analizama se ugao kontakta često smatra konstantnim, ali u stvarnosti nije tako. *Liao* [3] je predložio novi metod za analizu pomeranja i opterećenja u kugličnom ležaju sa promenljivim uglom kontakta. *Wang* [4] je razvio kvazistatički model za proračun kugličnih ležaja, koji su izloženi kombinovanom dejstvu radijalnih i aksijalnih sila kao i momenta. *Stribeck* [5] je prvi istražio distribuciju opterećenja za radijalno opterećenje kugličnih ležaja sa nultim zazorom, a kasnije je proširio istraživanje na različite zazore kod kugličnih ležaja. Na osnovu Stribeck-ovog istraživanja, *Sjovall i dr.* [6] su istražili raspodelu opterećenja na kotrljajnim telima i stanja kontakta kotrljajno telo - staza kotrljanja kugličnog ležaja pod zadatim radijalnim i aksijalnim prednaprezanjem. Ta istraživanja su bazirana na statičkoj analizi i zanemareni su uticaji centrifugalne sile i giroskopskog momenta kotrljajnog tela.

U ovom radu su prikazani i upoređeni rezultati dobijeni na osnovu kvazistatičkog model za analizu statičkog ponašanja kugličnih ležaja, koji je razvijen na bazi *Hertz-ove* teorije kontakta i *John-Harris*-ove raspodele opterećenja na kotrljajnim telima sa rezultatima dobijenim primenom metode konačnih elemenata.

2. RASPODELA OPTEREĆENJA KUGLIČNIH LEŽAJA

Kada pored aksijalnog opterećenja deluju radijalno opterećenje i moment na radijalni ležaj, unutrašnji prsten je pomeren u odnosu na spoljašnji za aksijalno i radijalno pomeranje u_a i u_r i ugaono pomeranje θ kao što je prikazano na slici 1. U tom slučaju kotrljajna tela neće biti ravnomernog opterećenja.



Sl. 1. Pozicija centra zakrivljenosti radijalnog ležaja nakon delovanja kombinovanog opterećenja

Na slici 1 je predpostavljeno da je centar zakrivljenosti spoljašnje staze (C_o) fiksan u prostoru, i da se centar zakrivljenosti unutrašnje staze (C_{i1}) pomera relativno u odnosu na fiksni centar na poziciju (C_{i2}). Pri ovome se i centar kotrljajnog tela (C_{bo}) pomera u novu poziciju (C_{b1}).

Sa slike 1 se dobija jednačina ravnoteže kinematskih ograničenja između kotrljajnih tela i staza kotrljanja:

$$\begin{aligned}&\left[A_{1j}-X_{1j}\right]^2+\left[A_{2j}-X_{2j}\right]^2-\Delta_{ij}^2=0\\&X_{1j}^2+X_{2j}^2-\Delta_{oj}^2=0\end{aligned}\qquad(1)$$

Jednačina ravnoteže sila na kotrljajno telo u zoni opterećenja sa slike 1 glasi:

$$\begin{aligned}&Q_{oj}\cos\alpha_{oj}-Q_{ij}\cos\alpha_{ij}-\frac{M_{gj}}{d_b}\left(\sin\alpha_o-\sin\alpha_i\right)-F_{cj}=0\\&Q_{oj}\sin\alpha_{oj}-Q_{ij}\sin\alpha_{ij}+\frac{M_{gj}}{d_b}\left(\sin\alpha_o-\sin\alpha_i\right)=0\end{aligned}\qquad(2)$$

Odnos između lokalnih *Hertz-ovih* kontaktnih sila $Q_{(j)}$ i ugiba $\delta_{(j)}$ između kotrljajnog tela i unutrašnje/spoljašnje staze kotrljanja se može napisati kao:

$$Q_{i,o(j)}=K_{i,o}\left(\delta_{i,o}^{3/2}\right)_j\qquad(3)$$

U prethodnim izrazima indeksi *i, o* označavaju unutrašnju i spoljašnju stazu kotrljanja respektivno, j = 1,2,3, ..., Z, gde je Z broj kotrljajnih tela; $K_{i/o}$ je *Hertz-ova* kontaktna krutost. Prethodna relacija važi za slučaj kada je $\delta_{i(j)}>0$. Kada su kotrljajna tela van zone opterećenja ugao kontakta sa spoljašnjom stazom kotrljanja je jednak nuli, kao i giroskopski moment. U tom slučaju je:

$$\begin{aligned}&Q_{i(j)}=0\\&Q_{o(j)}=F_{cj}\end{aligned}\qquad(4)$$

Kotrljajna tela koja su u zoni opterećenja uvek ostvaruju kontakt sa stazama kotrljanja, u tom slučaju mora biti ispunjen uslov:

$$\sqrt{\left(A_{1j}^2+\left(A_{2j}-\Delta_{oj}\right)^2\right)}\le\left(f_i-0{,}5\right)d_b\qquad(5)$$

Da bi se odredile vrednosti relativnog pomeranja prstenova za poznato spoljašnje opterećenje, formirane su jednačine delovanja sila na prstenove ležaja kao:

$$\begin{aligned}F_{(i,o)x}&=\sum_{j=1}^{Z}\left(Q_{i,o(j)}\sin\alpha_{i,o(j)}+\frac{M_{gj}}{d_b}\cos\alpha_{i,o(j)}\right)\\F_{(i,o)y}&=\sum_{j=1}^{Z}\left(\pm Q_{i,o(j)}\cos\alpha_{i,o(j)}\mp\frac{M_{gj}}{d_b}\sin\alpha_{i,o(j)}\right)\cos\varphi_j\\M_{(i,o)y}&=\pm\sum_{i=1}^{Z}\left\{r_{i,o}\left(Q_{i,o(j)}\sin\alpha_{i,o(j)}+\frac{M_{gj}}{d_b}\cos\alpha_{i,o(j)}\right)\mp f_{i,o}M_{gj}\right\}\sin\varphi_j\end{aligned}\qquad(6)$$

3. PRIKAZ REZULTATA MODELOVANJA STATIČKOG PONAŠANJA LEŽAJA

Sveobuhvatno testiranje matematičkih modela izvršeno je za radijalni kuglični ležaj FKL 6006. Verifikacija statičkog ponašanja razmatranog ležaja je izvršena poređenjem rezultata dobijenih kvazistatičkim modelovanjem i rezultata dobijenih primenom metode konačnih elemenata.

Analiza statičkog ponašanja radijalnog ležaja 6006 je izvršena za spoljašnje radijalno opterećenje od 1000 do 5000 N, pri čemu su posmatrani ležaji sa radijalnim zazorom 0, 10, 20, 30 i 40 μm. Analizom su obuhvaćeni uticaji kontaktnih deformacija, kontaktnih opterećenja, pomeranja centra ležaja i krutosti, pri delovanju datih opterećenja, u stacionarnom stanju i za brojeve obrtaja od 1000 do 6000 o/min.

Pri definisanju kvazistatičkog modela za određivanje napona i deformacija je korišćena *Hertz-ova* teorija kontakta. Na primer s jedne strane, maksimalni kontaktni naponi između kotrljajnih tela i unutrašnje staze kotrljanja iznose 2852 MPa pri delovanju radijalnog opterećenja od 3000 N, pri čemu maksimalne kontaktne deformacije iznose 13,38 μm. S druge strane maksimalni kontaktni naponi između spoljašnje staze kotrljanja i kotrljajnih tela iznose 2499 MPa i maksimalne kontaktne deformacije 12,96 μm.

Tabela 1. Poređenje kontaktnih napona određenih kvazistatičkim i MKE modelom

Elem. ležaja	Sila [N]	Maks. kontaktni napon [MPa]		Odstupanje [%]
		Kvazistatički model	MKE model	
Un. prsten	1000	1982	2077	-4,57
	2000	2497	2686	-7,04
	3000	2858	2933	-2,56
	4000	3146	3507	-10,29
	5000	3389	3809	-11,03
Sp. prsten	1000	1698	1813	-6,34
	2000	2139	2280	-6,18
	3000	2449	2536	-3,43
	4000	2695	3059	-11,90
	5000	2903	3293	-11,84

Pri modelovanju istog slučaja metodom konačnih elemenata dobijeni su slični rezultati sa odstupanjima od 2% do 8% zavisno od opterećenja. U tabeli 1 su prikazani rezultati modelovanja kontaktnih opterećenja u zavisnosti od spoljašnjeg opterećenja, dok su u tabeli 2

prikazane kontaktne deformacije određene preko razmatranih modela. Rezultati su prikazani za nulti zazor.

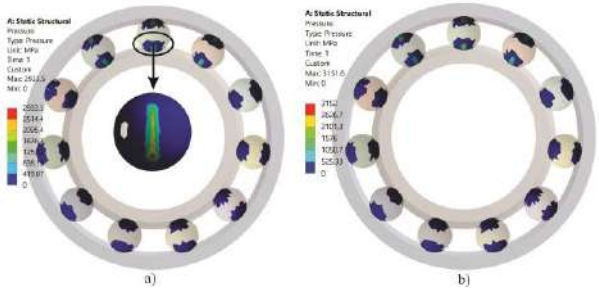
Tabela 2. Poređenje kontaktnih deformacija određenih kvazistatičkim i MKE modelom

Elem. ležaja	Sila [N]	Maks. kontaktne deformacije [μm]		Odstupanje [%]
		Kvazistatički model	MKE model	
Un. prsten	1000	6,43	7,11	-9,56
	2000	10,21	11,35	-10,04
	3000	13,38	14,9	-10,20
	4000	16,21	18,12	-10,54
	5000	18,81	21,08	-10,77
Sp. prsten	1000	6,23	6,86	-9,18
	2000	9,89	11,08	-10,74
	3000	12,96	14,62	-11,35
	4000	15,7	17,66	-11,10
	5000	18,21	20,62	-11,69

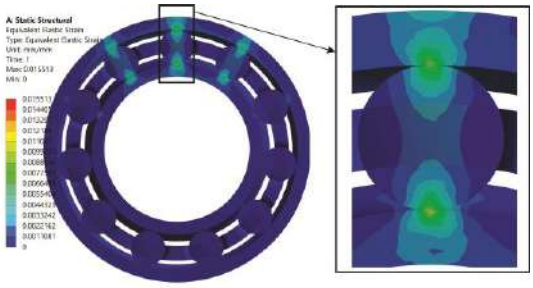
Na slici 2 je prikazana raspodela maksimalnih kontaktnih napona između staza kotrljanja i kotrljajnih tela pri delovanju radijalnog opterećenja od 3000 N za zazor od 0 i 40 μm.

Maksimalni kontaktni naponi se nalaze na kontaktnoj tački između najvišeg kotrljajnog tela i unutrašnje staze kotrljanja, odnosno spoljašnje staze kotrljanja, pri čemu se kontaktno opterećenje smanjuje od vrha prema donjoj polovini ležaja. Razlog ovome leži u činjenici da je prvo (najviše) kotrljajno telo postavljeno odmah iznad linije spoljašnjeg opterećenja ležaja i mnogo je bliže liniji delovanja opterećenja, tako da je kontaktna površina veća. Kontaktni naponi između donjeg dela kotrljanih tela i staza kotrljanja (tela ispod medijalne ravni ležaja) imaju napone jednake nuli. Svaka kontaktna površina između kotrljajnih tela i staza kotrljanja je prikazana u obliku eliptične raspodele, pri čemu se kontaktni naponi postepeno smanjuju od središta kotrljanih tela ka spolja (slika 2a), što je u skladu sa *Hertz-ovom* teorijom kontakta. Kontaktni naponi postoje samo na malom lokalnom području, pa čak i da kontaktni naponi prelaze granicu dozvoljenih napona (4200 MPa), mikroskopske plastične deformacije se javljaju samo u lokalnom području. Kontaktne površine postaju veće nakon plastičnih deformacija i kontaktni napon opada ispod granice tečenja materijala, tako da ni pri većim opterećenjim neće doći do strukturnih oštećenja u kratkom vremenskom periodu, ali pri tome treba imati u vidu da kotrljajna tela povremeno ulaze u zonu opterećenja, pri čemu se kontaktni naponi i deformacije nestabilno (periodično) menjaju tokom vremena.

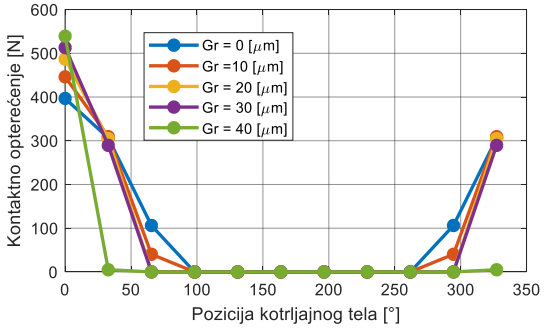
Na slici 3 su prikazane maksimalne elastične deformacije za F_r =3000 N i G_r = 40 μm, gde se vidi da su veća kontaktna pomeranja koncentrisana na gornjem delu unutrašnjeg prstena na mestu gde se javljaju i najveći kontaktni naponi. Najveće pomeranje ležaja iznosi 44 μm, dok najveća elastična deformacija iznosi 15 μm. U konkretnom slučaju, pri delovanju radijalnog opterećenja od 3000 N i radijalnom zazoru od 40 μm, najveće pomeranje se javlja na spoljašnjem prstenu, dok se na najopterećenijem kotrljajnom telu javlja maksimalna elastična deformacija, što je u skladu sa prethodno navedenim činjenicama.



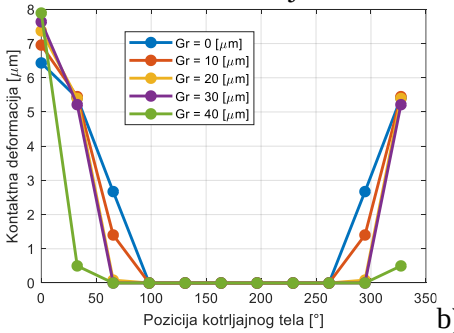
Sl. 2. Raspored maksimalnih kontaktnih napona: a) G_r=0 μm; b) G_r=40 μm



Sl. 3. Raspored maksimalnih elastičnih deformacija na elementima ležaja 6006



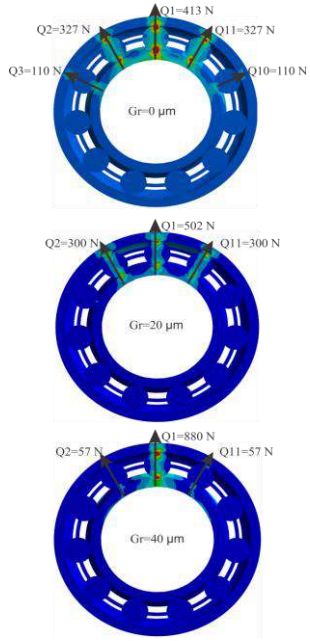
a)



b)

Sl. 4. Promena a) kontaktnih opterećenja; b) kontaktnih deformacija u zavisnosti od zazora za svaku poziciju kotrljajnih tela određenih kvazistatičkim modelom

Na slici 4 i slici 5 su prikazane promene kontaktnih opterećenja i deformacija određenih kvazistatičkim modelom i MKE modelom u zavisnosti od veličine radijalnog zazora pri spoljašnjem opterećenju od F_r=1000 N.



Sl. 5. Promena kontaktnih opterećenja određenih MKE modelom u zavisnosti od zazora

4. DISKUSIJA I ZAKLJUČAK

Unutrašnji radijalni zazor ima značajan uticaj na veličinu kontaktnih deformacija i promenu pomeranja centra ležaja usled ovih deformacija. Pored intenziteta spoljašnjeg opterećenja, na nivo kontaktnih deformacija presudan uticaj ima i broj kotrljajnih tela koja učestvuju u prenošenju spoljašnjeg opterećenja. Sa slike 4*a* i 5 se može videti da opterećenje na mestu najopterećenije kuglice raste, povećanjem zazora, dok se opterećenja na ostalim kotrljajnim telima smanjuju, a samim tim se smanjuje i nivo kontaktnih deformacija istih (slika 4*b*). Naime, kada manji broj kotrljajnih tela učestvuje u prenošenju spoljašnjeg opterećenja, ukupno spoljašnje opterećenje se deli na taj broj kotrljajnih tela. Prema tome, u slučaju maksimalno razmatranog zazora od 40 μm, samo jedno kotrljajno telo prima najveći deo spoljašnjeg opterećenja. Smanjenjem zazora ukupno spoljašnje opterećenje se deli na veći broj kotrljajnih tela, pa se i ravnomernije raspoređuje između njih. Kako radijalni zazor ima direktan uticaj na broj kotrljajnih tela koja učestvuju u prenošenju spoljašnjeg opterećenja, direktno utiče i na veličinu kontaktnih deformacija. Drugim rečima, povećanjem vrednosti radijalnog zazora, potrebno je ostvariti veće kontaktne deformacije elemenata ležaja, pa da *i*-to kotrljajno telo bude u kontaktu sa stazama kotrljanja. Prema tome, za posmatrani ležaj, sa povećanjem broja kotrljajnih tela, koja treba da budu u kontaktu sa stazama kotrljanja, povećava se uticaj radijalnog zazora na veličinu kontaktnih deformacija, koje bi omogućile da veći broj kotrljajnih tela bude u kontaktu sa obe staze kotrljanja. Međutim, za to je potrebno i veće spoljašnje opterećenje, koje ne sme preći vrednosti koje su dozvoljene maksimalnom statičkom i dinamičkom nosivosti ležaja. Broj kotrljajnih tela koja se nalaze u zoni opterećenja određen je odnosom relativnog pomeranja prstenova ležaja, odnosno centra ležaja usled kontaktnih deformacija i polovine radijalnog zazora.

5. REFERENCE

[1] Jones, A.B.: *A general theory for elastically constrained ball and radial roller bearings under arbitrary load and speed conditions,* ASME J.Basic Eng., 82: p.p. 309-320, 1960.

[2] Harris, T.A.: *Rolling bearing analysis,* Fourth edition, John Wiley and Sons, 2001.

[3] Liao, N.T., Lin, J.F.: *A new method for the analysis of deformation and load in a ball bearing with variable contact angle,* J. Mech. Des., 123(2): p.p. 304-312, 2001.

[4] Wang, W., et al.: *Modeling angular contact ball bearing without raceway control hypothesis,* Mechanism and Machine Theory, 82: p.p. 154-172, 2014.

[5] Stribeck, R.: *Ball bearings for various loads.* Trans. ASME, 29: p. p. 420-463, 1907.

[6] Sjovall, H.: *The load distribution within ball and roller bearings under given external radial and axial load,* Tekniks Tidskrift Mek., 1933.

ZAHVALNICA

Ovaj rad je podržan od stane Ministarstva prosvete, nauke i tehnološkog razvoja kroz projekat broj 451-03-9/2021-14/ 200156 "Inovativna naučna i umetnička istraživanja iz domena delatnosti FTN-a".

Autori: **dr Mirjana Bojanić Šejat, dr asis., dr Ivan Knežević, dr asis., Vanr. prof. dr Aleksandar Živković, Vanr. prof. dr Milan Rackov, Vanr. prof. dr Vojin Ilić,** Univerzitet Novi Sad, Fakultet Tehničkih Nauka, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2350, Fax: +381 21 454-495.

E-mail: bojanicm@uns.ac.rs
ivanknezevic@uns.ac.rs
acoz@uns.ac.rs
racmil@uns.ac.rs
vojin@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Karabegović, I., Husak,E., Karabegović, E., Mahmić, M.

IMPLEMENTATION OF INDUSTRY 4.0 - ROBOTIC TECHNOLOGY IN PRODUCTION PROCESSES: A REVIEW OF WELDING PROCESSES IN THE WORLD

Abstract: *The implementation of Industry 4.0 in all production processes is ongoing worldwide. The implementation of industrial robots in the production processes of the automotive industry, where they are mostly used, has been accelerated. Robotic technology is the core technology of Industry 4.0, because without its implementation, the implementation of Industry 4.0 would not be possible. Most industrial robots are implemented in welding processes in the automotive industry. The paper analyzes the ways to improve welding production processes by implementing second-generation industrial robots. New generation robots have advantages over first-generation industrial robots such as: working together with workers, workers perform their tasks in a safe environment, robots take up less space, robots do not need to be separated by fences, robots are easy to manipulate and cheaper to implement. The paper shows the trend of application of industrial robots in the world, with reference to implementation in welding production processes. An analysis of the implementation of industrial robots in ten top countries in the world was conducted, as well as the implementation of industrial robots in ten top countries per 10.000 employees in the automotive industry. The trend of application of new generation robots will have a growing character in the future, because the goals of the fourth industrial revolution cannot be achieved without collaborative robots. In other words,the aim is to achieve the ''smart production process'' or ''smart factory''.*

Keywords:*Industry 4.0, industrial robot, production process, welding process, intelligent automation*

1. INTRODUCTION

Modernization and automation of production processes in industry has begun in the 1960s when industrial robots were introduced in modernization and automation, and continues to this day. At that time, automation was welcomed, but from today's point of view, we must admit that this was rigid, not flexible, automation *(Karabegović et al., 2021,Schwab, 2016).* The reason for inflexibility lies in the fact that in order to manufacture another product, especially in the automotive industry where rapid changes are necessary, we needed to reprogram each industrial robot with its arms, change tools, etc., which causes a production delay that could last a long time and represent additional costs *(Zheng et al., 2018, Karabegović et al.,2020)* . Today, a production process would be inconceivable without modernization and automation, i.e., the application of industrial and service robots. The reason is very clear, because we have a continuous growth of production in the automotive industry, and in addition we often have to make changes in terms of product diversity. In the last 20 years, there has been a rapid development of new technologies such as robotic technology, digital technology, sensor technology, information technology, etc., which are being implemented in production processes. We are currently at the beginning of the fourth industrial revolution (Industry 4.0), because many industrial development strategies of technologically advanced countries in the world advocate the transformation of industrial production through the implementation of advanced technologies. Industry 4.0 creates radical new approaches in the production processes, through communication between the devices in the production process and the implementation of a large number of sensors that provide data necessary for decision-making, which, for example, gives the automotive industry great advantages. The linking of digital technologies with other advanced technologies will transform production processes in industrial production due to the fact that the price of these technologies is continuously declining in the market and they are becoming increasingly prevalent in production processes. Another reason is that ICT technologies are implemented with other technologies and enable digital transformation of production processes *(Karabegović, 2016, Crnja, et al.,2017, Karabegović, et al., 2017, Zhu,et al.,2011, Meniere, et al.,2017,Pelster & Schwartz, 2017).* When it comes to the transformation of production

processes in the automotive industry, it is impossible to imagine its developmentwithout the inclusion of robotics, digital, sensor technology and information technology that will enable networking. High flexibility of the production process in the automotive industry is necessary to reduce the vehicle production time, because today vehicles have a shorter lifespan and larger variants. In order to meet these requirements, we have introduced collaborative robots into production processes that have the ability to work side by side with workers. New generations of industrial robots compared to first-generation industrial robots have many advantages such as: during the production process industrial robots do not have to be separated from workers (today they work together with workers), they are light and flexible so they can be easily moved and equally easily and simply reprogrammed to perform new tasks. With these robots, automation becomes easier, flexible, cheaper and leads to ‘’smart automation’’. So far, automation has been too complex and expensive, as the installation of one industrial robot costs about two years’salary of one worker, and the use of a collaborative robot about half the annual salary. In many industries, there is a public fear that by applying robots, workers will lose their jobs, which is quite contrary to the reality. The use of robots and automation is necessary. Robots are used to improve the quality of work, to take on dangerous, dirty and boring jobs that man is unable to perform due to health problems or due to complexity that require flexibility, precision and reliability that man does not have *(Karabegović, et al.,2020,Thobe, et al.,2017, Mathieu, 2017)*. The development of new technologies, new methods and innovations, as well as advances in industrial production resulting from these trends, present new challenges for the robotics industry By implementing the second-generation robots or collaborative robots, we increase the reliability of the production process, reduce the production time of the finished product, and increase the precision and adaptability that exceeds human capabilities *(Karabegović, et al.,2019)*.The implementation of Industry 4.0 is constantly increasing, especially in the automotive industry, which indicates competition between car companies. This is to be expected as the implementation of industrial robots in the production processes of the automotive industry, as well as other industries, will continue to grow.

2. IMPLEMENTATION OF INDUSTRY 4.0 AND ITS ADVANTAGES

Industry 3.0 is followed by the Industry 4.0. The difference between these two industrial revolutions is reflected in the following: production processes in the third industrial revolution include manual labour in automated production, while in the fourth industrial revolution (Industry 4.0) intellectual labour and automatic design are used instead of physical labour (Figure 1). Between these two industrial revolutions, there has been an increase in applied innovations in computer hardware, software, operating technologies and information technologies that are becoming more sophisticated and integrated, leading to the transformation of society as a whole and into a global economy *(Karabegović, et al.,2020, Karabegović, 2016, Crnja, et al.,2017, Karabegović, et al.,2017,Tao, et al.,2019)*.

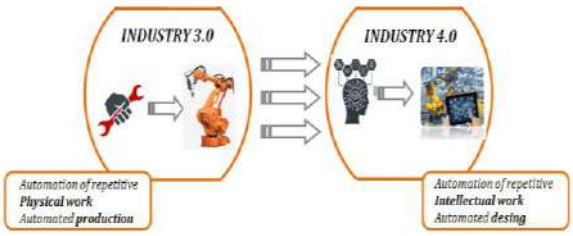


Fig. 1. Advantages of Industry 4.0 over Industry 3.0

The Industry 4.0 platform has one common goal which is to match supply and demand in a very affordable way by providing the customer with a wide range of products with both parties interacting. The linking of digital technologies with other advanced technologies will transform the production processes in industrial production due to the fact that the price of this technology is continuously declining in the market, thus making it increasingly prevalent in production processes. We must note that robots are not intended to completely replace workers, but rather to work with them and remove the fences in the production processes, which currently exist to enclose the first-generation industrial robots, as shown in Figure 2. *(Karabegović, et al.,2020,Karabegović, et al.,2029, Karabegović, 2020, Karabegović & Husak, 2014)*.

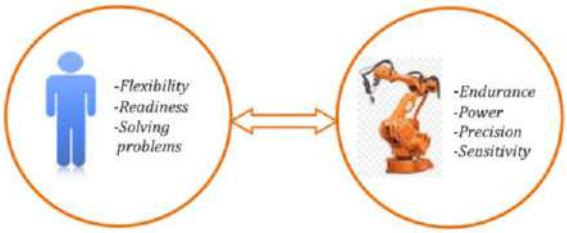


Fig. 2. Advantages and disadvantages between worker and industrial robot *(Karabegović, et al.,2017, Tao, et al.,2019)*

Workers can work in various fields, and perform very complex operations and analytical tasks. On the other hand, collaborative robot is easy to work with, performs monotonous repetitive operations, can handle dangerous matter, as well as lift heavy objects. The differences between workers and robots are shown in Figure 2. The implementation of the basic technologies of Industry 4.0 is increasing, as shown in Figure 3, which requires flexible automation in all industries as well as reducing the time of production and sale of finished products with continuous high quality *(Karabegović, et al.,2021, Kusmin,2016,Bechtold, et al., 2017, Daviesm, 2015, Bunse, et al., 2017).*

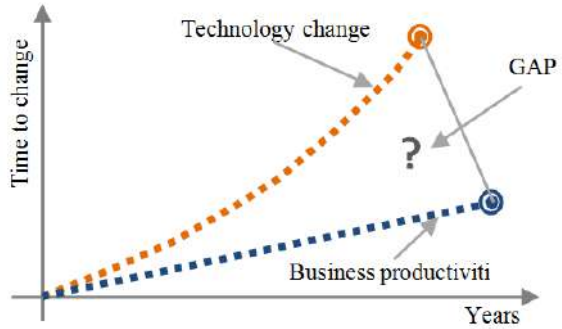


Fig. 3. Implementation of Industry 4.0 is making technological changes

With the Industry 4.0 application in production processes, we have technological improvements in flexibility, accuracy, security and simplification of the use of new technologies. Technological changes occur by the exponential function, while business productivity takes place by a linear function, as shown in figures. There is a gap between technological change and business productivity, which can remove human potential.

3. IMPLEMENTATION OF INDUSTRIAL ROBOTS IN THE WORLD, WITH REFERENCE TO THE IMPLEMENTATION IN WELDING PROCESSES

The trend of application of industrial robots on annual level is shown in Figure 4. The statistical data were taken from the International Federation of Robotics (IFR), the United Nations Economic Commission for Europe (UNECE) and the Organization for Economic Cooperation and Development (OECD) *(World Robotics 2020, World Robotics 2019, World Robotics 2018, World Robotics 2010, World Robotics 2009).* Based on the trend of application of industrial robots in the period 2009-2019 shown in Figure 4, we can conclude that it has the growing character, with 60.000 robot units applied in 2009 (the year of the global economic crisis) and increasing every year until 2018.

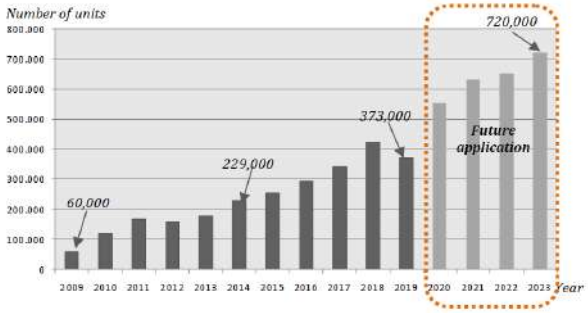


Fig. 4. Application of industrial robots in the world on annual basis in the period 2009-2019, with estimates of implementation by 2023

In 2019, slightly fewer industrial robots were applied compared to 2018, which still amounted to 373.000 robot units. The reason for the decline in application in 2019 is the corona virus pandemic that has struck the world. It is estimated that the growing trend will continue until 2023, where it will amount to 720.000 robot units.

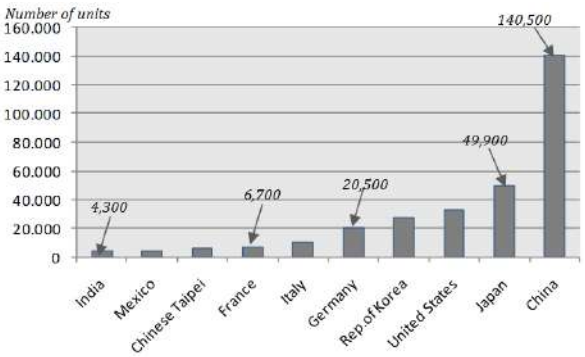


Fig. 5. Application of industrial robots in ten top countries in the world in 2019 *(World Robotics 2020)*

In order to understand the trend of application of industrial robots in the world by country, we have presented data for 2019 in which 373.000 robot units were applied, including data for top ten countries in the world with the largest number of applied industrial robots (Figure 5). We came to

the conclusion that China holds the first place with 140.500 applied industrial robots. This trend is expected for two reasons, the first being that China has developed a strategy called ‘’Made in China 2025’’ which aims to position the country as the technologically most advanced country. The second reason is the fact that China produces 27.80% of total cars produced in the world,and industrial robots are most widely used in the automotive industry. 91.7 million vehicles were produced worldwide in 2019, (less than in 2018, when 95.6 million vehicles were produced, due to the global corona virus pandemic). China has produced 25.7 million vehicles, while Japan produced 9.7 million vehicles or 10.57% of world vehicle production *(Production-statistic/2019)*.

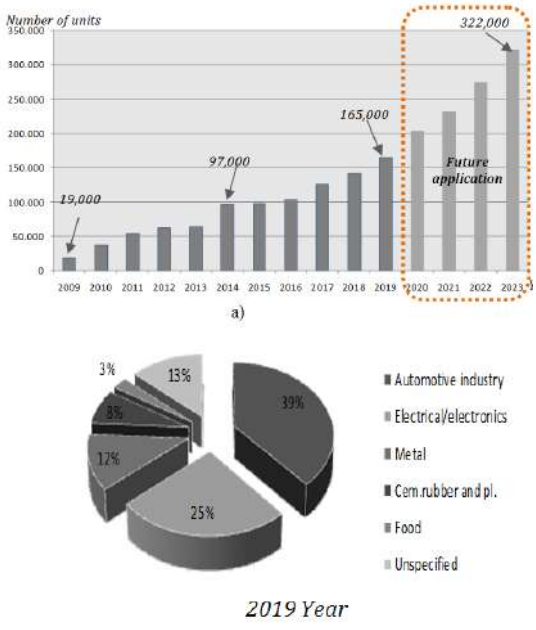


Fig. 6. Application of industrial robots in the world in the automotive industry:
a – annually in the period 2009-2019, with estimates of implementation by 2023;
b – percentage share of robot applications in industrial branches for 2019
(World Robotics 2020, World Robotics 2019, World Robotics 2018, World Robotics 2010, World Robotics 2009)

Figure 5 shows that 49.900 industrial robot units were installed in Japan that year, which places Japan as the second in the world. 20.500 robot units have been used in Germany, whereas India holds the tenth place with 4.300 robot units installed. The top ten countries in terms of application of industrial robots include the countries in which the automotive industry is highly developed or is developing (Karabegović, 2020, Thobe, et al.,2017,Karabegović & Husak, 2018). With the aim of confirming this conclusion, a trend of application of industrial robots in the world in the automotive industry is presented, as well as in welding processes where industrial robots are most represented,and shown in Figure 6 and Figure 7. (Karabegović, et al.,2012).

The trend of application of industrial robots in the automotive industry is growing every year, and from 19.000 robot units applied in 2009 it reached the value of 165.000 robot units in 2019. A growing trend is estimated to continue in the future, so that in 2023 the use of about 322.000 robot units is expected (Figure 6.a). Based on Figure 6.b), we can conclude that out of the total amount of applied industrial robots in the world in 2019, the largest application was recorded in the automotive industry with 39%, followed by the electronics industry with 25%.

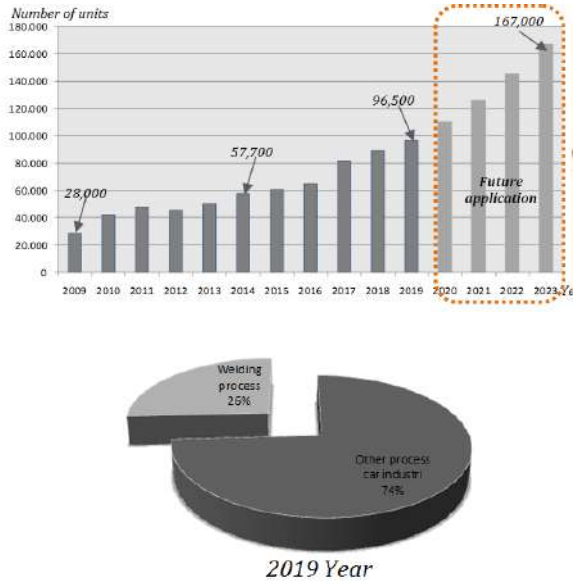


Fig. 7. Application of industrial robots in the world in welding processes on an annual basis in the period 2009-2019, with estimates of application by 2023 *(World Robotics 2020, World Robotics 2019, World Robotics 2018, World Robotics 2010, World Robotics 2009)*

The application of industrial robots in the welding process (Figure 7) is continuously increasing on annual basis, so that 28.000 robot units were appliedin 2009, while 96.500 industrial robot units were applied in 2019. Of the total number of 373.000 robot units applied in 2019, only 96.500 robot units were applied in welding processes or 25.87%, as shown in Figure 7. It is estimated that the growing trend will continue in the coming years so that 167.000 industrial robot units are predicted to be appliedin 2023. The extent to which production processes are automated in one country is provided by data on the density of industrial robots per 10.000

employees in industrial production. The trend of robot density in the top ten countries is shown in Figure 8. We can see that the top countries include: Singapore, Republic of Korea, Japan, Germany, Sweden, Denmark, Hong Kong, Chinese Taipei, United States and Italy. The first place in 2019 is held by Singapore with 918 robot units per 10.000 employees in production processes.

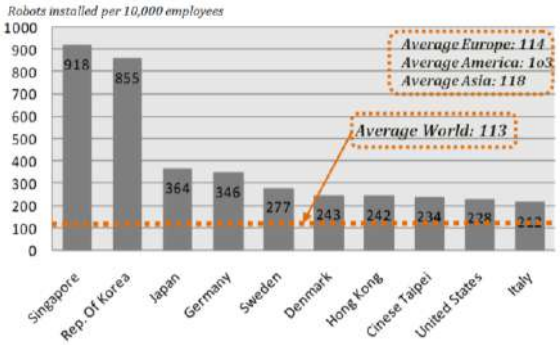


Fig. 8. Robot density in the manufacturing industry per 10.000 employees in the top ten countries in the world for 2019 *(World Robotics 2020)*

The second place is held by Republic of Korea with 855 robot units. Singapore came to the lead in 2019 instead of Republic of Korea which has been in the first place for years. The reason is that Singapore is a small country with a very small number of employees in the manufacturing industry, which according to statistics is about 240.000 people. Of the European countries, the top countries are Germany with 346 robot units, followed by Sweden with 277, Denmark with 243 and Italy in tenth place with 212 robot units per 10.000 employees in the manufacturing industry. As can be seen, the top ten countries are industrially developed countries and countries with the developed automotive industry. With the implementation of Industry 4.0, there is a greater implementation of industrial robots and second-generation industrial robots – collaborative robots.

4. IMPLEMENTATION OF SECOND-GENERATION INDUSTRIAL ROBOTS - COLLABORATIVE ROBOTS AND THEIR ADVANTAGES

Collaborative robots in the robotic industry are currently the top subject of research in the world. The aim is to create safe environment for workers so that they can work together with robots, which will help them in performing their daily tasks without any risk *(Ecker,2015, Ostrgaard,2015, Karabegović & Karabegović, 2020)*. The challenges of the development of robotic technology from the first-generation industrial robots to the second-generation industrial robots – collaborative robots lie in three directions, i.e., three technical areas, as shown in Figure 9.

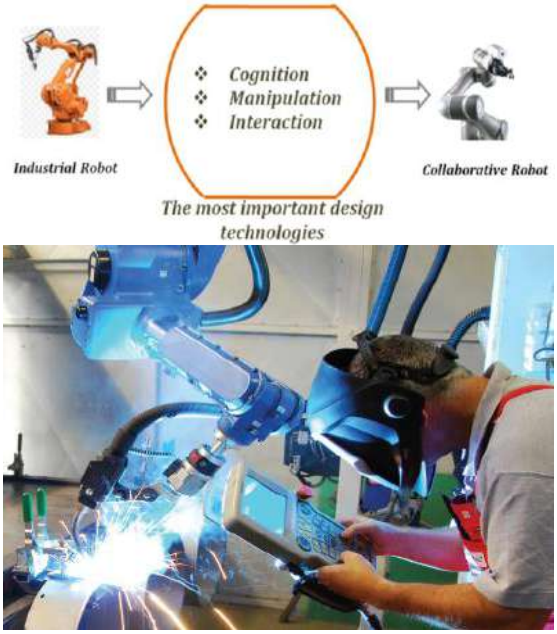


Fig. 9. The most important technologies for shaping the future capabilities of collaborative robots *(Franklin, 2017)*

The first technical area is understanding that gives the robot the ability to perceive, understand, plan, and move in the real world. This feature improves cognitive abilities of the robot so that it can work independently in various complex environments. The second technical area is manipulation, which gives the robot precise control and readiness to manipulate objects in its environment. In this way, we have a significant improvement in robot control, which allows the robot to take on a greater variety in performing tasks in different production processes.

The third technical area is interaction, which is one of the most important areas, because it gives robots the opportunity to learn and cooperate with people. Furthermore, this implies improving robot-human interaction, for both verbal and nonverbal communication. The robot has the ability to observe and copy human behavior and learn from experience. The absolute condition for robots to work with people in a disordered environment is safety, which should come first. Digital technology with information and communication technologies, together with microelectronics, sensors, drives and landline and wireless networks enables machine to machine communication *(Karabegović, et al.,2019, Ostrgaard, 2015, Baupre, 2015)*. This digital interaction between and within machines and

systems is the heart of the fourth industrial revolution - Industry 4.0. Collaborative robots are already present in production processes and their implementation increases every year, as shown in Figure 10. *(World Robotics, 2020).*

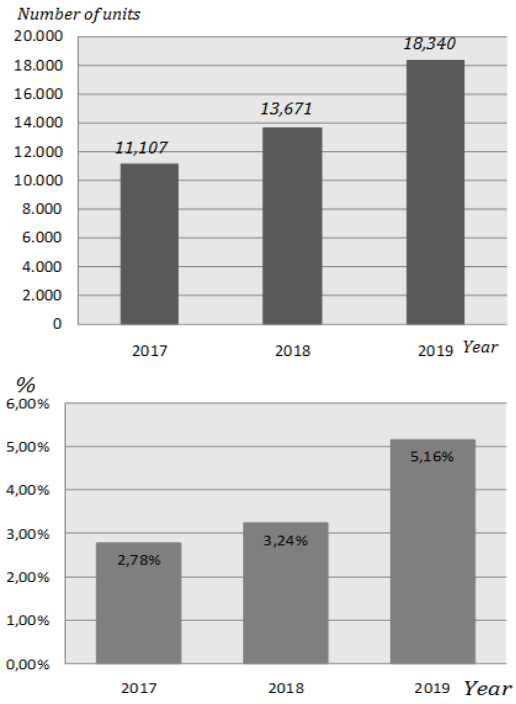


Fig. 10. Implementation of collaborative robots in production processes in the world for the period 2017-2019

Second-generation industrial robots – collaborative robots are already taking their place in production processes, as shown in the diagrams in Figure 10. In 2017, 11.107 collaborative robot units were applied worldwide, which equals to 2.78 % of the total amount of applied industrial robots in 2017 in the world. The percentage is rather small, but expected since it was only the beginning of their application. The application trend is continuously increasing, so that 18.340 robot units were appliedin 2019 or 5.16 % of the total application. The implementation of Industry 4.0 will lead to an exponential function of the application of collaborative robots, because production processes are expected to be fully automated, flexible, cheap, which is enabled by the use of collaborative robots *(Karabegović, et al.,2019, Karabegović & Karabegović,2020, Franklin, 2017).*

The advantages of the application of collaborative robots are huge, to name just a few:

- Safe work in the robot workspace (joint work of robots and workers),
- Collaborative robots are characterized by simple and manageable tasks for handling,
- The use of collaborative robots enables us to significantly improve performance in the division of operations between workers and robots,
- By using collaborative robots, we have the possibility of different levels of automation in the production process, so we can partially automate tasks in those cases when full automation is too complex or not economical,
- Non-ergonomic workstations can be significantly improved with the help of collaborative robots, and we must keep in mind that worker safety is an absolute prerequisite,
- Collaborative robots have the most significant role in Industry 4.0, which connects the real-life factory with virtual reality, and opens future perspectives in global production,
- Reducing product lifecycle and increasing product diversity requires automation flexibility, which will result in increased use of collaborative robots. However, simplification such as ready-to-use applications are becoming increasingly popular with customers which will result in increased use of collaborative robots in small and medium companies.

The basis for the implementation of ‘’Industry 4.0’’ is robotic technology, i.e., the implementation of collaborative robots in production processes. In order for the company to be competitive in the global market, it is inevitable that it will follow the direction of the implementation of ‘’Industry 4.0’’, which will result in an increase in the use of collaborative robots. When using collaborative robots, companies have the following motives: reducing operating costs, reducing capital costs, improving product quality and consistency, improving the quality of work for employees, respecting health and safety rules, increasing production rates, increasing flexibility in production, saving space, etc. It is expected that in the future the trend of application of collaborative robots will be growing, i.e., it will completely replace the first-generation industrial robots.

5. CONCLUSION

Global competition requires continuous modernization of production facilities. In order for companies to be competitive, they must have fast production and delivery of customized products at competitive prices, which become the incentives for production automation, because only the

automation of production processes allows the manufacturer to continue production. Automation of production processes would not be possible without the implementation of industrial robots. As we have seen, the trend of application of industrial robots is constantly increasing on annual basis, and the use of industrial robots is expected to increase in the coming years. The largest implementation of industrial robots is recorded in the automotive industry with between 30-40 % of the total application in the world. The welding production process holds the first place in the implementation of industrial robots with between 25-30% of the total installed robots in the world. The development of Industry 4.0 core technologies, the leading one being the robotic technology, has contributed to the implementation of Industry 4.0 in production processes in the world. In other words, there is a digitalization of production that connects the real-life factory with virtual reality. We can conclude that robotic technology will play an increasingly important role in global production. The range of industrial robots continues to expand. The positions in the production processes are occupied by collaborative robots that can safely work together with humans, they can be fully integrated and easy to program, they are easy to integrate and give a wide advantage for process optimization. They can easily adjust their parameters to the real-timeconditions, reduce the risk of failures, and enable the improvement of the production processquality. The very integration of industrial robots gives workers the opportunity to move on to more skilled tasks such as production planning and supervision.

6. REFERENCE

[1] Karabegović, I., Karabegović E., Mahmić, M., Husak, E., *The Implementation of Industry 4.0 by Using Industrial and Service Robots in the Production Processe*s, Research Anthology on Cross-Industry Challenges of Industry 4.0, IGI Global, Hershey, Pennsylvania, USA, 2020,pp.656-683

[2] Schwab, K., *The Fourth Industrial Revolution*, World Economic Forum, Geneva, Switzerland, 2016.

[3] Zheng, P., Wang, H., Sang, Z., Zhong, RY., Liu, Y., Liu, C., et al. *Smart manufacturing systems for Industry 4.0: conceptual framework, scenarios, and future perspectives*. Front Mech. Eng. 2018;13(2):pp.137–50.

[4] Karabegović, I., Kovačević, A.. Banjanović-Mehmedović, L., Dašić P., *Handbook of Research on Integration Industry 4.0 in Business and Manufacturing*, IGI Global, Hershey, Pennsylvania, USA, 2020.

[5] Karabegović I., *Role of Industrial Robots in the Development of Automotive Industry in China*, International Journal of Engineering Works, Kambohwell Publisher Enterprises, Multan, Vol.3., Iss.12., Pakistan, 2016, pp:92-97.

[6] Crnjac, M., Veža, I., Banduka, N., *From Concept to the Introduction of Industry 4.0*, International Journal of Industrial Engineering and Management (IJIEM), Vol. 8 No 1, 2017, pp. 21-30.

[7] Karabegović, I., Karabegović, E., Mahmić, M., Husak, E., *Contribution of Fourth Industrial Revolution to Production Processes in China*, 1st International Conference "Engineering and Entrepreneurship", ICEE-2017, 17-18 November 2017, Tirana, Albania, Proceedinga Book, pp.295-301.

[8] Tao , F., Qi , Q., Wang, L., Nee, A.Y.C., *Digital Twins and Cyber–Physical Systems toward Smart Manufacturing and Industry 4.0: Correlation and Comparison*, Published by Elsevier LTD on behalf of Chinese Academy of Engineering and Higher Education Press Limited Company,Engineering 5, 2019 pp.653–661.,

[9] Karabegović , I., Karabegović, E., Mahmić, M., Husak, E., *The role of smart sensors in production processes and implementation of Industry 4.0*, Journal of Engineering Sciences, Vol. 6(2), 2019. pp.B8-B13.

[10] Karabegović, E., *Implementation of Industry 4.0 and Robots in Production Processes of the Metal Industry*, International Journal of Advanced Engineering Research and Science (IJAERS), Vol-7.Issue-1,2020,

[11] Thobe,K-D., Wiesner, S.A.,Wuest T., *Industrie 4.0" and Smart Manufacturing – A Review of Research Issues and Application Examples*, International Journal of Automation Technology 11(1):4-19.,

[12] Karabegović, I., Husak, E., *Significance od industrial robots in development of automobile industry in Europeand the World*, Journal Mobility and Vehicle. University of Kragujevac, Fakulty of Engineering, Kragujevac, Serbia,2014; 40(1): 7-16.

[13] Zhu, Q., Rieger, C., Bas,_ar T., *A hierarchical security architecture for cyber–physical systems*. In: Proceedings of the 4th IEEE International Symposium on Resilient Control Systems (ISRCS); 2011 Aug 9–11; Boise, ID, USA. Washington, DC: IEEE; 2011. p. 15–20.

[14] Karabegović, I.**,** Karabegović, E., Pašić, S., Isić, S., *World wide Trend of the Industrial Robot Applications in the Welding Processes*. International Journal of Engineering and Technology, IJET-IJENS 2012; 12(1): 69-74.

[15] Meniere, Y., Rudyk, I., Valdes, J., *Patents and the Fourth Industrial Revolution*, European patent Office,Munich, Germany, 2017,

[16] Pelster, B., Schwartz, J., (Ed.), *Rewriting the rules for the digital age*, Deloitte Global Human Capital Trends, Deloitte University Press, 2017.

[17] Mathieu, d'A., *Data analytics beyond data processing and how it affects Industry 4.0, Insight Centre for Data Analytic, Dublin, Irska*, 2017.

[18] Karabegović, I., Husak, E., *Industry 4.0 based on industrial and service robots with application in China***,** Journal Mobility and Vehicle Mechanics, v**o**l. 44, no. 4, pp. 59-71, 2018**.**

[19] Kusmin, K.-L., *Industry 4.0 Analytical Article*,IFI8101 - Information Society Approaches and ICT Processes, School of Digital Technologies, Tallinn University, Estonia, 2016.

[20] Bechtold, J., Lauenstein, C., Kern, A., Bernhofer, L., Executive Summary: *The Capgemini Consulting Industry 4.0 Framework*, Capgemini Consulting, Pariz, France, 2017.

[21] Daviesm R., *Industry 4.0: Digitalisation for productivity and growth*, 2015.

[22] Bunse, B., Kagermann, H., Wahlster, W., *Smart Manufacturing for the Future*, Germany Trade & Invest,Berlin,Germany, 2017, pp. 12-24.

[23] World Robotics 2020, *The International Federation of Robotics*, Statistical Department, Frankfurt am Main, Germany, 2020

[24] World Robotics 2019, *The International Federation of Robotics*, Statistical Department, Frankfurt am Main, Germany, 2019

[25] World Robotics 2018, *The International Federation of Robotics*, Statistical Department, Frankfurt am Main, Germany,2018

[26] World Robotics 2010, *The International Federation of Robotics*, Statistical Department, Frankfurt am Main, Germany,2010

[27] World Robotics 2009, *The International Federation of Robotics*, Statistical Department, Frankfurt am Main, Germany, 2009

[28] Karabegović, E., Karabegović, I., Husak, E., *Collaborative Robots Innovate Automation in metal and Car Industry in the World*, Journal of Scientific and Energeering Research,Vol. 6. No.8., 2019, pp.136-145.

[29] Ecker, C., *Advantages and Challenges for Small manufactureres*, Internationa Collaborative Robots,Workshop, Columbia, 2015.

[30] Ostrgaard, E., Collaborative Robot Technology and Applications, *International Collaborative Robots*, Workshop, Columbia, 7. October 2015.

[31] Karabegović, I., Karabegović E., *Increased worker safety through the use of collaborative robots in the production processes of Industry 4.0*,Journal SAFETY: journal for safety in the work and living environment**,** Vol. 62 No. 1, 11-18, 2020.

[32] Beaupre, M., *Collaborative Robot Technology and Applications*, International Collaborative Robots, Workshop, Columbia, 7. October 2015.

[33] Matthias, B., *Industrial Safety Requirements for Collaborative Robots and Applications*, Worksplace Safety in Industrial Robotics: Trends, integration and standarde ERF, Columbia,1. October 2014.

[34] https://www.oica.net/category/production-statistics/2019-statistics/, 2.07.2021.

[35] Franklin, C., *Technology enables humans and robots to work together*,,10.07.2021.

Autori: **Akademik [1]Isak Karabegović, Prof. dr. [2]Ermin Husak, Prof. dr. [2]Edina Karabegović, Prof. dr. [2]Mehmed Mahmić,** [1]Academy of Sciences and Arts of Bosnia and Herzegovina, Bistrik 7, 71000 Sarajevo, Bosnia and Herzegovina,Univesity of Bihać, Technical faculty Bihać, Ul.Irfana Ljubijankića bb, 77000 Bihać, Bosnia and Herzegovina Tel: +381 61 138 856, Fax: +381 37 226-273.
E-mail: isak1910@hotmail.com
erminhusak@yahoo.com
edina-karabeg@hotmail.com
mmahmić@gmail.com

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE**
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Kosec, P.D., Bernetič, J., Kosec, G., Burzić, Z., Nagode, A. Soković, M., Kosec, B.

HEAT TREATMENT AND CHARACTERIZATION OF ARMOUR STEEL OF NEW GENERATION

Abstract: *Steel armour plates are intended for ballistic protection of military and civilian vehicles and structures, parts of machines and devices.*
The work includes heat treatment and characterization of mechanical, microstructural and thermal properties of new steel for ballistic protection with internal code SA600. Steel is the result of the development and knowledge of firm SAAT, d.o.o. in collaboration with scientific institutions and industry partners, produced in an industrial environment.
The results of the research carried out as part of the investigation confirmed that the optimal austenitization temperature for SA600 steel is 870 °C and the tempering temperature is 150 °C. Under these conditions, the hardness of the steel is 632 HV10, which means that it is suitably high. The yield strength is 1640 MPa and the tensile strength is 2052 MPa. The $Rp_{0,2}$/Rm ratio is equal to 0.7992 and is correspondingly low. The thermal conductivity increases with temperature and is equal to 28.33 W/m·K at room temperature, and 39.67 W/m·K at 400 °C.
Key words: *steel, armour protection, heat treatment, characterization, production, testing, properties*

1. INTRODUCTION

Steel armour plates are intended for ballistic protection of military and civilian vehicles and structures, parts of machines and devices. When selecting or developing the appropriate materials for the armour it is necessary to achieve the best possible compromise between the required mechanical properties of materials, its density and the final price of the product [1]. With the appropriate production technology, which includes synthesis, hot forming, heat treatment, etc. [2], high strength low alloy steel of good functional properties at affordable prices can be produced. By improving the strength and toughness of the steel, the required thickness and the weight of the armour can be reduced.

New steel for ballistic protection with internal code SA600 belongs to the group of high strength low alloy (HSLA) steels [3]. Steel is the result of the development and knowledge of SAAT, d.o.o. in collaboration with scientific institutions and industry partners, produced in an industrial environment of VOEST Alpine GmbH.

Table 1 shows the mass percentages of the elements that make up SA600 steel in addition to iron. The optimal chemical composition enables the achievement of the desired mechanical and physical properties and the planned microstructure.

The relevant mechanical properties are achieved by quenching and tempering [4].

The first and most important purpose of SA600 steel is resistance to the penetration of projectiles from small arms. The resistance depends mainly on the following mechanical properties: hardness, yield strength, tensile strength, plastic deformation capabilities, impact and fracture toughness, and stretching [5].

Table 1. Indicative chemical composition of SA600 steel (in m.%)

C	0.43
Si	0.80
Mn	0.70
Cr	0.80
Ni	0.30
P	0.015
S	0.003
B	0.005
Fe	rest

With the alloying elements silicon, chromium, molybdenum and boron, the appropriate manufacturing technology and heat treatment, all the desired mechanical properties can be achieved.

Table 2. Mechanical properties of SA600 steel

Hardness	590 – 640 HB
Yield strength	1600 MPa
Tensile strength	2050 MPa
Elongation	7.5 %
Impact toughness (at -40°C)	15 J

Table 2 shows the approximate values of the mechanical properties of SA600 sheet steel.

2. EXPERIMENTAL WORK

The experimental work includes heat treatment and characterization of mechanical, microstructural and thermal properties of new steel for ballistic protection with internal code SA600. In Figure 1 is testing SA600 steel plate from which samples were cut to perform heat treatment, mechanical tests, microstructure analysis and thermal properties description.

Fig. 1. Testing SA600 steel plate.

As part of the research (at the Faculty of Mechanical Engineering, University of Ljubljana and in SIJ ACRONI, d.o.o.), we first cut samples from the supplied plates with a water jet for heat treatment and investigations of microstructure and mechanical properties (Figure 2).

Fig. 2. Water jet cutting machine Water Jet NC 2525 D in SIJ ACRONI d.o.o.

We performed heat treatment of SA600 steel in the delivered state, which consisted of hardening and tempering.

Based on experience and previous preliminary research, we determined a temperature of 870 °C for the optimal austenitization temperature, i.e. the temperature at which the original crystal grains of austenite do not grow more noticeably, and at which high hardness is obtained after quenching. The easing was performed at temperatures of 150, 200, 300 and 400 °C

In the Metallographic Laboratory of the Department of Engineering Materials, Faculty of Natural Sciences and Engineering, University of Ljubljana, samples cut from SA600 steel in the supplied and heat treated state were examined and analyzed with an OLYMPUS BX61 optical microscope, and a scanning electron field emission microscope Thermofischer Quattro S (Figure 3). We focused on the microstructural characterization of steel in the delivered state and after heat treatment.

Fig. 3. Scanning electron field emission microscope Thermofischer Quattro S.

For the optimal austenitization temperature 870 °C was determined, i.e. the temperature at which the original austenite crystal grains do not yet grow more noticeably and at which high hardness is obtained after quenching. When examining the microstructure, the size of the original austenite crystal grains was measured. The grains grow more noticeably at temperatures above 870 °C (Figure 4).

Fig. 4. Microstructure of SA600 steel hardened from 870 °C; magn. 500x (OM).

Figure 5 shows the microstructure after tempering at 150 °C. At this tempering temperature, the first stage of tempering takes place, which involves the elimination of i.e. transition ε-carbides of formula $Fe_{2,4}C$. Elimination takes place by lowering the carbon content of martensite to form low-carbon martensite. In Figure 5, these carbides are very fine and in the form of thin needles. At this magnification, they are

barely noticeable. They are excreted on the cubic planes of the martensite nut and on dislocations.

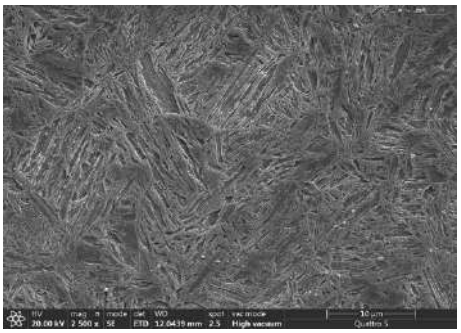


Fig. 5. Microstructure of SA600 steel, hardened at 870 °C and tempered at 150 °C/ 1h; etched with Nital, (SEM).

Hardness was measured on all four samples after heat treatment and the sample immediately after the first phase of heat treatment - quenching. Hardness measurements were performed with an instrument dynaTESTOR 10. We used a load of 100 N. Hardness with tempering temperature decreases from initial (immediately after quenching) hardness of 671 HV, to 632 HV at tempering at 150 °C / 1 h and up to 455 HV at tempering at 400 °C / 1 h.

Based on the results of hardness measurements, the temperature of 150 °C was chosen as the optimal temperature for the tempering.

The tensile test was performed on a universal tensile / pressure tearing machine INSTRON 1255 in accordance with ISO 6892-1: 2009 [6].

sij acroni

SIJ ACRONI d.o.o. - Služba Kakovost
Cesta Borisa Kidriča 44 SI - 4270 Jesenice
T: +386 4 584 1[illegible] F: +386 4 584 1[illegible]
E: [illegible]@acroni.si

Poročilo o Nateznem Preizkusu / Test report

Obrazec/Form	:	OB 10.25.04a(14)	Vrsta vz./Spec type	:	Prop. type D
Št./No.	:	AHP_EN_BPC-F0600_2019-08-02_29642	Test Standard	:	SIST EN ISO 6892-1:2017 E
Dat. Prevzema	:	24.1.20[illegible]	Temp./Test temp.	:	Sobna/Room
Nar./Custom.	:	Predelava Debele Plocevine	E-Modulus speed	:	60 MPa/s
Stroj/Mechine	:	BPC-F0600.R09	Yeld point speed/hit. do ReH	:	60 MPa/s
		S. št.171877-2006	Yeld range speed/hit. ReH-ReL	:	0,0025 1/s
Merilo/Measure	:	Klj. mer.7001398	Test speed/ hit. pr.	:	0,008 1/s
			Automatic force zeroing	:	Yes
			Calc. of str. Ax to ISO 2566- 1/2	:	Yes

LOT	Vzorec	Material	Dn mm	a_0 mm	b_0 mm	L_0 mm	Rp0,2 MPa	Rp1,0 MPa	ReH MPa	Rm MPa	$A_{g,ss}$ %	A50 %	Z %
[illegible]		600	9,50	9,8	14,8	100	1565	1918	-	2040	7,0	7,0	27
20[illegible]		600	9,50	9,7	14,7	100	1691	1964	-	2060	7,0	7,5	21
[illegible]		600	9,50	9,7	14,6	100	1654	1939	-	2054	8,0	8,5	29
2[illegible]		600	9,50	9,7	14,6	100	1651	1938	-	2054	6,5	7,0	25
20/12960[illegible]		600	9,50	9,7	14,6	-	-	-	-	-	-	-	-

Fig. 6. Results of tensile test.

The temperature 150 °C was chosen for the optimal tempering temperature. At this temperature, SA600 steel achieves the most suitable combination of mechanical properties for armour steels.

The hardness in our case is high and amounts to 632 HV (580 - 640 HV is prescribed). The $Rp_{0.2}/Rm$ ratio is the lowest at this temperature (0.7992). A low $Rp_{0.2}/Rm$ ratio means higher resistance to local steel flow and thus better armour protection. The elongation at this temperature is 7.5% and thus reaches the required elongation value for armour steel.

Measurements and analysis of thermal properties of testing samples from the steel SA600 were performed in accordance with ISO 22007-2 standard [7] In our research, we used one of the most advanced instruments for determining the thermal properties, Hot Disk TPS 2200, a product of Hot Disk AB company, Gothenburg, Sweden [8]. In Figure 7 is instrument Hot Disk TPS 2200 in the Laboratory for Thermotechnical Measurements, Faculty of Natural Sciences and Engineering, University of Ljubljana.

Fig. 7. Instrument Hot Disk TPS.

In Figure 8 are presented results of thermal properties measurements at ambient temperature.

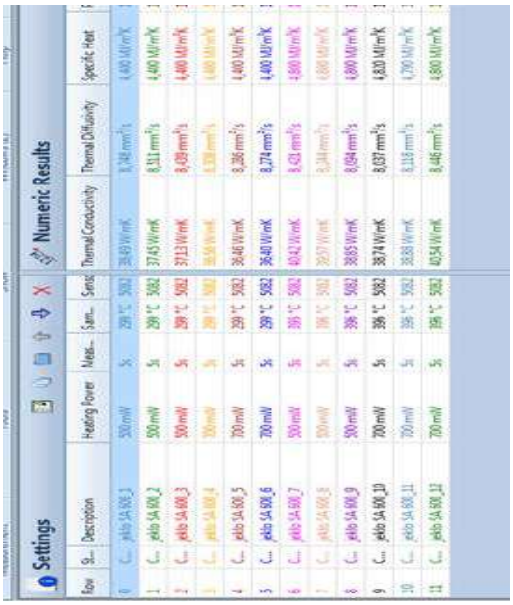


Fig. 8. Results of measurements.

In Table 3 are presented thermal properties (thermal conductivity, specific heat and temperature conductivity) of steel at ambient temperature (approx. 22 °C). The thermal conductivity increases with temperature, and is

equal to 28.33 W/m·K at ambient temperature, and 39.67 W/m·K at 400 °C.

Table 3. Thermal properties of steel SA600 at ambient temperature

Steel	SA600
Thermal conductivity	28.33 W/m·K
Specific heat	4.44 MJ/m^{3}K
Temperature conductivity	6.37 mm^2/s

3. CONCLUSIONS

The work includes heat treatment and characterization of mechanical, microstructural and thermal properties of new steel for ballistic protection with internal code SA600. Steel is the result of the development and knowledge of firm SAAT, d.o.o. in collaboration with scientific institutions and industry partners, produced in an industrial environment.

The results of the research carried out as part of the investigation confirmed that the optimal austenitization temperature for SA600 steel is 870 °C and the tempering temperature is 150 °C. Under these conditions, the hardness of the steel is 632 HV10, which means that it is suitably high. The yield strength is 1640 MPa and the tensile strength is 2052 MPa. The $Rp_{0,2}$/Rm ratio is equal to 0.7992 and is correspondingly low.

The thermal conductivity increases with temperature and is equal to 28.33 W/m·K at room temperature, and 39.67 W/m·K at 400 °C.

4. REFERENCES

[1] Crouch, I. G., *The Science of Armour Material*. Amsterdam: Elsevier, 2017.

[2] Dobrzanski, L.A., *Technical and Economical Issues of Materials Selection*, Silesian Technical University, Gliwice, 1997.

[3] Totten, G. E., *Steel heat treatment: equipm- ent and process design*. Boca Raton: CRC Press, Taylor & Francis Group, 2006.

[4] Bernetič, J., *Development of model for predicting hardenability of high strength low alloy steels*: (B. Kosec, A. Smolej), Doctoral Thessys, University of Ljubljana, Ljubljana, 2013.

[5] Bernetič, J., Kosec, G., Kosec, B., *Steel of new generation PROTAC 500*, IRT 3000, 8, 48, 30-31, 2013.

[6] Slovenian standard SIST EN ISO 6892-1:2010: *Metal Materials – Tensile Testing Part 1: Testing Methods at Room Temperature* (01 – march- 2010).

[7] International standard ISO 22007 (2009). Plastics – *Determination of thermal conductivity and thermal diffusivity – Part 1: General principles*. Reference: ISO 22007:2009(E).

[8] Kosec, B., Karpe, B., *Instrument for the thermal properties analysis Hot Disk TPS 2200*, IRT3000, 67, 2017.

Acknowledgement

The authors want to thank dr. Slavko Ažman$^+$ (ACRONI d.o.o.), professor Ladislav Kosec (University of Ljubljana), professor Franc Vodopivec$^+$ (Institute of Metals and Technology), dr. Milan Rimac (Metallurgical Institute K. Kapetanovic Zenica), and professor Anton Smolej (University of Ljubljana) for mentorship at study armoured steels.

Authors: **Domen P. Kosec, Prof. Dr. Mirko Soković,** University of Novo mesto, Faculty of Mechanical Engineering, Na Loko 2, 8000 Novo mesto, Slovenia, Phone: +386 7 3930019, Fax: +386 7 3930013.
E-mail: domenpk@gmail.com
mirko.sokovic@gmail.com

Dr. Jure Bernetič, SAAT d.o.o., Cesta na Lisice 4, 1000 Bled, Slovenia, Phone: +386 41 308145.
E-mail: jure.bernetic@saat.si

Dr. Gorazd Kosec, SIJ ACRONI d.o.o..,c. B. Kidriča 44, 4270 Jesenice, Slovenia, Phone: +386 4 5840016, Fax: +386 4 5840003.
E-mail: gorazd.kosec@acroni.si

Prof. dr. Zijah Burzić, Military Technical Institute, Ratka Resanovica 1, 11030 Belgrade, Serbia, Phone: +381 11 2508308, Fax: +381 11 2508474.
E-mail: zijah.burzic@vti.vs.rs

Prof. Dr. Borut Kosec, Prof. Dr. Aleš Nagode, University of Ljubljana, Faculty of Natural Sciences and Engineering, Aškerčeva 12, 1000 Ljubljana, Slovenia, Phone: +386 1 2000410, Fax: +386 1 4704560.
E-mail: borut.kosec@ntf.uni-lj.si
ales.nagode@ntf.uni-lj.si

*Corresponding author **Prof. Dr. Borut Kosec**, e-mail: borut.kosec@ntf.uni-lj.si

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE**
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Žmak, I., Kuljanac, J., Culjaga, I., Hren, S.

PREVENTING CASTING DEFECTS IN FIRE PUMP SYSTEMS WHEN USING RECYCLED ALUMINIUM ALLOYS

Abstract: *Pressurized water dividers in fire trucks must be watertight and not contaminating to potable water. The paper studies the problem of a cast aluminium divider leaking through the wall at 5 bar. Radiographic X-ray analysis and liquid penetrant testing is done to study the defects. Microscopy, chemical analysis, and hardness tests are performed to compare the declared material to the applied material. Casting design and casting process modifications, as well as the use of controlled recycled aluminium alloys are suggested.*
Key words: *fire pump, leakage, casting defects, aluminium, recycling*

1. INTRODUCTION

Sand casting of alloys is a technique known from ancient times. Nevertheless, it is still widely used in many engineering applications, since it is very coft effective, flexible, suitable for both large and small-size batches, and for small to extremely large castings.

Aluminium alloys for casting have found their widespread applications due to their, often, very good castability, i.e., low viscosity and narrow solidification range. Aluminium is also well-known for its low density, good corrosion resistance in non-acidic and non-alkali media, and good mechanical properties [1].

Most fire pump components operate using pure, often potable water, so good corrosion resistance to water is an important request. Also, fire trucks are sometimes used for dispensing water to citizens, so the pump system must not contaminate the water in any way. These exploitational requirements are easily met by most aluminium alloys [2].

One important functional requirement for any water pump system component is, of course, its watertightness.

Nowadays, many aluminium alloys are often recycled, due to easy identification, typically large amounts of available scrap, and low cost of using secondary aluminium compared to virgin aluminium alloys.

This paper results the study of analysis of improper functioning of a sand cast aluminium alloy divider, used on fire trucks since the divider was leaking water through the wall at 5 bar. Figure 1 shows an isometric drawing of the studied fire pump water divider, where the width is approximately 600 mm, and the depth is approximately 300 mm.

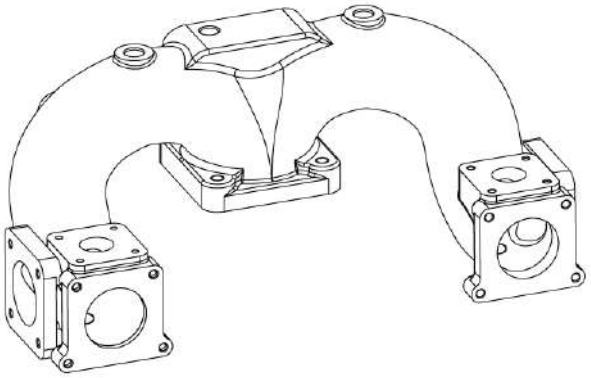


Fig. 1. 3D drawing of fire pump water divider

2. MATERIALS AND METHODS

To determine the possible cause of leaking water, several tests and analyses were performed.

2.1 Chemical composition

According to the available technical documentation, the declared standard alloy grade that was be used for casting is EN AC-51400S, i.e., ISO AlMg5(Si) or Material Number 3.3261, Table 1 [3].

Table 1. Chemical composition of EN AC-51400S, wt. % [3]

Fe	Si	Mn	Ti	Cu	Mg	Zn
Max	Max	Max	Max	Max		Max
0.55	1.5	0.45	0.2	0.05	4.5 to 6.5	0.1
Others: each 0.05; total 0.15 Al – remainder						

Chemical composition of the water divider was analysed on three different locations using the hand-held X-ray fluorescent (XRF) analyser X-

200 (SciAps, Woburn, MA, USA). Also, the method of Glow discharge optical emission spectrometry (GD-OES), using the optical emission spectrophotometer GDS 850A (St. Joseph, MI, USA) was used for rechecking the chemical composition after XRF analysis.

2.2 Vickers hardness

Vickers hardness measurements HV5 were performed on three locations of the casting using the portable hardness tester MIC-10 (Krautkramer, Germany).

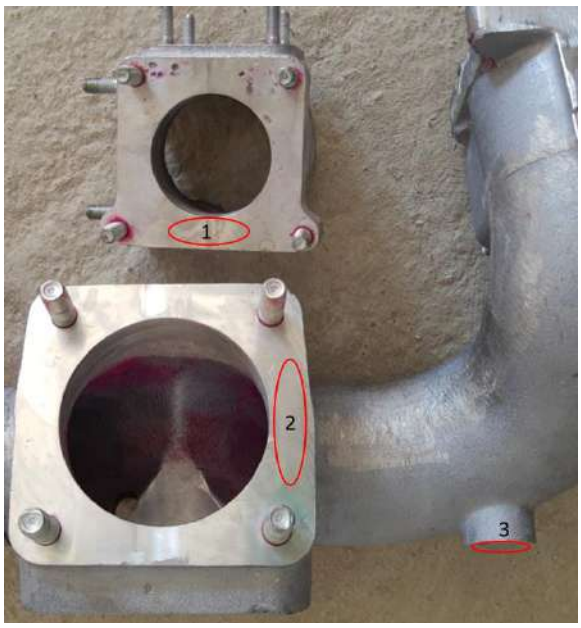


Fig. 2. Hardness measurement locations

2.3 Dye penetrant inspection

Dye penetrant inspection is a non-destructive test which has the purpose of detecting surface irregularities. The method is often used when testing welds but is also used when testing seams and other sensitive elements where surface cracks are strictly prohibited.

The pressured water divider was thoroughly cleaned and degreased. The penetrant was applied to the surface of the casting, which was divided into segments, and the penetrant was removed after 30 minutes. After that, the developer was applied, and the growth of indications was observed. The degreaser used was MR 79, the penetrant MR 68NF, and the developer MR 70, all by the manufacturer Mr Chemie (Unna, Germany).

2.4 Radiographic testing

After numerous pores were observed on the surface by the penetrant method, it was necessary to perform one of the volumetric methods to gain insight into the interior of the material. One of the volumetric methods is radiography, a common non-destructive testing method.

Radiographic testing was performed by X-ray device 300D (Balteau, Belgium), which has a maximum voltage of 300 kV, and currents from 3 mA to 5 mA.

2.5 Metallographic testing

A sample was cut from the pressure divider and subjected to metallographic analysis. The sample was ground using sanding papers 600 and 1200, and polished with diamond paste on a MetaServ 250 device (Buehler, IL, USA).

The microstructure was observed under 100 times and 500 times magnification on a StructureExpert structure verification system (Struers, OH, USA).

3. RESULTS AND DISCUSSION

3.1 Results of chemical composition tested by XRF and GD-OES

The results of chemical composition using the hand-held XRF analyser is presented in Table 2. The results are given as value range, since three measurements were made.

Table 2. Chemical composition by XRF, wt. %

Chem. elem.	Content:	Compared to standard alloy
Fe	0.3 – 0.33	OK
Si	0.93 – 1.63	Too high
Mn	0.58 –0.6	Too high
Ti	0.07 – 0.1	OK
Cu	0.03 – 0.04	OK
Mg	3.23 – 3.64	Too low
Zn	0.07 – 0.07	OK
Other elements:		
Cr	0.03 – 0.04	OK
Pb	0.002 – 0.003	OK
Ni	0.007 – 0.008	OK
Others total: 0.051		OK

The results obtained by XRF-analysis were compared with the standard chemical composition of the EN AC-51400S alloy, Table 2. Silicon and manganese content was too high, while the magnesium content was too low.

The XRF-analyser was not able to detect any standard aluminium alloy designation on any of the tested locations.

Since the XRF method was not able to confirm that the analysed material is the EN AC-51400S, nor was it able to assign any other standard designation (i.e., the material was not identified), an additional chemical analysis using GD-OES, a more complex and destructive testing, was

performed, Table 3.

Chemical composition analysed with the more reliable method of GD-OES has confirmed that the analysed material does not fit the composition requirements for the standard aluminium alloy EN AC-51400S.

Table 3. Chemical composition by GD-OES, wt. %

Fe	Si	Mn	Ti	Cu	Mg	Zn	Cr
0.3	1.11	0.53	0.09	0.03	3.56	0.07	0.03
OK	OK	Too high	OK	OK	Too low	OK	OK

3.2 Results of Vickers hardness test

Table 4 presents the average values plus–minus one standard deviation for Vickers HV5 testing, measured ten times on three locations, as previously shown in Figure 2.

Table 4. Vickers hardness HV5 results

Location 1	70 ± 3.1
Location 2	74 ± 4.0
Location 3	76 ± 4.3

Measured hardness values indicate that hot spots (spots harder than the surroundings) occur. Differences in local hardness increase cutting tool wear during machining. Hot spots occur when a part of the melt is cooled more quickly than the surrounding melt. To avoid them, a slower cooling of thinner cross sections should be enabled [4].

3.3 Dye penetrant inspection

Dye penetrant testing has shown many casting defects. Defects on water sealing surfaces explained the leakage that occurred on water dividers when subjected to 5 bar water. Figure 3 shows blowholes of different sizes, appearing after surface machining.

Fig. 3. Gas porosity on tight fit surface

This indicated that there are both open holes as well as subsurface blowholes present in the casting [5].

Gas porosity may be prevented by improving the permeability of the mould and cores, either by increasing the sand size or by a more thorough drying of the cores. Also, a more rapid solidification by reducing the melt temperature may help [4].

Cold shuts were also observed on tight fitting surfaces, Figure 4. Cold shuts occur when the melt cools down too much when two or more streams meet. These non-fused junctions can be avoided by increasing the melt temperature or by improving the mould gas permeability. Also, improving the design of the gating system is typically advised.

Defects identified as open holes on non-functional (non-sealing) surfaces were neglected.

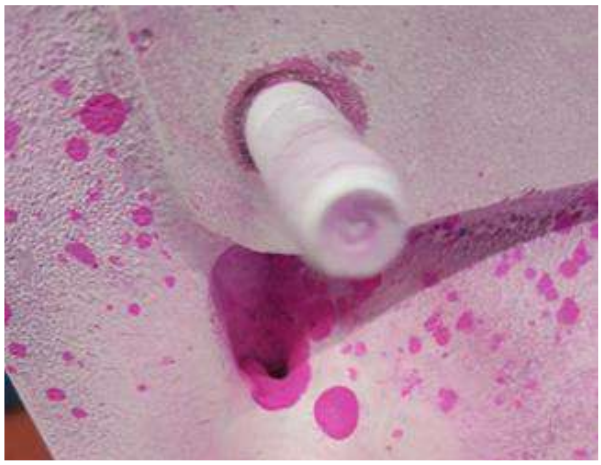


Fig. 4. Cold shut at wall thickness transition

3.4 Radiographic testing results

Radiogram has shown porosity on volumetric level as well, Figure 5. When the film is used as an X-ray detector, areas where the film is less irradiated are lighter, indicating the locations with larger wall thickness, higher density, or a material with less or without inclusions [6].

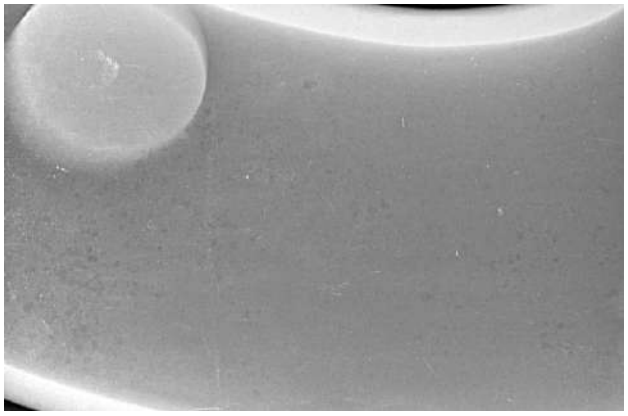


Fig. 5. Enlarged view of pores in thin walls

3.5 Metallographic analysis results

The analysis of microstructure has confirmed that it is an aluminium alloy with magnesium and silicon, which forms the typical crystals, called the Chinese script [7].

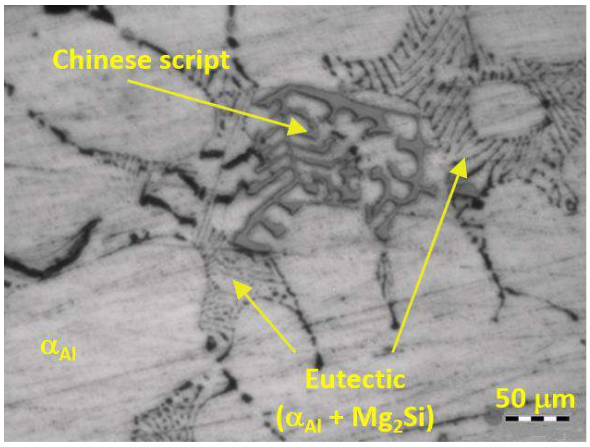


Fig. 6. Main microstructural phases

Such alloys are heat treatable, i.e., they can be hardened by precipitation hardening, which is not a requirement for fire pump dividers.

4. POSSIBLE PROCESS AND DESIGN IMPROVEMENTS

The required chemical composition of the alloy for the studied water divider is adjusted in the foundry itself: pure secondary aluminium sheets are purchased from local suppliers, which is then recycled and alloyed with manganese, silicon, and magnesium to achieve the composition of EN AC-51400S alloy. The melt is refined with AlTi5B1, which is believed to cause the formation of Al_3Ti and TiB_2 particles, which act as crystal nuclei. Furthermore, when refining an alloy with AlTi5B1, it is necessary to stir regularly and thoroughly the melt. Each further remelting of AlTi5B1 refined alloys decreases the number of nuclei particles. Recycling by self-remelting, without additional metallurgical control of the composition, microstructure and key mechanical properties of the alloy should be minimized.

The casting should be redesigned to avoid strong transitions from thin to thick wall, since these contribute to the formation of pores.

To reduce the porosity, it is recommended to degas the melt using nitrogen prior to pouring. Also, minimizing the water content in the sand to 3.6 % to 4 % will decrease the gas porosity.

5. CONCLUSION

Using scrap aluminium for in-house recycling should be carefully monitored and performed with broad metallurgical knowledge, to obtain or maintain good properties of the aluminium castings.

Whenever possible, common casting process mistakes should be minimised or eliminated by, mostly, well known technological strategies described in literature.

Certainly, an elaborate design of the casting and the mould should be done in accordance with the professional rules.

6. REFERENCES

[1] Polmear, I., StJohn., D., Nie, J.-F., Qian, M.: *Light Alloys: Metallurgy of the Light Metals*, Butterworth-Heinemann, Oxford, 2017.

[2] Isman, K. E.: *Fire Pump Handbook*, National Fire Protection Association, Quincy, MA, 1998.

[3] Hesse, W.: *Aluminium-Schlüssel: Deutsch / Englisch*, Beuth Wissen, Berlin, 2016.

[4] Neff, D.: *Casting Defects Handbook: Aluminum & Aluminum Alloys*, American Foundry Society, Schaumburg, IL, 2011.

[5] Tracy, N. A., Moore, P. O. Liquid Penetrant Testing, American Society for Nondestructive Testing, Columbus, OH, 1999.

[6] Bossi, R. H., Iddings, F. A., Wheeler, G. C.: *Radiographic Testing*, American Society for Nondestructive Testing, Columbus, OH, 2002.

[7] Davis, J. R.: *Aluminum and Aluminum Alloys (ASM Specialty Handbook)*, ASM International, Novelty, OH, 1993.

Authors: **Prof Dr Irena Žmak, Jurica Kuljanac, Mag Ing, Ivančica Culjaga, Mag Ing, Smiljan Hren, Dipl. Ing.,** University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Ivana Lučića 5, 10000 Zagreb, Croatia, Phone.: +385 1 6168 320. Metalska industrija Varaždin d.d., Fabijanska 33, 42000 Varaždin, Croatia,
E-mail: irena.zmak@fsb.hr
jurica.kuljanac@gmail.com
ivancica.culjaga@miv.hr
hren.smiljan@gmail.com

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Goluža, B.

GREŠKE ALATA I KOREKCIJA ALATA U EKSTRUZIJI ALUMINIJA

Rezime: *Ekstrudiranje je vrlo raširen proizvodni proces. Veliki broj dijelova u automobilskoj, zrakoplovnoj i građevinskoj industriji proizvode se od aluminija procesom ekstruzije. Mnogi nedostaci u ekstrudiranim proizvodima nastaju upravo zbog alata. Problemi s alatima mogu biti posljedica problema sirovine, dizajna i proizvodnje. Ovi problemi se mogu izbjeći održavanjem kvalitete trupaca, kontroliranjem parametara procesa istiskivanja i kroz rutinsko održavanje. Problemi s alatima koji se javljaju svakodnevno uglavnom se mogu popraviti i ispravljaju se različitim vrstama operacija korekcije alata. U ovom radu će biti opisani nedostatci koji se mogu popraviti na alatu prije procesa ekstruzije aluminija, te kratka statistička analiza najčešćih grešaka.*
Ključne reči: *ekstruzija metala, greške alata, korekcija alata, analiza učestalosti.*

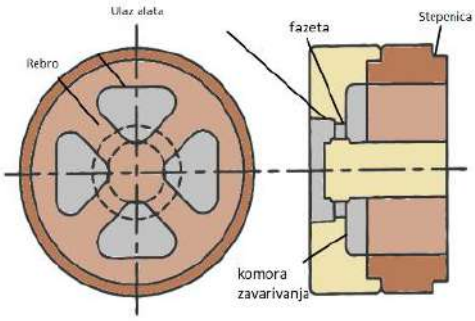
1. UVOD

Zbog svoje svestranosti i sposobnosti oblikovanja rešetke, ekstruzija je vrlo čest proizvodni proces, posebno za aluminijske legure. Ekstrudirani proizvodi se koriste u građevinskoj, auto i zrakoplovnoj industriji. Smanjenje grešaka proizvoda direktno vodi smanjenju dorade i odbijanja, te smanjenju vremena proizvodnje i troškova. Alat je vjerojatno najvitalnija komponenta u procesu prešanja zbog visoke cijene koštanja, jako uskih tolerancija i dobrih svojstava otpornosti na ponavljajuće termo-mehaničke utjecaje. Točnost i trajnost kompleta alata osigurava dobru kvalitetu proizvoda i smanjenju problema, vodeći ka većoj produktivnosti i smanjenju troškova[1,2].

Mnoge greške proizvoda u ekstruziji imaju u korijenu problem koji je vezan za alat i matricu. Neke od njih vezane su za dizajn alata, materijal alata te izradu alata, dok se druge pojavljuju tokom radnog vijeka alata.[3-5]. Naposljetku uključuju neodgovarajuće potporne alate, neodgovarajuću temperaturu, eroziju, udubljenja, kvalitet materijala trupaca, trenje itd. Problemi alata mogu se spriječiti kontrolom kvalitete trupaca i parametara procesa prešanja. Mnogi rutinski problemi alata su popravljivi i naslovljeni su kroz razne tipove korekcije. Nakon nekog vremena, korekcija više nije moguća te se alat mora odbaciti. Uobičajeni razlozi za nesipravnost alata su pukotine, trošenje fazete, odsjecanje, otklon, lom i trošenje.

2. STRUKTURALNI DIJELOVI ALATA

Terminologija korištena u sljedećim dijelovima može se razlikovati od tvrtke do tvrtke. Kako bilo, većina izraza je zajednička u cijelom svijetu. Nomenklatura alata općenito se odnosi nestrukturne dijelove alata. Shematski prikaz alata za presanje je prikazan na Slici 1. Glavni dijelovi su fazeta, izbacivač, stepenica, ulazi, komore za zavarivanje, rebro, dovodni kanali i podresci (do fazete, dovod materijala na trn).



Sl. 1. Glavni dijelovi otvorenog alata

Fazeta formira vanjski izgled presanja koji teče kroz alat najvećom mogućom preciznošću. Dio fazete alata određuje i profil i završetak presanja. Fazeta se ponaša kao „vodilica“ koja osigurava finu kontrolu trenja tečenja metala. Kako bilo, trenje metala koji teče može prouzročiti povećanje temperature. Zadnji dio alata je leđni dio, te se modifikacije mogu raditi na njemu kako bi se utjecalo na tečenje metala. Mora se osigurati stabilna nosivost kako bi se izbjegao otklon fazete. Stepenica je dio alata kojim se fiksira alat na nosač alata. Ulazi olakšavaju distribuciju toka metala (posebno za presanje otvorenih profila) kako bi svi dijelovi presanog profila poprimili istu količinu metala. Njihova veličina je uvijek maksimizirana kako bi se doveo materijal profilu najvećom brzinom. Čvrstoća materijala alata utječe na ovu najveću veličinu. Velika veličina

otvora će također dozvoliti manju otpornost tečenju alata, smanjujući potrebni tlak presanja.

Komore za zavarivanje olakšavaju sjedinjenje metala iz otvora prije nego što dođe u područje fazete. Dublje komore pomažu ostvarenju većih brzina presanja. Rebra podupiru dio trna u otvorenom alatu koji omogućavaju oblikovanje unutarnjeg dijela otvorenog profila. Alat mora biti čvrst i lak za prešanje istodobno. Neki faktori (uključujući smicanje i savijanje) moraju se uzeti u obzir i biti balansirani u dizajnu alata za minimalno povaćanje temperature i maksimalnu brzinu. Ograničavajući faktor je brzina pri kojoj se metal može ponovno zavariti nakon prolaska dijelova rebara. Zatvarajući kut mora biti dovoljno mali kako bi osigurao brzo zavarivanje.

Podrezak je korak u jezgri alata, neposredno prije površine fazete. Ponaša se kao rub za naprezanje prije nego se metal ispresa kroz otvore alata. U slučaju presanja otvorenog profila, konvencionalni ravni trn generira toplinu zbog trenja uzrokovanog naprezanjem tečenjem materijala preko trna. Podrezivanje fazete do trna poboljšava tečenje i dovođenje temperature. Također stvara korisnu mrtvu zonu koja omogućava metalu da puno lakše teče (s manje trenja) preko naknadnih slojeva. Značajke profila mogu sadržavati nekoliko kontra značajki za generiranje važnih geometrijskih elemenata ekstrudiranog profila (poput utora, sjedala itd.) koji će biti potrebni kasnije tijekom ugradnje i uporabe presanih dijelova. Najčešći dijelovi profila u alatu su jezik, mjesto četkica, vijak i vrh.

3. MATERIJALI I METODE

3.1 Greške alata i matrice

Kako je spomenuto iznad, većina grešaka alata i matrice mogu se ukloniti kroz proces pod nazivom korekcija alata. Neke greške alata su u prirodi kritične te se ne mogu popraviti te tako direktno vode neispravnosti alata. U ostalim slučajevima, daljne popravke nisu moguće nakon što su odrađene razne korekcije alata, rezultirajući odbacivanjem alata u otpad. Mnogi istraživači su pokušali istražiti ili analizirati pojedine greške alata. [6] Arif i suradnici [7] proveli su opsežnije istraživanje o neispravnostima alata i mehanizmima te prezentirali statističku analizu glavnih vrsta neispravnosti alata te njihovu potpodjelu.

Glavne kategorije neispravnosti alata su lom, trošenje, otklon (plastična deformacija), dizajn/izrada. Prva tri odnose se na strukturno i geometrijsko stanje alata nakon duge uporabe i može se vidjeti općenito bez uporabe mjernih uređaja. Za posljednji su potrebni uređaji da bi se otkrio uzrok.

3.2 Korekcije alata

Kako je spomenuto ranije, propisno stanje alata i matrice je krucijalno za dobru kvalitetu proizvoda i produktivnost pogona. Neispravnosti alata koji vode ka odbijanju rezultiraju prekidima u proizvodnji, a zamjena škartnog alata nadodaje se na troškove utrošenog vremena i novca. Stoga, korekcija alata igra krucijalnu ulogu u održavanju produktivnosti i profitabilnosti radeći defektne alate ponovno korisnima i izbjegavajući (ili odgađajući) konačno odbijanje.

Alatnica je mjesto gdje se alati rutinski provjeravaju i popravljaju. Općenito rečeno, postoje dvije vrste korekcije alata: korekcija prije uporabe i korekcija poslije uporabe. Korekcije prije uporabe su one koje se rade na novim alatima nakon probnog prešanja, prije stavljanja alata u serijsku proizvodnju. Korekcije nakon uporabe se rade svaki put nakon što se alat skine nakon prešanja. Većinom se fokusiraju na korekciju toka, oštećenja i trošenja, lomove, odstupanja i gubitak tvrdoće.

3.3 Uobičajne radnje korekcije alata

Kako naziv sugerira, uobičajne radnje korekcije su radnje obavljene na alatu na rutinskoj bazi. Prvo u ovoj kategoriji je čišćenje i poliranje alata. Na primjer, alati u ekstruziji aluminija su skloni nakupljanju aluminijevog oksida na podrescima ili proširenjima blizu fazete. Ponekad se ovi oksidi mogu nalaziti zalijepljeni unutar komore za zavarivanje i na ulazima ili čak na licu alata. Ova nakupljanja su začepljenja koja mogu prouzrokovati greške kao što su crtice i uključci, pa bi se trebali eliminirati prije svakog ciklusa rada. Nakon uporabe se alati hlade i zatim uranjaju u spremnik otopine kaustične sode na 60–80˚C na oko osam sati. Vrući alati bi pukli kad bi se stavili u spremnik bez propisanog hlađenja. Kaustična soda reagira sa nakupinama oksidata na alatu i uklanja ih. Ti otopljeni ostaci se zatim uklanjaju temeljitim pranjem. Mora se paziti da se osigura potpuno uklanjanje ostataka, jer mogu uzrokovati greške na proizvodu.

Nakon ispiranja, primjenjuje se gel na alat te se polira brusnim papirom 600-320 granulacijom. Tokom poliranja, brusni papir i turpija savršeno su poravnati s fazetom. Ako se poliranje ne radi oprezno, mogu se pojaviti zaobljenja ili oštri vrhovi pa se rubovi fazete mogu zaobliti, rezultirajući neželjenim oblikom.

Iduća rutinska korekcija alata je nitriranje ili karbo-nitriranje, vrsta otvrdnjavanja površine ili otvrdnjavanje omotača. Ovo je potrebno za nove alate ako nisu u potpunosti otvrdnjeni kod

proizvođača. Ovi alati se također karbo-nitriraju nakon čišćenja i poliranja. Otvrdnjavanje se također radi nakon predodređenog broja presanja kroz alat kako bi se osigurala propisna razina tvrdoće. Nakon što se alati očiste, ispoliraju i nitriraju, površina fazete i ostali kritični dijelovi su zaštićeni prije odlaganja alata, koristeći lubrikantne spojeve kao što su boja u spreju, srednje teško ulje, grafitni sprej itd.

3.4 Specifične korekcije alata

Specifične korekcije alata se koriste za specifične probleme promatrane od strane kontrole kvalitete ili osoblja alatnice. Problemi s prešanim proizvodom mogu biti usljed problema povezanog s alatom, trošenja, razaranja itd. alata i matrice.

Neke od specifičnih vrsta korekcije su prikazane ispod:

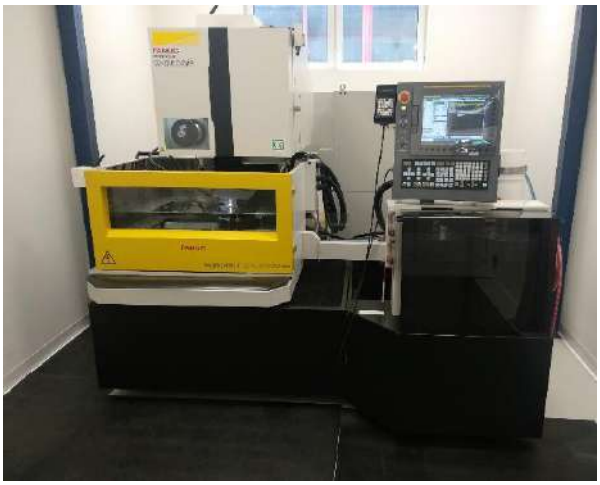
a) brušenje (Slika 2.) ,
b) glodanje (Slika 3.),
c) zavarivanje (Slika 4),
d) dorada alata na Erozimatu (Slika 5).

Sl. 2. Korekcija alata brušenjem

Sl. 3. Korekcija alata glodanjem

Sl.4. Korekcija alata zavarivanjem

Postoje i mogućnosti provjere alata prije same ekstruzije. Načini na koje se mogu provjeriti urađene korekcije alata su: a) na erozimatu (Slika 5) , b) na 3D skeneru (Slika 6).



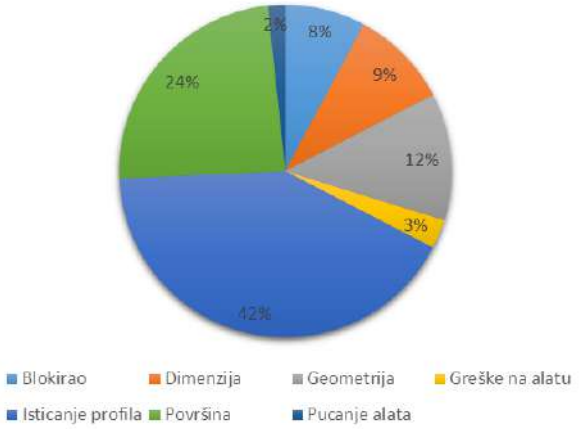
Sl.5. Provjera alata žicom (erozimat)

Sl.6. Provjera alata 3D skenerom

Prvo se snimi stanje alata, nakon toga se radi određena korekcija te se na kraju snimi stanje.

4. REZULTATI I DISKUSIJA

Kako bi se postigla veća produktivnost i smanjile dorade i odbijenice, važno je prepoznati učestale probleme vezane uz alat te smanjiti i eliminirati pojave. Ovaj dio predstavlja kratku statističku analizu koja je temeljena na frekvenciji stvarnih ispravljivih grešaka alata. Podatci su prikupljeni iz regionalnog pogona za ekstruziju aluminija, predstavljajući tipičnu srednje do veliku tvrtku. Informacija se bazira na broju alata koji su poslani na korekciju u roku jedne godine.Svi alati napravljeni su od H13 čelika, a aluminijski trupci su od legure 6060.



Sl. 7. Prikaz najučestalijih grešaka koje su se dogodile na alatima tijekom jedne godine

Ova analiza provedena je na godišnjoj razini. Klasifikacija glavnih grešaka je: lom, trošenje, odstupanje, dizajn/izrada. Slika 7. prikazuje podatke u obliku dijagrama. Za skup podataka, korekcija alata (oko 90%) bila je posljedica vrsta lomova, trošenja i drugo. Najušestalija pojedina kategorija (42%) bilo je isticanje profila, slijedi površina (24%), geometrija (12%), dimenzija (9%).

U slučaju neuspjelih alata, najučestalije greške bile su blokirao alat, lom alata i greške na alatu. Kako bilo, najučestalije korektibilne greška alata bile su trošenje, lomovi i ostalo. Alati su se doveli u alatnicu nakon svakog ciklusa prešanja, ili za rutinsku ili specifičnu korekciju. Lomovi nisu uvijek bili reparabilni i vodili su ka odbacivanju alata, tako da je učestalost bila manja od korekcija usljed trošenja. Alati s izraženim odstupanjem su odbacivani u otpad (radije nego korigirani), jer korekcija zagrijavanjem i poravnavanjem najčešće ne vrijedi.

5. ZAKLJUČAK

Veliki broj proizvoda proizveden je kroz deformacijski proces ekstruzije. Uočavanje i smanjenje grešaka proizvoda je jako važno u održavanju produktivnosti i profitabilnosti ekstruzijske tvrtke. Greške alata i matrice su jedan od glavnih izvora grešaka proizvoda. Korektivno održavanje ekstruzijskih alata se provodi na dnevnoj bazi usljed pojavljivanja reparabilnih grešaka. U ovome radu je prikazano statističko istraživanje korektivnih grešaka alata na temelju učestalosti, te je prikazana i mogućnost prepoznavanja najčešćih problema. Ovaj rad može poslužiti kao detaljna referenca za popravljive greške alata i povezane korektivne operacije.

6. REFERENCE

[1] Arif, A.F.M.; Sheikh, A.K.; Qamar, S.Z.; Raza, M.K.; Al-Fuhaid, K.M. Product Defects in Aluminum Extrusion and Their Impact on Operational Cost. In Proceedings of the 6th Saudi Engineering Conference, Dhahran, Saudi Arabia, 14–17 December 2002.

[2] Qamar, S.Z. Introduction to extrusion: From gear manufacturing to production of cereals. In Extrusion of Metals, Polymers, and Food Products; Qamar, S.Z., Ed.; INTECH Open Science: Pleasanton, CA, USA, 2018.

[3] Akhtar, S.; Arif, A.F.M. Fatigue failure of extrusion dies: Effect of process parameters and design features on die life. J. Fail. Anal. Prev. 2010, 10, 38–49.

[4] Li, T.; Zhao, C.; Guan, Y.; Sun, X.; Li, H. Effect of process parameters on die wear behavior of aluminum alloy rod extrusion. Mater. Manuf. Process. 2013, 28, 312–318.

[5] Qamar, S.Z. Modeling and Analysis of Extrusion Pressure and Die Life for Complex Aluminum Profiles.Ph.D. Thesis, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia, June 2004.

[6] Zhang, C.; Zhao, G.; Guan, Y.; Gao, A.; Wang, L.; Li, P. Virtual tryout and optimization of the extrusion die for an aluminum profile with complex cross-sections. Int. J. Adv. Manuf. Technol. 2015, 78, 927–937.

[7] Arif, A.F.M.; Sheikh, A.K.; Qamar, S.Z. A study of die failure mechanisms in aluminum extrusion. J. Mater. Process. Technol. 2003, 134, 318–328.

Autor: **Božo Goluža, mag. ing. mech.,**
Fakultet strojarstva računarstva i elektrotehnike, Sveučilište u Mostaru, Matice hrvatske b.b, 88000 Mostar, BiH, Tel: +387 36 337 033, Fax: +387 36 337 033.
E-mail: bozo.goluza90@gmail.com

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Némedi, I., Sánta R., Simon, J.

KONSTRUKCIJA PROTOTIPA MEŠALICE ZA HOMOGENU SMEŠU GLAZURE

Rezime: *U ovom radu je dat prikaz konstrukcije prototipa jedne mešalice, koja je namenjena za izradu homogene smeše glazure. Ideja je da se uvede novina u građevinarstvu, pošto još uvek ne postoji primenljiva konstrukcija za ovaj tip posla. Uvođenje ovakve mešalice u građevinarstvu bi rezultovalo značajnom uštedom vremena izrade i broja potrebne radne snage, a dobila bi se i mnogo kvalitetnija smeša koja se ručno ne može obezbediti. Treba imati u vidu da se radi o prototipu, koja je izrađena prema sličnim idejama i konstrukcijama nekih drugih mašina za slične tipove posla. Pre finalizacije konstrukcije za serijsku proizvodnju obavezno treba da se izradi ovaj prototip, kako bi se uočili eventualni nedostaci, i na osnovu sugestija potencijalnih korisnika, dopunila trenutna rešenja za date probleme.*

Ključne reči: *prototip, homogena smeša, glazura, mešanje, sitno zrnasti materijali i prahovi*

1. UVOD

Površina betonskog poda je obično neravna, što komplikuje postavljanje keramičkih pločica, laminata, parketa i sličnih podnih obloga. Neophodna je ravna, glatka i čvrsta površina, na koju se može uspešno postaviti bilo koja vrsta podne obloge. Radi povećanja kvaliteta i smanjenja ključnih faktora za ovaj vid posla, izrađena je konstrukcija, prema principu mešalice za beton, međutim zbog specifičnosti smeše dodati su mašinski elementi kojih nema u konstrukciji obične mešalice za beton.

Cilj je bio da se izradi konstrukcija prototipa koja zadovoljava sledeće uslove:

- smeša sastojaka mora da bude homogena već nakon suvog mašanja;
- konstrukcija mora biti što jednostavnija, sa najmanjim mogućim brojem mašinskih elemenata;
- posebna pažnja se mora obratiti na stabilnost konstrukcije, kako tokom transporta, tako i tokom primene;
- rukovanje mora biti bezbedno i što jednostavnije, uz minimalno potrebnu fizičku snagu rukovaoca;
- dnevno i periodično održavanje takođe mora biti jednostavno i brzo;
- cena izrađene konstrukcije za serijsku proizvodnju mora zadovoljiti uslove tržišta.

2. OSNOVE TEORIJE MEŠANJA

Prilikom mešanja, dva ili više materijala (različiti osobina) vrši se distribucija svake komponente prinudnim protokom kako bi se osiguralo da se dobije željeni odnos pomešanih elemenata u specificiranoj minimalnoj zapremini. Primarni cilj je da se ravnomerno rasporedi masa sastojaka u mešalici,odnosno da se dobije fino dispergovan sistem. Sistem se može podesiti i za drugu svrhu, kao što je npr. ubrzanje prenosa toplote i/ili prenosa mase i podsticanje hemijske reakcije. [1,2]

2.1 Mešanje čvrstih zrnastih materijala i prahova

Prilikom mešanja čvrstih zrnastih materijala i praha koriste se mešalice koji se mogu primeniti za mešanje nisko i visoko viskoznih materijala. Tu spadaju pužni i trakasti mikseri. Mešanje praha ili čvrstih materija je obično „suv" proces, mada u nekim slučajevima može doći i do dodavanja tečnosti.[1]

Rezervoar pužnih mešalica je cilindričan sa konusnim dnom (Slika 1.).

Sl. 1. Princip vertikalne pužne mešalice

U uređaju se stvara spiralno kretanje skupa čestica koje se mešaju, tako da se rotira oko uzdužne ose mašine i takođe se kreće napred u uzdužnom pravcu. Rezultat dva pokreta rezultira

spiralnim tokom. Pužne mešalice obezbeđuju veoma intenzivno mešanje čestica, pa su pogodne za homogenizaciju prahova i za temeljno mešanje čak i vlažnih čestica.

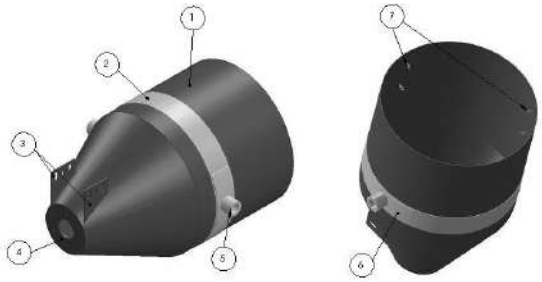
Ravnomerna raspodela pojedinih čestica u velikoj meri zavisi od konstrukcije mešalice, od veličine čestica pomešanih materijala, od vremena i intenziteta mešanja. Sferne čestice imaju bolja svojstva kotrljanja, te kod njih je proces homogenizacije mnogo temeljnije. [3]

3. PRIKAZ KONSTRUKCIJE PROTOTIPA

U nastavku sledi prikaz osnovnih delova konstrukcije mešalice.

3.1 Bubanj

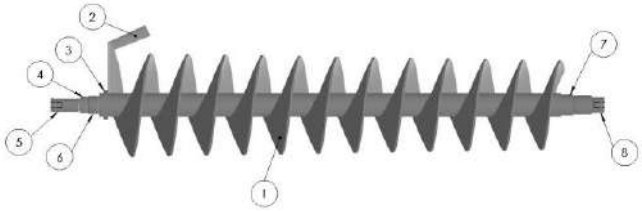
Dimenzije mešalice u velikoj meri su određene telom bubnja (1), koje je višeelementna zavarena konstrukcija. Bubanj (Slika 2) ima kapacitet od 260 litara i može da primi 150 litara (kapacitet tri kolica) smeše. Njegov dizajn je pogodan za mešanje s pužnim vratilom. Telo bubnja je ojačano u položaju osovina (5) omogućavajući okretanje bubnja prstenom (2) i ojačivačima (6). Njegovo ojačanje je neophodno kako bi se sprečila deformacija pod opterećenjem. Ploče (3) koje drže motor nalaze se na konusnoj površini tela bubnja. Na dnu tela bubnja nalazi se ploča (4) koja drži kućište ležaja, a unutar tela bubnja nalaze se pričvrsne ušice (7) za koje su pričvršćeni unutrašnji elementi.



Sl. 2. Bubanj

3.2 Puž

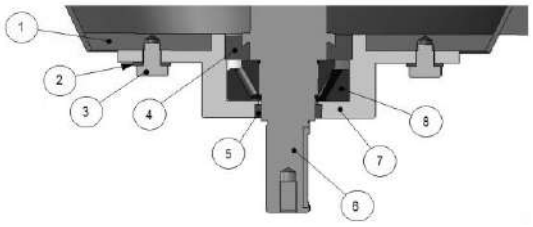
Puž (Slika 3) je element koji transportuje/meša materijal pomerajući ga vertikalno od dna bubnja. Telo puža (1) je dizajnirano tako da može da zahvata što je moguće više materijala. Prinudno pomeranje materijala ka telu puža obezbeđuje lopata (2). Na dnu puža nalaze se, između ostalog, specijalni zaptivni prsten (3) i standardni zaptivni prsten (4). Površina naleganja kaišnika (5) je takođe sastavni deo tela puža. Mesta uležištenja puža su obeležena pozicijama 6 i 8. Površina naleganja raspršivača je u poziciji 7. Za izradu tela puža je predviđena operacija preciznog livenja, što omogućava minimalan obim potrebne obrade rezanjem jedino krajeva puža, na mestima naleganja ležajeva.



Sl. 3. Puž

3.3 Sklop donjeg uležištenja puža

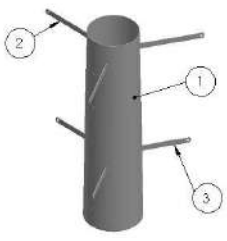
Slika 4 prikazuje pomenuti sklop sa montiranim krajem puža (6). Prilikom izrade uzeta su u obzir dva bitna aspekta. Prvi je da se obezbedi pravilno i potpuno zaptivanje, a drugi je jednostavnost montaže i demontaže radi održavanja i zamene delova. Za dno bubnja zavrtnjima (3) i podloškama (2) je pričvršćeno kućište ležaja (7), koje uključuje i zaptivke (4), (5). Svi elementi ugrađeni u kućište se izrađuju rezanjem, osim standardnih elemenata.



Sl. 4. Sklop donjeg uležištenja puža
1 – dno bubnja, 2 – podloška, 3 – zavrtanj za fiksiranje, 4 – specijalni zaptivač, 5 – standardni zaptivač, 6 – kraj puža, 7 – kućište ležaja, 8 – ležaj.

3.4 Centralna cev

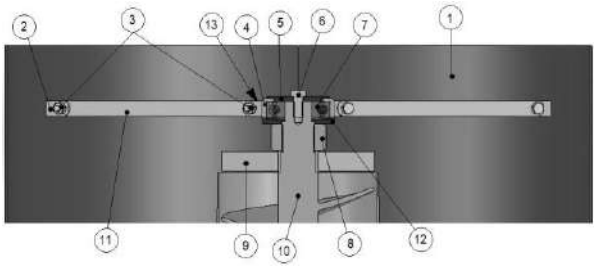
Funkcija centralne cevi je obezbeđivanje dopremanja celokupne mase smeše do vrha puža. Centralna cev je eksperimentalno dodata prototipu. Testiranjem prototipa će se ustanoviti stvarna potreba radi pravilnog i potpunog mešanja. Na Slici 5 prikazano je telo centralne cevi (1) i šest komada šipki za fiksiranje (2) i (3) povezanih sa njim. Šipke za fiksiranje se za telo centralne cevi pričvršćuju zavarivanjem, dok se krajevi šipki uz unutrašnju površinu bubnja montiraju zavrtnjima.



Sl. 5. Sklop centralne cevi

3.5 Sklop gornjeg uležištenja puža

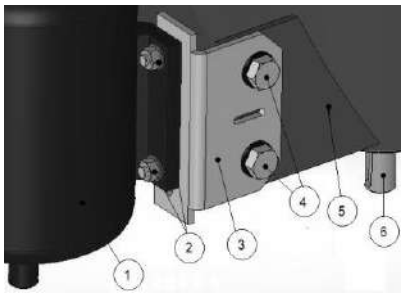
Na Slici 6 prikazan je gornje uležištenje puža, njegovo pričvršćivanje na telo bubnja kao i lopata za raspršivnje smeše (9). Raspršivač je namenjen za poboljšavanje efekta mešanja. Pričvršćena je standardnom navrtkom (8). Kućište ležaja (4) se sastoji od mašinski obrađenih i pločastih (13) delova koji su međusobno zavareni. Kućište ležaja je pričvršćeno na ušice (2) na bubnju (1) preko šipki (11). Zaptivači (5 i 12) štite ležaj od smeše i svih drugih nečistoća. Zaptivni elementi (5 i 12) su mašinski obrađeni.



Sl. 6. Sklop gornjeg uležištenja puža
1 – bubanj, 2 – uška za fiksiranje, 3 – zavrtanj i navrtka, 4 – kućište ležaja, 5 – zaptivni element, 6 – zavrtanj, 7 – ležaj, 8 – navrtka, 9 – raspršivač, 10 – puž, 11 – šipka za povezivanje, 12 – zaptivni element, 13 – uška za fiksiranje.

3.6 Rešenje fiksiranja pogonskog motora

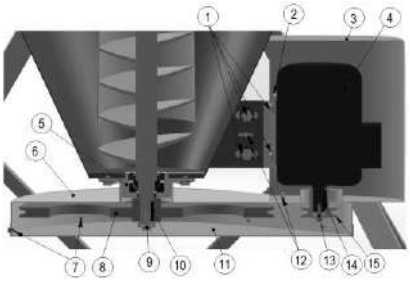
Na Slici 7 prikazano je rešenje za pričvršćivanje elektromotora (1). Elektromotor je pričvršćen za međuelement (3) pomoću zavrtanjske veze (2). Položaj elektromotor je podešljiv kako u vertikalnom, tako i u horizontalnom pravcu pomoću međuelementa (3). Tako se može obezbediti pravilno i dovoljno zatezanje kaiša. Međuelement (3) je za bubanj (5) pričvršćen takođe zavrtanjskom vezom (4).



Sl. 7. Fiksiranje pogonskog motora
1 – elektromotor, 2 i 4 – zavrtanjske veze, 3 – međuelement, 5 – bubanj, 6 – donji kraj puža.

3.7 Sklop prenosa pogona

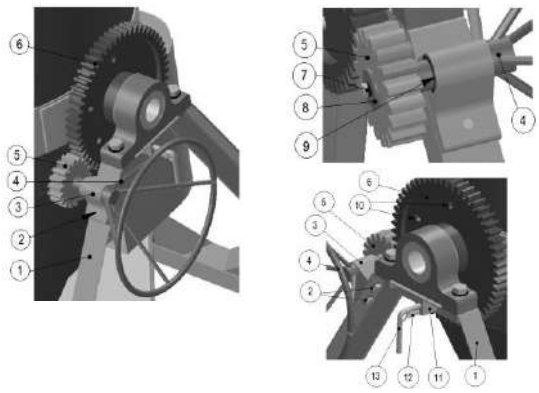
Na Slici 8 je dat prikaz sklopa prenosa pogonskog obrtnog momenta sa elektromotora na vratilo puža. Na Slici su takođe prikazani i elementi oblaganja svih prikazanih elemenata.



Sl. 8. Sklop gornjeg uležištenja puža
1 – zavrtanjske veze, 2 – međuelement, 3 – obloga pogonskog elektromotora, 4 – elektromotor, 5 – kućište ležaja, 6 – gornji deo obloge, 7 – samourezni zavrtnjevi, 8 – veliki kaišnik, 9 – pomoćni element, 10 – klin, 11 – donji deo obloge, 12 – zavrtanjska veza, 13 – pomoćni element, 14 – klin, 15 – mali kaišnik.

3.8 Mehanizam okretanja bubnja kod pražnjenja

Okretanje bubnja prilikom pražnjenja mešalice je rešeno pomoću točka za okretanje (4). Okretanje je olakšano zupčastim prenosom zupčanicima (5 i 6). Veliki zupčanik (6) se nalazi na vratilu bubnja, a mali zupčanik (5) je u direktnoj vezi sa točkom za okretanje (4). Vratilo točka (4) je montirano u posebni držač (3) preko distantnog prstena (9). Držač točka je pričvršćen za noseću konstrukciju mešalice (1) zavrtnjem (2). Položaj vijaka (2) na nosećoj konstrukciji (1) je projektovan tako da omogućava podešavanje osnog rastojanja zupčanika (5 i 6). Mali zupčanik (5) je pričvršćen za točak (4) pomoću pomoćnog elementa (8) i zavrtanjske veze (7).



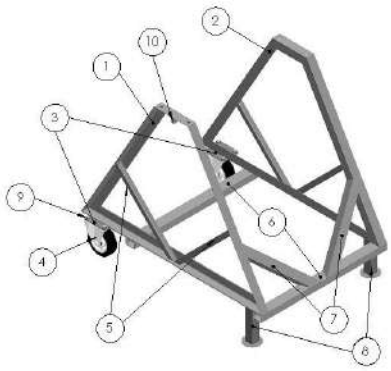
Sl. 9. Mehanizam okretanja bubnja
1 – noseća konstrukcija, 2 – zavrtanjska veza, 3 – držač točka za okretanje, 4 – točak zaokretanje, 5 – mali zupčanik, 6 – veliki zupčanik, 7 – zavrtanj, pomoćni element, 8 – pomoćni element, 9 – distantni prsten, 10 – otvori za fiksiranje položaja, 11 – nosač ručke za pozicioniranje, 12 – opruga, 13 – ručka za pozicioniranje.

Položaj bubnja se može fiksirati u četiri razna ugaona položaja pomoću poluge za pozicioniranje

(13). Poluga za pozicioniranje (13) nalazi se u potpornom elementu (11) na nosećoj konstrukciji mešalice. Da bi se sprečilo pomeranje poluge za pozicioniranje (13) iz otvora za fiksiranje položaja (10), koristi se opruga (12).
Na prototipu postoje četiri stabilna položaja: u prvom se prazni, u drugom se puni, u trećem (kad je bubanj okrenut vertikalno naviše) se vrši mešanje, a u četvrtom (kad je bubanj okrenut vertikalno naniže) se transportuje ili skladišti.

3.9 Noseća konstrukcija

Na Slici 10 prikazana je noseća konstrukcija prototipa mešalice. Elementi konstrukcije su međusobno zavareni. Za izradu noseće konstrukcije predviđeni su standardni L-profili, zatvoreni kvadratni profili kao i pljosnato željezo. Konstrukciju čine dva glavna elementa: leva potporna noga (2) i desna potporna noga (1). Postoji mala razlika između dve potporne noge zbog mehanizma za okretanje bubnja i držača ručke za pozicioniranje bubnja (10). Dve potporne noge su povezane poprečnim gredicama (6). Ukrućenje konstrukcije je rešeno pomoću elemenata ukrućenja (5 i 7). U cilju pokretanja i stabilnosti tokom rada, mešalici su dodata dva točka (4) i dva nogara (8). Točkovi su pričvršćeni zavrtnjima (9) za ploču (3), zavarenu za konstrukciju.



Sl. 10. Noseća konstrukcija

1 – desna potporna noga, 2 – leva potporna noga, 3 – nosači točkića, 4 – točkovi, 5 i 7 – elementi ukrućenja, 6 – poprečne gredice, 8 – nogari, 9 – zavrtanjske veze pričvršćivanja točkića, 10 – nosač ručice za pozicioniranje bubnja.

4. EKONOMSKI PRORAČUN

Radi kontrole isplativosti izrade prototipa urađen je ekonomski proračun izrade prototipa konstruisane mešalice. Rezultat ovog proračuna se ne poklapa sa očekivanom cenom gotovog proizvoda, pošto se cene izrade kod serijske proizvodnje ne mogu uporediti sa cenama izrade jednog komada – znači izrade u pojedinačnoj proizvodnji. Međutim iskustvo ukazuje na to da se po izradi prototipa mogu uvesti pojednostavljenja konstrukcije uz zadovoljavanje prethodno postavljenih tehnoloških i ekonomskih ciljeva.

Troškovi izrade će se na ovom mestu prikazati u glavnim crtama.

1. Troškovi noseće konstrukcije sa cenom potrebnih elemenata i sa pretpostavljenim brojem potrebnih radnih sati – 12 radnih sati (po 550 dinara/radni sat u bruto iznosu) iznosi *20 927* dinara.
2. Troškovi izrade bubnja sa svim pripadajućim standardnim i nestandardnim elementima i sa pretpostavljenim brojem potrebnih radnih sati – 38, iznosi *115 036* dinara.

Ukupna cena izrade prototipa tako iznosi *135 963* dinara u bruto iznosu.

5. ZAKLJUČCI

U ovom radu je prikazana konstrukcija prototipa jedne mešalice za glazuru. Pri izradi prototipa se pošlo od osnovnih tehnoloških i ekonomskih pretpostavki, radi dobijanja takvog rešenja koja se može lako primeniti u proizvodnji, a čiji rezultat bi bio konkurentan i na tržištu.

Mora se međutim naglasiti da se radi o prototipu, koji se mora nakon izrade podvrgnuti detaljnim ispitivanjima, nakon kojih će se iskristalisati konačno rešenje konstrukcije koja će prethodno postavljene ciljeve zadovoljiti u najvećoj meri. Jedan od najbitnijih ciljeva je postizanje prodajne cene ne više od 500 evra, što po mišljenju konstruktora, a nakon analize tržišta, može se smatrati konkurentnim.

6. REFERENCE

[1] Chowhana Z.T., Linna E.E.: *Mixing of pharmaceutical solids. I. Effects of particle size on mixing in cylindrical shear and V-shaped tumbling mixers*, Powder Technology, 24,2, 237-244, 1979.
[2] Fejes, G.: *Ipari keverőberendezések*, Műszaki Könyvkiadó, Budapest, 1970.
[3] McCabe W.L, Smith J.C.: *Unit Operations of Chemical Engineering*, Mc Graw Hill Companies Inc. 2005.

Autori: **dr Imre Nemedi, dr Robert Šanta, dr Janoš Šimon,** Visoka tehnička škola strukovnih studija Subotica, Marka Oreškovića 16, 24000 Subotica, Srbija, Tel: +381 24 655 201.
E-mail: nimre@vts.su.ac.rs
santa@vts.su.ac.rs
simon@vts.su.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Topčić, A. Nurkić, A. Cerjaković, E. Lovrić , S. Herić, M.

APPLICATION OF "SOFT" THREE-DIMENSIONAL PRINTING TOOLS IN INJECTION MOULDING OF PLASTIC PARTS

Abstract: *Finding the possibility of efficient, cost-effective and time-efficient production of products in the global market, characterized by increasing individualization of products and reducing serial production, is one of the important aspects of maintaining and increasing the competitiveness of manufacturing companies. One of the modern approaches that can give an adequate answer to the set requirements is the application of rapid tool development in a wide range of potential applications determined by available RP systems, available building materials and adequate choice of pre- / post- / process parameters. In order to analyse the possibilities and limitations of this approach, the paper presents an example of production and application of "soft" RT tools produced by the 3DP process for the production of plastic parts by injection moulding of plastic.*

Key words: *Three-dimensional printing (3DP), Rapid Tooling (RT), Injection moulding of plastic*

1. INTRODUCTION

The term processing of plastics means all processes by which semi-finished products or finished products are obtained from raw plastic materials (polymers). Plastic processing methods can be classified in different ways (aspects of technological processing, state of polymers, type and composition of polymers, etc.) [1]. One of the processes of processing plastic materials from the aspect of processing technology, regardless of chemical and physical changes that take place during the processing is injection moulding (pressing) of plastic a parts, which is basically processing of plastic using pressure with heating/cooling of processed material. Immediate realization of the production process is performed on injection moulding machines, where essentially plastic mass (thermoplastic) in the form of granules melts to a state where it can be injected by pressure into the injection tool, where it is cooled to the desired product shape, Fig. 1.a. In order to realize the technological process of injection moulding of plastic materials, it is necessary to provide an adequate tool - injection mould (kokila), which contains one or more profiled recesses with a contour that corresponds to the shape of the desired part into which molten plastic material is injected and subsequently cooled. Thanks to its characteristics and capabilities, plastic injection is one of the most common methods of processing plastic materials in mass production.

Rapid Tooling (RT) encompasses a range of techniques and approaches based on additive manufacturing processes used to rapidly produce segments or entire tools. This approach is sometimes combined with conventional machining processes to eliminate certain shortcomings or further improve the qualitative characteristics of parts produced by additive manufacturing processes. RT is most often used when it comes to geometrically complex tools whose production would be very expensive by conventional procedures, provided that the characteristics of building materials meet the purpose of RT tools application [2], Table 1.

Table 1. Classification of RT processes according to the method of application and tools service life

Method of application...		Tools service life ...	
Direct	Indirect	„Soft“	„Hard“
production of functional tools	production of RP part that will be used for the production of functional tools	one-time / limited use of tools that are destroyed during production	multiple application / longer tool life in production

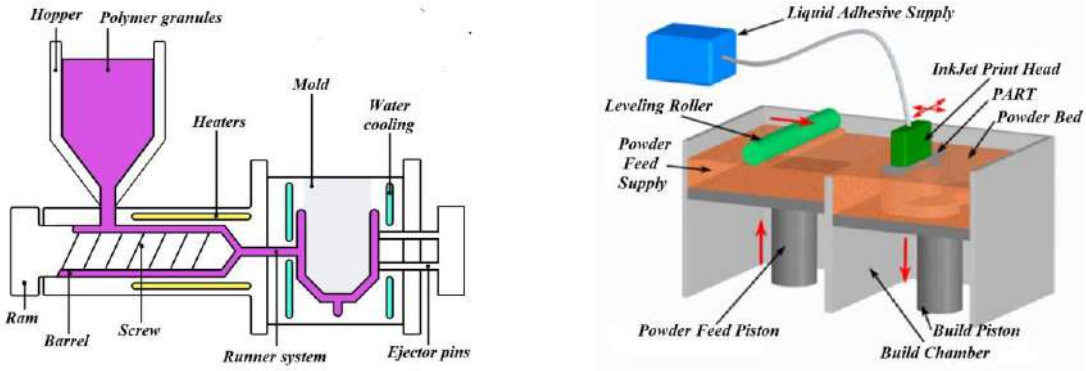
Classification of RT tools into "soft" and "hard" tools primarily is determined by the mechanical characteristics of building materials, methods of pre- / post-processing and production, which affect the mechanical characteristics of manufactured RT tools, as well as with characteristics of the production process for which RT tool designed and where it will be used.

One of the additive manufacturing processes which, thanks to its characteristics, enable the production of prototypes, functionally usable parts and tools in a wide range of available building materials is the process of three-dimensional printing (3DP), Fig. 1.b. 3DP process based on

patented 3D™ MIT (Massachusetts Institute of Technology) technology essentially is based on chemical binding by adhesive liquid medium (binder) of building material – powder (ceramics, metals, polymers and composite, etc.), whereby the 3D physical objects are "printed" directly from 3D CAD environment by successive application of layers of building material with appropriate appearance).

2. EXPERIMENTAL WORK

In order to analyse the possibility of applying 3DP parts, as a "soft" RT tools, for the needs of individual production of plastic components, the development and design of plastic injection

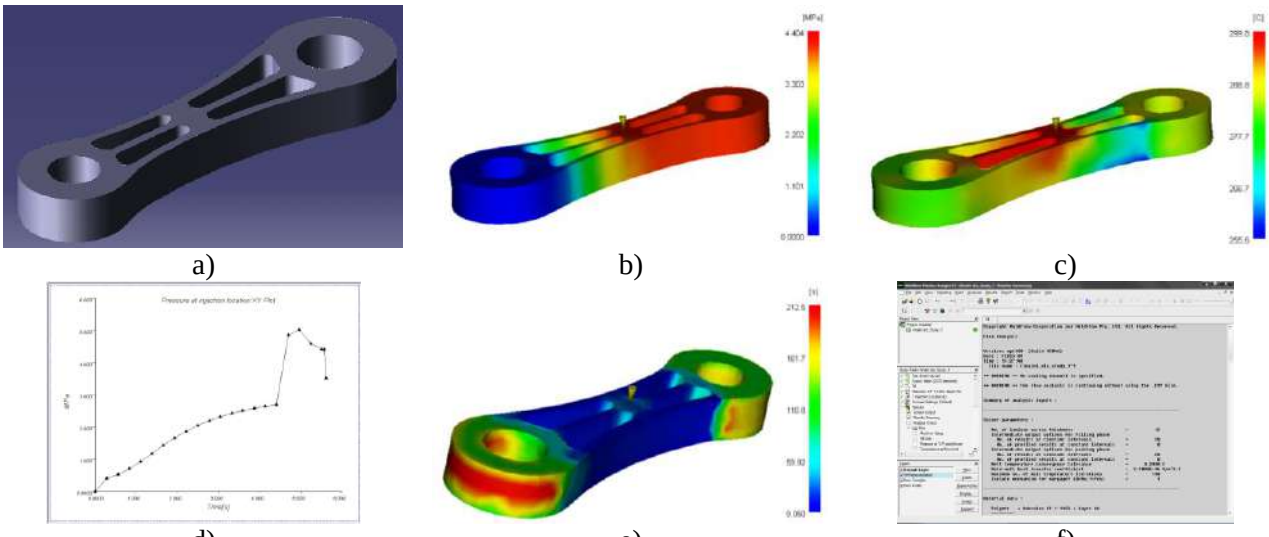


a) b)

Fig. 1. a) General Injection molding system [3], b) Process of three-dimensional printing [4]

thickness (function of the desired accuracy) according to pre-processed 2D cross sections generated from 3D CAD model. 3DP production process implies adequate realization of pre-processing (triangulation, **.stl* creation, etc.), processing operations (local control over: binding of building material, microstructure and surface texture of produced parts, orientation of part in working chamber, etc.), and post-processing of so called "green" part (removing form building chamber, de-powdering, infiltration of parts with suitable infiltrates, heat processing, sand blasting, painting, lacquering or metalizing for better visual

moulding tools was approached. Appreciating the fact that the mechanical characteristics of the produced 3DP parts do not allow the application of the same as conventional tools for direct injection moulding of plastics on existing production machines, it was necessary to find an adequate solution. According to the set limitations, the solution was found in the design of a modular tool for plastic injection, which is basically consists of a metal support - single-sided mould with associated elements (guides, punches,…) made of steel and mounted on a conventional plastic injection machine serving as a carrier for a modular



a) b) c)

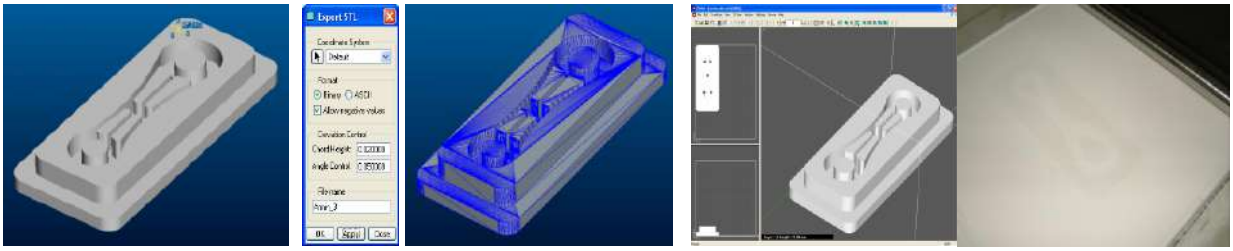
d) e) f)

Fig. 2.a) 3D geometric shape of the test piece, b) simulation of filling time, c) melting temperature, d) pressure change at the injection site, e) cooling time, f) settings of the FROMAG 70/20 injection molding machine used for FEM simulation in *Moldflow Plastic Insight*

3DP insert. The modular 3DP insert are placed on one side of the mould and serve to form the shape of the desired plastic part, i.e. the plastic material is injected into it. This design of the tool enabled the application of the 3DP printed part - modular insert as a "soft" RT tool, but in this case for direct application in the production process. In addition, the designed modular concept creates preconditions for the individual production of different geometric shapes of finished plastic products in the dimensions defined by the insert by simply changing of the modular segment.

For the test piece the geometric shape of the product which is used as spacer and for positioning of the pipes for guiding the coolant (oil) in the cooling system during the production of plastic parts (Fig 2.a) was selected. In order to ensure as much information as possible during the production of test pieces, they are geometrically modified in relation to the real part by performing a variable wall thickness of longitudinal ribs (1 ÷ 4 [*mm*]), as well as choosing slightly higher conicity compared to the recommended values of standard plastic injection tools. For the purpose of designing the modular part of the tool - 3DP insert, FEM analysis of polymer flow was performed in the software package *MoldFlow Plastics* in order to define the optimal parameters of the injection moulding process, Fig. 2.b, c, d, e, according to the defined settings of the production machine FROMAG 70/20 which was used for the production of the experimental plastic part, Fig. 2.f.

According to the results of the performed analysis, a modular 3DP insert was design (Fig. 3.a), its pre-processing (Fig. 3.b) was performed in the *ProEngineer* software package, as well as in the operating software of the 3DP machine (*ZPrint*, Fig. 3.c), and it was produced on a 3DP machine ZCorp 310+ (Fig. 3.c). For the production of the 3DP insert, the building material zp130 (plaster based) with the hardener zb58 was used.

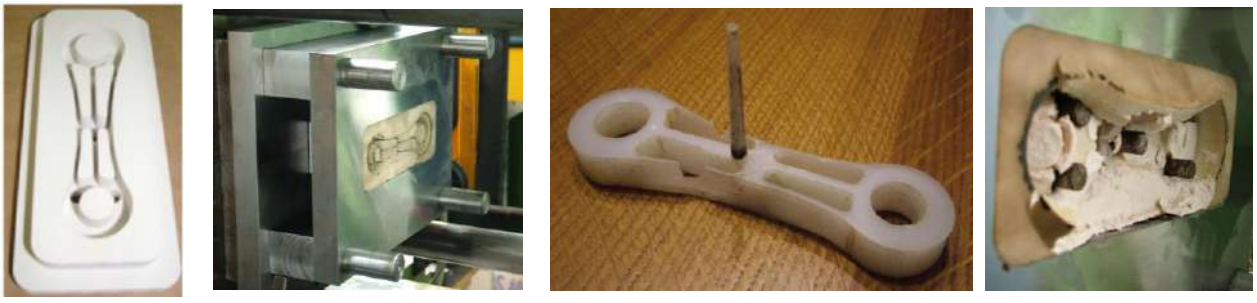


a) b) c)

Fig. 3. a) 3D CAD model of 3DP insert, b) pre-processing of 3DP insert - **.stf* format with parameters of triangulation approximation, c) position of 3DP insert in the working chamber of the 3DP machine and the finished 3DP insert in the working chamber

Due to the high pressures occurring inside the mould (Fig. 2.d) during injection moulding, achieving the appropriate mechanical characteristics of the 3DP insert required adequate attention. Consequently, during the pre-processing of the 3DP insert the selection of the following parameters were taken in to account: three-dimensional approximations parameters, scaling factor, generation of cross-section controls and according to [4], [5], [6] suitable building orientation of the pieces within the working chamber of 3DP machine, as well as during post-processing of the "green" 3DP insert (Fig. 4.a) appropriate de-powdering, heat treatment and infiltration with epoxy hardener Z-Max were done.

After the production and preparation of the tool (Fig. 4.b), direct plastic injection was started, and



a) b) c) d)

Fig. 4. a) "green" 3DP modular insert, b) completed one-sided mold tool with 3DP insert ready for the realization of the production process, c) produced part with the rest of the inflow channel, d) appearance of modular 3DP insert (kokila) after eruption of the produced part

the produced plastic part is shown in Fig. 4.c. As can be seen in Fig. 4.d there was a complete disintegration of the 3DP modular insert as a result of the action of the punch (seen in the figure) and it could no longer be used to inject the new part. Produced plastic part retained the desired geometric shape, but clearly is indicated the limitations of the wall thickness of the longitudinal ribs, i.e. the walls of thickness 1 and 2 [*mm*] were damaged during the eruption from the modular part of the mould. Repeated experiments on the identical part resulted in the same conclusions.

3. CONCLUSION

The use of "soft" RT tools for direct production of parts is accompanied by a number of limitations that need to be taken into account before they are directly used in production processes. In order to ensure optimal characteristics of "soft" RT tools designed for direct production of the plastic parts, it is important to know the characteristics of used additive manufacturing system in terms of choosing of the appropriate building material, pre-processing (triangulation approximation, scaling, orientation in the working chamber), processing (defining of additive manufacturing processes parameters) and post-processing (heat treatment, infiltration). By adequately choosing the appropriate parameters, it is possible to achieve the optimum in terms of the required accuracy of the manufactured part, and to a limited extent to influence the mechanical characteristics of manufactured "soft" RT tools that in principle limit their usage to single or strictly limited purpose [2]. In addition to the above mentioned limitation, the justification for the use of "soft" RP tools in everyday practice can be found in the relatively low cost of production of such tools in terms of the cost of construction materials as well as the cost of procurement and operation of additive manufacturing systems.

The presented example of the application of "soft" RT tools in the individual production of parts by the process of injection moulding of plastics fully confirms the previously stated claims. Of course, this application required certain adjustments, which are primarily reflected in the design of the modular tool - a mould with a modular 3DP insert. As noted, this approach enabled the production of a single functional plastic piece, it resulted in the destruction of the modular insert, and pointed to limitations on the minimum wall thickness of the injected plastic piece (> 2 [*mm*]). However, given the low production costs of the modular 3DP insert, the potential of this approach is pointed out, which is reflected in the production of functional prototypes / individual plastic parts of different shapes and sizes within the dimensions of the modular insert, and optimization of injection mould geometry (cavity) for potential mass production.

4. REFERENCES

[1] Jaarsma, F.: *Injection molding and design with plastic*", New York, 2001.

[2] Topčić, A., Lovrić, S., Fajić, A., Cerjaković E.: *Brza izrada prototipa i reverzibilno inženjerstvo u proizvodnji alata za livenje u pijesku*, Tuzla, 2016

[3] https://www.sourcingallies.com/plastic-injection-moulding, accessed website: 08 October 2021

[4] Topčić, A., Cerjaković, E., Lovrić, S.: *Analysis of dimensional accuracy of ceramic parts produced by three dimensional printing process*, Journal of Production Engineering, Vol.17, No.1, pp 63÷66, Fakultet tehničkih nauka Novi Sad, 2014.

[5] Fajić, A., Tufekčić, Dž., Topčić A: *Effect of processing parameters on tensile strength of 3D printed parts*, Proceedings of 13th International Conference – Mechanika, Kaunas, Litvania, 2008.

[6] Topčić, A., Tufekčić, Dž., Fajić, A., Cerjaković, E.: *Implementation of Three Dimensional – 3DP printing process in casting*, 5. Zbornik radova 5. međunarodnog simpozija "Konstruisanje, oblikovanje i dizajn, KOD 2008", Novi Sad, Srbija, 2008.

[7] D. Siminiati, L. Pomenić, F. Oršić: *The base parameter adjustment for injection moulding of plastic*, file:///C:/Users/Alan/AppData/Local/Temp/16_ER_Siminiati_Pomenic_Orsic_28_1.pdf , accessed website: 29 September 2021

[8] Jurković, M., Mahmić, M., Jurković, Z.: *Evolution and application of Rapid Prototyping technologies*, Journal for Technology of Plastic, Vol. 30, Num. 1-2, str. 95÷108, 2005.

Autors: **Prof. dr Alan Topčić, Armin Nurkić, dip.inž.maš., Prof. dr Edin Cerjaković, Prof. dr Slađan Lovrić, Mr.sc. Muhamed Herić, dipl.inž.maš.,** University of Tuzla, Faculty of Mechanical Engineering, Urfeta Vejzagića 4, 75000 Tuzla, Bosnia and Herzegovina, Phone: +387 35 320 920, Fax: +385 35 320 921.

E-mail: alan.topcic@unitz.ba
nurkicarmin@hotmail.com
edin.cerjakovic@unitz.ba
sladjan.lovric@unitz.ba
muhamed.heric@hotmail.com

ETIKUM 2021

INTERNATIONAL SCIENTIFIC CONFERENCE
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Živković, M., Beloica, N.

HOW TO MAKE HYDRAULIC SYSTEMS MORE ENERGY EFFICIENT?

Abstract: *In addition to taking into account the basic design principle, "**4E**" (**E**conomy + **E**fficiency + **E**rgonomics + **E**nvironmental friendliness) in recent years there is more and more talk about the survival of the planet and about "**3R**" (**R**ational use of resources + **R**eduction of harmful gas emissions + **R**ecycling). All these have become binding recommendations in the design of machines and plants, as well as all production processes. For that reason, the author of the paper will, experientially and using literature data, point out the tendencies and ways of regulation and control of hydrostatic energy, considering all the problems of this way of transmission and meeting the above recommendations. The emphasis is on energy efficiency and cost - effectiveness of hydraulic energy management and control solutions, as well as all tendencies in the development of the device, which achieves the same. All this must be harmonized with the manufacturers of machines (plants) and harmonized with the needs of the user (customer).*
Key words*: economy, efficiency, ergonomics, recycling, circular economy*

1. INTRODUCTION

The abbreviations "4E" and "3R" have a connection with the concept of circular economy, a term introduced to explain in more detail the importance of responsible behavior of manufacturing companies in today's / changed business conditions. New business conditions as well as legal regulations are forcing manufacturing companies to abandon the linear model, ie the linear economy. It is based on the concept of "take - make - use - reject", ie to exploit natural resources. This trend of behavior has led to the generation of large amounts of waste, which has had a negative impact on the quality of the human environment. Large amounts of waste require the construction of large landfills, which disrupts the flora and fauna as well as the quality of the land itself. Based on the experience of some countries, most discarded materials can be reused in primary production. When waste is recycled, ie. reuse / repair is called circular economy. Such a concept is based on the circulation of materials in the economy and waste is considered a raw material. The significance of this approach is shown in Figs. 1 and table 1, [1]. Figure 1 shows the percentage needs for steel as well as the forecasts for its utilization by recycling, by industry. A similar analysis can be observed on the example of hydraulic oils. They are specially important for ecology.

Considering the importance of energy saving, the authors of this paper will, using their many years of experience in the design, manufacture and maintenance of hydraulic devices and systems, point out the tendencies and application of new concepts in solving this type of power generation, transmission and conversion.

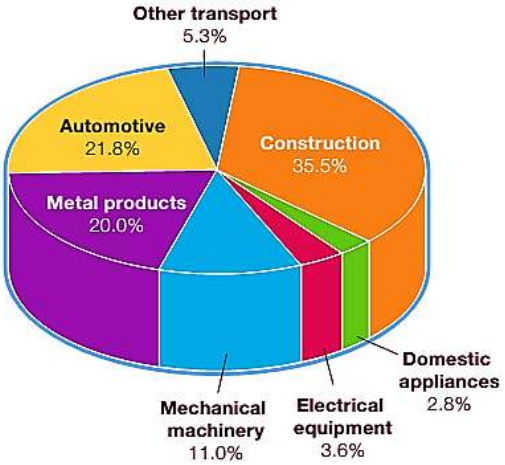


Fig. 1. Typical use of steel similar to applications in developed countries today

Table 1. Predicting the utilization of recycled steel by areas of application

Economic sector	Recovery rate 2007 (%)	Recovery rate 2050 (%)	Life cycle in years
Construction	85	90	40 -70
Automotive	85	90	7 - 15
Machinery	90	95	10-20
Electrical and domestic appliances	50	65	4 - 10
Weighted global average	83	90	N/A

As pumps are the heart of every hydraulic system and, it can be said, they have a crucial impact on their productivity and efficiency. Also working fluid, ie. oil is no less a significant economic and environmental indicator. It is also necessary to talk about the lowest possible operating costs and maintenance costs.

2. HOW TO DESIGN ENERGY EFFICIENT HYDRAULIC SYSTEMS TODAY?

The initiative of the European Union, ie. The "Green Deal", as well as the important document of the German government "Energy Efficiency Strategy 2050", are politically defined almost binding recommendations on increasingly significant reductions in CO2 emissions, [2,3]. All this has and will have a significant impact on the overall technical and technological development in the coming period. For this reason, it is required that all solutions be propulsion alternatively efficient as well as hybrid, which should be especially true for mobile machines, fig. 2 [2,3]. In the future, they will be equipped with battery-powered electric drives, fuel cells or diesel generators. The hydraulic system, therefore, requires more efficient components and motion control systems. All this imposes some themes and dilemmas on both designers and constructors:

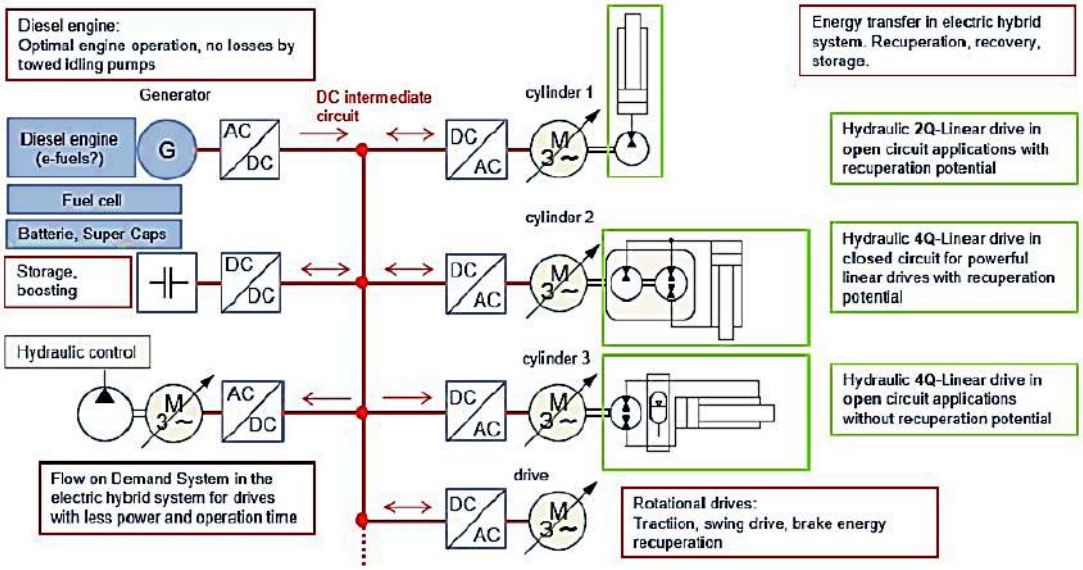


Fig. 2. Hydraulics of electrically driven mobile machines

▪ **Challenges for propulsion technology**: In order for mobile machines to run on electricity, it must be economical to ensure, between two charges, a sufficiently long operating time and that their operation is reliable and fast, at high power levels, similar to previous machine drives. Low noise emission as well as low costs are required, in terms of energy consumption and maintenance costs.

▪ **Efficiency is the primary factor**: Using efficient components or systems can only prove useful. As electric drives already have high efficiency in a fairly wide operating range, in relation to today's significant application of hydraulics, [2]. That is why it is necessary to pay special attention to the improvement of all drive solutions by hydraulic transmission.

▪ **Pressure limits of existing hydraulic systems**: Pressure requirements, with the help of variable volume pumps, so-called load-sensitive systems (LS systems), are not optimal for electric drives, [2,3]. Noise emissions from conventional axial pistons axial piston pumps with variable flow are too high. This should be especially emphasized in the case of electric pump drives due to the absence of diesel engine noise. However, the efficiency level of pumps with "LS water" is not optimal in the entire operating range. For this reason, it is not recommended to just replace the diesel engine with electric motor drive, and thus leave the existing hydraulic system unchanged.

▪ Due to many advantages, reciprocating axial pumps (of all design solutions) have found significant application in the solution of many drives by hydrostatic power transmission. The main advantages are the compactness of the drive, the ability to adapt to changing operating conditions and high power density. Their application is, for design reasons, limited to 450 bar, including medium and higher volumes. In order to expand the scope of application of piston-axial pumps, some manufacturers offer new /

improved solutions, [6,7]. When higher operating pressures are required, reciprocating radial pumps, constant working volumes are usually used or their achievement is achieved. pressure multiplier. Pumps that operate at lower pressures, such as gear pumps with a constant working volume, are generally used in lower-cost applications.

▪ Power losses, in hydraulic systems with built-in variable flow pumpstabela T–2,[6]. With modern operating solutions with pumps of constant and variable working volume and the achieved effects, Figure 3 [7] and Figure 4 show a decrease in efficiency with an increase in working pressure to maximum [8,9].

Fig. 3. Electro-hydraulic hybrid drive system

Table 2. Typical power losses in hydraulic systems with variable flow pump

Ordinal number	Loss of strength	% share
1.	Leaks in the pump due to leaks	10
2.	Mechanical friction losses	10
3.	Losses in the pipeline system	15
4.	Losses in valves	30
5.	Useful (used) power	35
	IN TOTA: ∑	100

Thus, the basic version of the A4VSO type pumps has been redesigned so that the pressure has been increased to 630 bar and thus the historical pressure value of 450 bar has been exceeded. This significant increase in pressure level allows users to significantly reduce the nominal size of the components, without the need for a pressure transducer. The power density of the redesigned HA4VSO was increased by 36% compared to the standard A4VSO as well as a significant increase in the possibility of self-suction [6]. On the other hand, the scope of application applications, such as mobile machines of lower power (small tractors, forklifts and mini loaders), is expressed by a pronounced demand for the same, which leads to lower exhaust emissions and better fuel efficiency [6,10].

The potential for energy savings is the replacement of hydraulic systems with constant displacement pumps with variable flow pumps (all types of regulation) as shown by applications with high installed power [10].

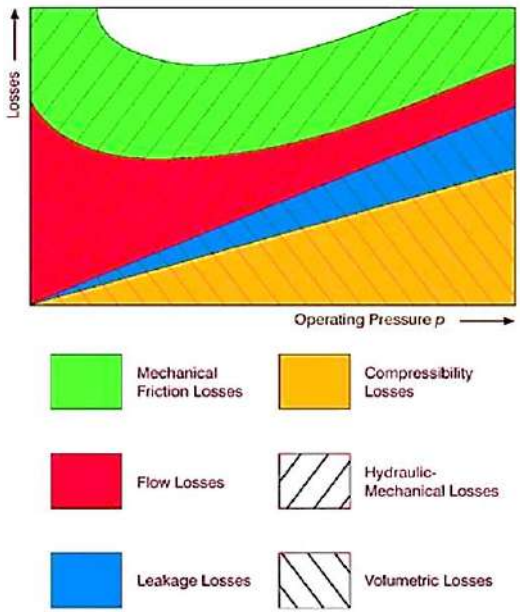


Fig. 4. Dependence of piston pump efficiency on operating pressure

The energy efficiency of heavy machinery is of wider interest due to the increased fuel costs, where the preservation of the environment is important. The dynamic performance of such drives is more favorable compared to electric or electro-mechanical drive systems in large drive systems, as illustrated in the table T-3[10,11,12].

Table 3. Overview of energy transmission technologies

Comparison parameters	Electro mechanically (EM)	Electro hydraulic actuator (EH)	Electro hydrostatic actuator (EHA)
Energy Efficiency	+++	++	+++
Environmental impact	+++	+	+++
Low Noise Emission	+++	+	+++
High Forces	+	+++	+++
No Backlash	+++	+++	+++

When the actuator is required to accelerate or decelerate, using a flow control valve, the pressure in the control circuit drops. Damping the valve converts it into heat, which can have negative effects on environmental environment and systemic energy loss. For this reason, problems in the operation of hydraulic systems are manifested, expressed through an increase in temperature, contamination, vibration as well as increased leakage and noise. Therefore, it is necessary to reduce energy loss and thus heat, which is especially characteristic of conventional hydraulic systems. They usually use pumps that receive a constant drive of 1450 rpm. By controlling the speed of rotation of the hydraulic pump, unnecessary energy losses are prevented and thus an increase in drive efficiency is achieved. A basic example of control, in conventional conventional hydraulic systems, are shown in Figure. 5,[10,12]. From it you can see the ways of conversion and the corresponding expressions for power

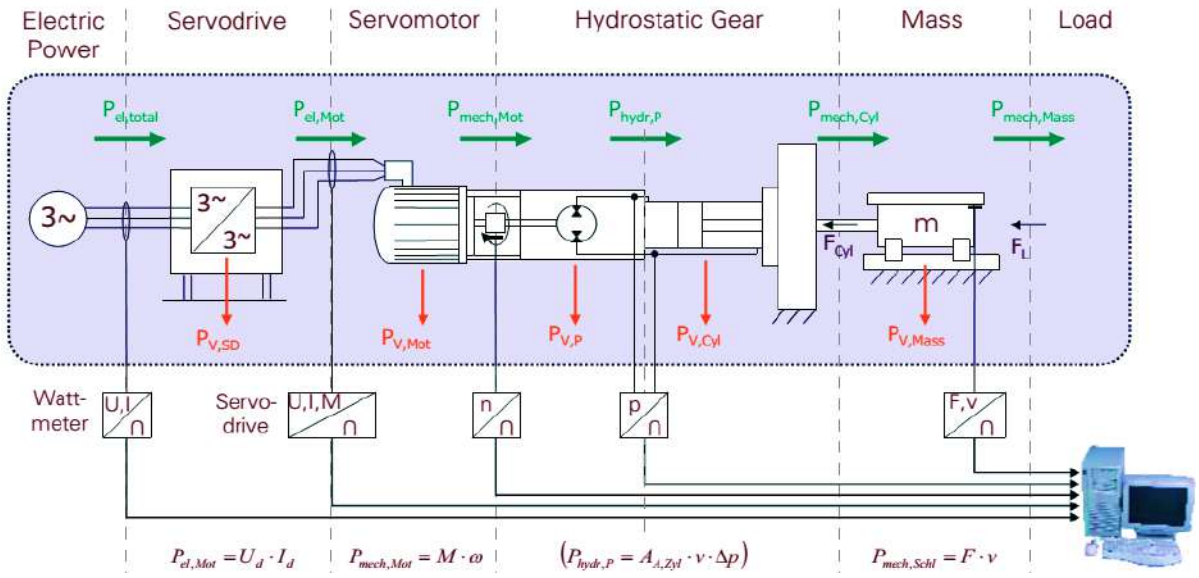


Fig. 5. Example of modern control of operating parameters

▪ **Actuator replacement**: Replacing hydraulic cylinders with electromechanical linear actuators has proved impractical. Power transmission using gears is not convenient because they cannot withstand the large loads that characterize construction machines. Therefore, any electromechanical linear drive would require an electric motor of adequate power, which would make the installed power quite high, which is almost never needed at the same time.

▪ More efficient hydraulics with the condition "flow as needed": A compromise between high efficiency and low cost, it is considered that the hydraulic system is optimal. Closed-loop linear drives are an excellent choice for high-performance functions, where there is the possibility of feedback energy conversion. These are the systems with the least energy losses. For this reason, each linear function requires a combination of electric motor and pump, which can be comparable to electric - mechanical linear drives. For precise movements, control valves with the possibility of flow control are used, which has proven to be an economical solution, [3,5]. However, it is possible to combine combinations of electric drives and hydraulic systems optimally in an electrical system with a DC intermediate circuit. An example is the solution with a hydraulic pump of constant working volume where the speed of the electric motor is set in accordance with its optimal operation (min. - max). Optimal system operation depends on the current load and pressure losses, which can be minimized

by optimizing and designing the system. This means adjusting the valve opening speed and controlling the speed of the pump shaft, ie. simultaneous control, however as the response speed is very fast it can be said that it is comparable to the performance of electric drives.

▪ **Pump efficiency**: Working with variable speed, the pump is especially important because, as is well known, it is considered to be the heart of any hydraulic system. However, compared to the efficiency of high-quality electric motors, it would have to work with an efficiency of 92 to 94%, in a wide operating range. By reducing the power loss on the hydraulic pump by reducing volume and mechanical losses, for example from 5 to only 2.5 kW, it significantly contributes to the overall energy efficiency of the machine. Leading manufacturers of hydraulic pumps today offer high-performance pumps with low and "pleasant" noise levels, which is what end users expect. Current design solutions of pumps are characterized by the ability to start under high pressure and the ability to work at very low speeds, without premature and excessive wear, [3,4,5]. Based on all the above, it is recommended to use drive devices of well-known and proven hydraulic manufacturers for the formation of drive units. They produce and offer standard components, which cover almost all project requirements. By combining modular components, efficient functional units can be formed, which also applies to hydraulic distributors and / or battery stations. Apply the universal system method for energy efficiency on the same principle for all hydraulic units. The power of the drive should be determined on the basis of all future load characteristics, ensuring that the drive is not oversized. With the drive solution, strive for the highest possible efficiency in order for hydraulic pumps to use energy economically. Compared to fixed displacement systems, innovative solutions of variable speed pumps and their drive control, both torque and speed (eg Sytronix), energy consumption is reduced by up to 40%, [2,3]. It also allows for a significant reduction in installed power as well as a smaller amount of available working fluid. Rexroth on the example of "4E" uses four principles in the design and selection of components, which perhaps best shows the importance and benefits, Figure 6, [2,3,4]:

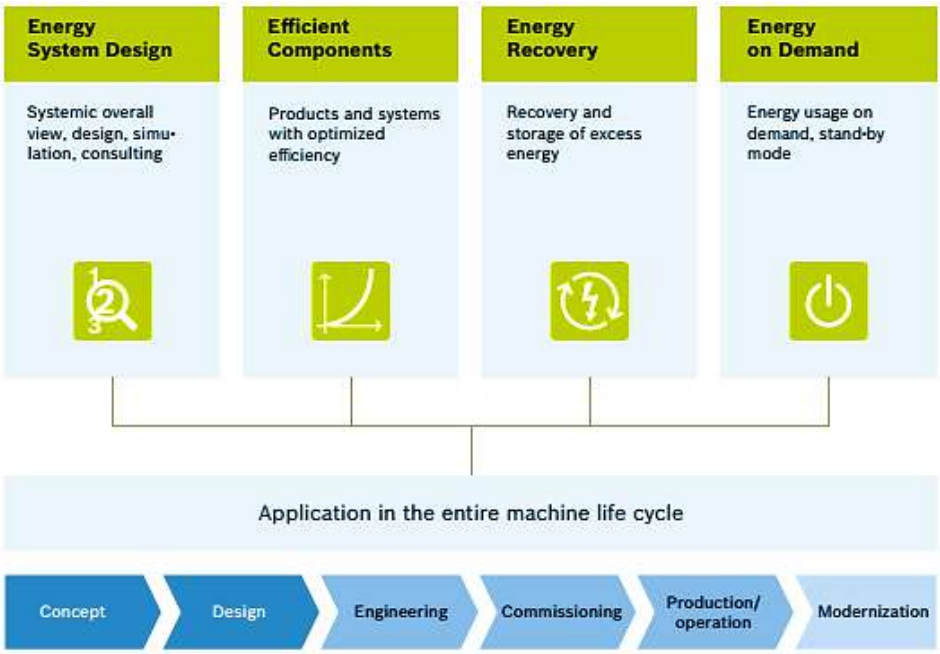


Fig. 6. Energy efficiency measures in all phases of product/machine life

• Energy efficient systems,
• Energy efficient and integrated components,
• Energy is converted, and
• Energy at the request of the user (optimal).

With larger installed drive forces and the so-called. peak load cascade assembly (motor - pump - motor), additional energy advantages are offered, [2,3,4,5]. In cases of partial load, it should be possible to disconnect unnecessary assemblies from operation and bring them into "idle operation" mode, which enables significant energy savings. je In recent years, everything has been noticeable more pronounced trend that the legal regulations, which apply to mechanical engineering and construction of industrial plants, provide, from year to year, lower and lower limit values of permissible emissions of noise and harmful gases. Thus, almost as a rule, many users apply even stricter standards and recommendations. Therefore, the world's leading and well-known pump manufacturers use

innovative solutions to reduce noise directly at its source and thus reduce investment in subsequent insulation, which would otherwise make their work more difficult and increase maintenance costs. Variable speed pump drives even reduce the average noise emission up to 20 dB (A), [3,4]. All device manufacturers must cooperate with international certification companies, which provides security to machine manufacturers and later to the operators themselves. They thus fulfill their responsibility towards the safety conditions of both employees and the environment.

According to many years of experience, the recommendation is that regular maintenance of the hydraulic system is necessary, which increases the availability for its entire working life. Today, it is possible, according to innovative solutions, to monitor the status and overall efficiency based on the Internet connection. Also, extending the service life of the hydraulic medium can significantly reduce operating costs, so their choice is the basis for that. Reliable clean fluids ensure trouble-free operation and integrity of the hydraulic system. Properly selected and installed in the hydraulic system filter elements, in addition to separating all mechanical impurities (wear products), can remove even the smallest amount of water from the hydraulic oil, which prevents corrosion and cavitation.

3. CONCLUSION

Manufacturers of hydraulic devices and direct users today must adhere to the basic principles of circular economy:

- As little material consumption as possible (lighter construction and better dynamic properties);
- Reduced power consumption;
- Savings on operating costs;
- Increasing reliability as well as service life;
- Reduction of noise produced;
- Reduced component dimensions;
- Reduced amount of oil in the system;
- Recycling and disposal of both component materials and working fluid...

4. REFERENCES

[1] World Steel Association; *SUSTAINABLE STEEL−At the core of a green economy*, ISBN 978-2-930069-67-8, Beijing, Chinahaoyang District Beijing 100125 China,(pp. 40), 2012.

[2] BUCHER hydraulics: *Overall Efficiency Optimized*, Fachartikel Technical Article, https://www.boschrexroth.com, 2020.

Compliance with the European Machinery Directives and all recommendations is a matter of course. Likewise, designers must comply with and apply all international and regional standards and regulations specific to hydraulics.

[3] Rexroth Bosch Group: *The Drive & Control Company*; R999000118, www.bosch rexroth.com, (pp.16), 2012.

[4] Rexroth Bosch AG: *Rexroth 4EE Rexroth for Energy Efficiency*, RE 08503/09. 11, The drive &Control Company, (pp. 14), 2018.

[5] Teresa B., Fornai B., Colla V., Ilaria Pistelli M.: *Industrial Symbiosis and Energy Efficiency in European Process Industries: A Review*, sustainability, pp. 37, 2021

[6] Mohn G., Nafz T.: *Swash plate pumps – the key to the future*, 10th International Fluid Power Conference/ Dresden, March 8 – 10 , Group 3 – Pumps, Paper 3 -1, (pp. 139-150), 2016.

[7] Kawasaki Hevy Industries: *KAWASAKI ECO SERVO (Electro - Hydraulic hybrid system - offers optimal* solutions to various), Cat. No. KPM1624, Japan (pp. 10), 2018.

[8] EATON: *Full Speed Ahead For Energy Efficiency*, Powering Business Worldwide, 4 o15081 670062, (pp. 32), 2018.

[9] NACHI: *Energy Saving Hydraulic Space Saving Low Ambient Temperature* - More Accuracy Noise Reducing Precise Pressure & Flow Control, (pp. 6), 2019.

[10] Michel S., Weber J.: *Energy-efficient electrohydraulic compact drives for low power applications*, Fluid Power and Motion Control, 2012.

[11] Ramesh.S, S. Denis Ashok, Shanmukha Nagaraj, M. Lohith Kumar Reddy, Niranjan Kumar Naulakha,Adithyakumar. C.R: *Energy conservation strategy in Hydraulic Power Packs using Variable Frequency Drive*, IOP Conf. Series: Materials Science and Engineering, 2018.

[12] Alamgir A. Choudhury, Prajna Paramita, Jorge Rodriguez P.E: *Study of Energy Efficiency Characteristics of a Hydraulic System Component*, American Society for Engineering Education, Paper ID #24018, (pp.10), 2018.

Authors: **dr Milutin Živković prof.s.s; Assis. Nikola Beloica,** Akademija strukovnih studija Šumadija (ASSŠ) – Odsek Trstenik, 37240 Trstenik (Srbija), Phone: +381 37 714 121
E-mail: mzivkovic@asss.edu.rs
nikola.beloica.ts@gmail.com

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Bobić, Z., Kovačević, L., Škorić, B., Čapo, I., Bulajić, D., Drljača, J., Csik, A., Terek, P.

INFLUENCE OF AFM SCANNING PARAMETERS ON CHARACTERIZATION OF FIBROBLAST CELLS ON COATED SURFFACES

Abstract: *In this study, we examined the influence of various atomic force microcopy (AFM) scanning parameters in contact mode on deformation of fibroblast on coated surfaces during measurements. The influence of the scanning parameters: the setpoint and scanning rate was observed. It was found that all scanning parameters have the significant influence on cell deformation during measurements and image quality and that the scanning rate has the highest influence. The lower value of setpoint and scanning rate lead to minimal cell deformation during measurements. Therefore, surface characterization of fibroblast cells should be performed with low values of setpoint and rate.*
Key words: *Biomedical application, Fibroblast cells, AFM, Cell size, Scanning parameters*

1. INTRODUCTION

Atomic force microscopy (AFM) is a well-established technique that is widely employed for characterization of biological samples. This technique provides topographic images and volume of living and fixed cells attached to a substrate. Numerous studies investigated the effects of type of substrate and influence of hormones on cell growth characterized by changes in cell volume [1–3]. In these studies, the evaluation of alive and fixed cells is predominantly performed by contact AFM method. This method is applied due to its excellent resolution and ease of use. However, one intrinsic problem concerning the contact AFM method is that in some cases the recorded cell dimensions are lower than the actual one. This occurs due to deformation of soft cellular material in interaction with the AFM tip [4–9]. Therefore, the following study was performed to indentify the influence of scaning parameters and evaluate their effect on cells measurements.

2. MATERIALS AND METHODS

The morphology of Fibroblast cells was investigated on coated steel samples. Surgical stainless steel (EN X2CrNiMo18-15-3) discs were grinded and polished with 3 μm diamond paste. TiAlN/CNx coating was deposited on disc samples by unbalanced magnetron sputtering unit, CC800/9 (CemeCon, Germany).

Cells were cultured in DMEM medium supplemented with 10% FBS and 1% penicillin-streptomycin and maintained in an incubator at 37 °C and 5% CO_2. Cells in the logarithmic growth phase were used in the experiments. Cells were seeded in a 24-well plate with a density of 5x104 cells per well. At the end of the treatment period (3 days), cells were washed with PBS (containing Ca/Mg), and then sufficient glutaraldehyde was added to cover the surface. After incubation for 20 minutes, paraformaldehyde was added, incubated for 20 minutes and cells were washed (at least 5x) with PBS.

AFM (CP-II di, Veeco) measurements were performed in contact mode, using symmetrically etched Silicon-Nitride tip (0.5 N/m). The employed scanning parameters were as follows: fast scanning direction Y-axis, scanning area 30 x 30 μm, gain 0.5 while the values of setpoints and rate are given in Table 1. All topographic images were acquired in two directions of tip movement during scanning, trace (TR) and retrace (RETR). Measurements were performed sequentially by a gradual increase of setpoint and scan rate.

Table 1. Varied AFM scanning parameters

	Setpoint [nN]	Rate [Hz]
Case 1	25	0.25
Case 2	25	0.5
Case 3	50	0.25
Case 4	50	0.5

3. RESULTS AND DISSCUSION

Representative topography images and profiles for Case 2, with different scanning directions of the fibroblast cell, are presented in Figure 1. Comparing the topographic images (Figure 1a and 1b) and profiles (Figure 1c), it can be noticed that during probe movement upward the cell, the cell was deformed (obliquely hatched in Figure 1e and 1f) and an overshot effect can be seen (vertically

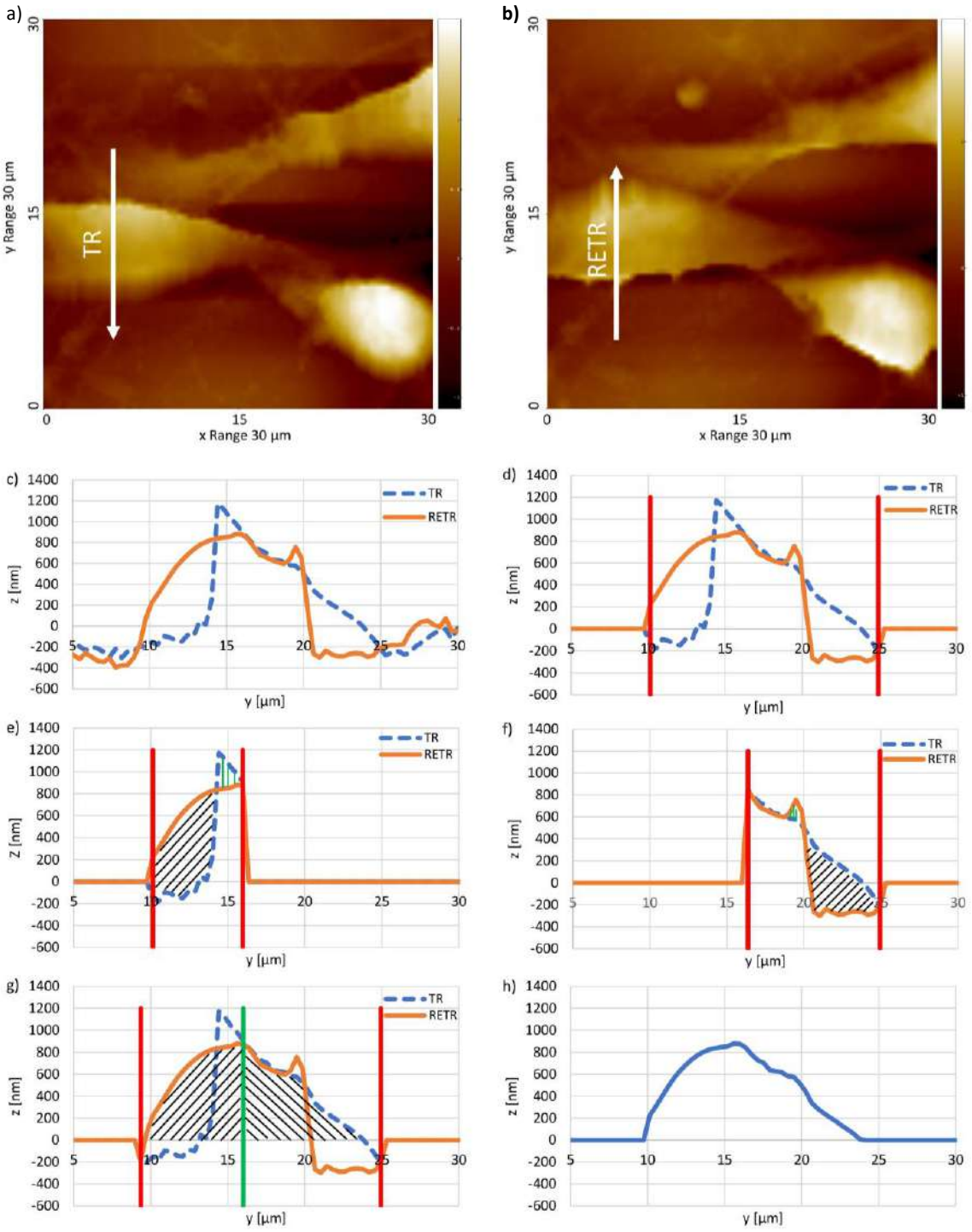


Fig. 1. Representative images: a) topography images in trace direction TR; b) topography images in retrace direction RETR; c) Profiles of same line in TR and RETR; d) Extraction of cell area; e) Deformation and overshot effect in TR; f) Deformation and overshot effect in RETR; g) Data used for approximation of real cell area; h) approximation of fibroblast cell area.

hatched on Figure 1e and 1f). While for both scan directions the cell deformation is less pronounced in downward probe path (Figure 1d and 1e). Also, it can be noticed, that the difference between topographic images, obtained in opposite scanning directions, is smallest on the highest sections of the cells. Such result is also obtained in previous investigations in which the cell volume was characterized [3,6,8]. Also, in previous investigations, it was reported that different parts of the cells have different stiffness [5,8]. Nucleus, the highest cell part, has the highest stiffness [3]. In other words, stiffness decreases with increase in distance from the nucleus [3,8]. Therefore, in order to observe the effects of scanning parameters on cell volume and cell deformation, we employed the following procedure. After extraction of the

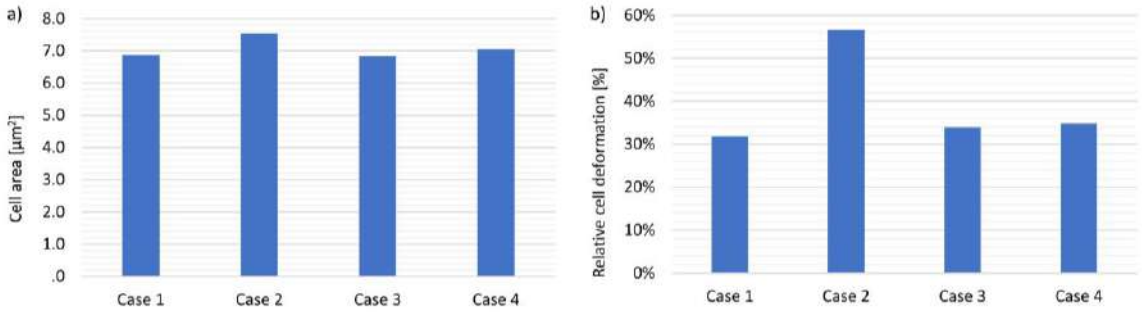


Fig. 2. Comparisons of scanning parameters influence on a) size of the fibroblast cell; b) the fibroblast cell deformation.

profile for both scanning directions (Figure 1c), a profile section that envelops the cell was observed for further analysis (Figure 1d). We assume that the AFM probe during its downward movement on fibroblast cell cause its minor deformation. Therefore, for approximation of the cell real cross-section area (Figure 1h) the data from downward probe paths, for both directions, is used (hatched in Figure 1g). For the same set of scanning parameters, the cell deformation was determined as a ratio between the deformed cell area and the approximated cell area.

The approximation cell area calculated for different scanning parameters is presented in Figure 2a. It can be seen that the highest cell area is obtained for parameters in the case 2 (0.5 Hz and 25nN). The smallest cell area is calculated for images obtained with parameters from the case 3. The second and third cell areas were calculated for images obtained with parameters from cases 1 and 4. Generally, these results indicate that the increases in scanning rate (from 0.25 to 0.5 Hz) and decrease in setpoint (from 25 to 50 nN) lead to an increase of cell cross-sectional area. However, it is evident that the cell cross-sectional area for case 2 is notably higher than the cell area for other cases. We assume that the scanner did not react fast enough to accommodate the large difference in cell height. This could be caused by an inadequate combination of scanning parameters, such as scanning rate, setpoint, and gain. This phenomenon could be suppressed by an adequate setup of the gain value. In previous investigations, where the influence of the setpoint (range of 20 - 1500 pN) on cell the deformation was observed, and the same effect was recognized [4,10]. The increase of setpoint leads to a decrease in cell cross-sectional area [4,10].

Cell deformation (in percent) is for different cases presented in Figure 2b. It can be seen that the deformation of cells is for all cases above 30%. These relatively high values of cell deformation are probably caused by a high value of setpoint which causes high deformation during the upward probe path on the cell, and also due to the overshoot effect. However, a similar effect which was significantly less pronounced is reported in investigations from the field [4,5,10]. Fibroblast cell underwent the smallest deformation in case 1 while the highest for case 2. The medium values of cell deformation were obtained for cases 3 and 4. These results indicate that in the observed range decreasing the value of setpoint and rate, , lead to smaller deformation of a cell.

Results obtained for cell areas (Figure 2a) and cell deformations (Figure 2b) indicate two trends. In cases with low setpoints, the increase of scanning rate leads to a large increase of cell cross-sectional area and deformation. On the other side, in cases with high setpoints this effect is less pronounced. Such finding indicate that the increase in setpoint decreases the influence of the scanning rate on the approximation of cell cross-section area. This effect is probably caused by a more appropriate ratio of gain and setpoint at high setpoints. Therefore, for a low setpoints, it is necessary to adjust the gain. In this study, it is determined that the most optimal AFM scan parameters, are the one in case with minimal setpoint and minimal scanning rate (case 1). A considerably high value of cell deformation (30%), which is determined in this study, indicates that in cases of contact AFM measurements these effects should be inevitably taken into account.

4. CONCLUSIONS

In this investigation the influences of setpoint and scanning rate, in contact AFM measurements, on the quality of fibroblast cell characterization were investigated. The analysis presented in this work lead to the following findings:

- Different parts of fibroblast cells have different susceptibility to deformation by AFM tip in contact mode.
- In the observed ranges, the increase of setpoint and decease of scanning rate lead to a decrease of measured fibroblast cell cross-sectional area.

- At lower value of setpoint (25 nN), the increase in scanning rate from 0.25 to 0.5 Hz had higher influence on deformation of fibroblast cells than in cases with high setpoints (50 nN).
- Values of setpoint above 25 nN cause high cell deformation during measurement. These deformations can reach up to 30% of approximated cross-sectional cell area. Therefore, in characterization of fibroblast cells with contact AFM mode the value of the setpoint should be selected below 25 nN

.

ACKNOWLEDGMENT

This research was founded by Serbian-Hungarian bilateral project (2021-2023) grant No.1. The results presented in this paper are part of the research within the project "Interdisciplinarity of technologies in production engineering", at the Department of Production Engineering, Faculty of Technical Sciences, University of Novi Sad. Serbia.

5. REFERENCES

[1] LK. Andersen, SA. Contera, J. Justesen, M. Duch, O. Hansen, J. Chevallier, M. Foss, FS. Pedersen, F. Besenbacher, *Cell volume increase in murine MC3T3-E1 pre-osteoblasts attaching onto biocompatible tantalum observed by magnetic AC mode atomic force microscopy*, Eur. Cell. Mater. 10 (2005).

[2] SW. Schneider, Y. Yano, BE. Sumpio, BP. Jena, JP. Geibel, M. Gekle, H. Oberleithner, *Rapid aldosterone-induced cell volume increase of endothelial cells measured by the atomic force microscope*, Cell Biol. Int. 21 (1997) 759–768.

[3] D. Docheva, D. Padula, C. Popov, W. Mutschler, H. Clausen-Schaumann, M. Schieker, *Researching into the cellular shape, volume and elasticity of mesenchymal stem cells, osteoblasts and osteosarcoma cells by atomic force microscopy*, J. Cell. Mol. Med. 12 (2008) 537–552.

[4] C. Le Grimellec, E. Lesniewska, M.C. Giocondi, E. Finot, V. Vié, J.P. *Goudonnet, Imaging of the surface of living cells by low-force contact-mode atomic force microscop*y., Biophys. J. 75 (1998) 695

[5] A. Berquand, C. Roduit, S. Kasas, A. Holloschi, L. Ponce, M. Hafner, *Atomic Force Microscopy Imaging of Living Cells*, Micros. Today. 18 (2010) 8–14

[6] A. Ortega-Esteban, I. Horcas, M. Hernando-Pérez, P. Ares, AJ. Pérez-Berná, C. San Martín, JL. Carrascosa, PJ. de Pablo, J. Gómez-Herrero, *Minimizing tip-sample forces in jumping mode atomic force microscopy in liqui*d, Ultramicroscopy. 114 (2012) 56–61.

[7] H.X. You, J.M. Lau, S. Zhang, L. Yu, *Atomic force microscopy imaging of living cells: a preliminary study of the disruptive effect of the cantilever tip on cell morphology*, Ultramicroscopy. 82 (2000) 297–305.

[8] H.X. You, L. Yu, A*tomic force microscopy imaging of living cells: Progress, problems and prospects*, Methods Cell Sci. 21 (1999) 1–17.

[9] K. Sinniah, J. Paauw, J. Ubels, *Investigating live and fixed epithelial and fibroblast cells by atomic force microscopy*, Curr. Eye Res. 25 (2002) 61–68.0.

[10] J. Domke, S. Dannöhl, W.J. Parak, O. Müller,W.K. Aicher, M. *Radmacher, Substratedependent differences in morphology and elasticity of living osteoblasts investigated by atomic force microscopy*, Colloids Surf. B. Biointerfaces. 19 (2000) 367–379.

Authors: **M.Sc. Zoran Bobić, Associate Prof. Lazar Kovačević, Full Prof. Branko Škorić, M.Sc. Vladimir Terek, Assist. Prof. Pal Terek,** University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Phone.: +381 21 485 2330,
E-mail: zoranbobic@uns.ac.rs
lazarkov@uns.ac.rs
skoricb@uns.ac.rs
palterek@uns.ac.rs

Associate Prof. Čapo Ivan, Bulajić Dragica, Drljača Jovana, University of Novi Sad, Faculty of Medicine, Hajduk Veljkova 3, 21000 Novi Sad, Serbia.
E-mail: ivan.capo@mf.uns.ac.rs
dragica.bulajic@uns.ac.rs
jovana.drljaca@uns.ac.rs

PhD Attila Csik, Institute for Nuclear Research, Debrecen, Hungary.
E-mail: csik.attila@atomki.mta.hu

ETIKUM 2021

INTERNATIONAL SCIENTIFIC CONFERENCE
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Brdar, A., Ilić, K., Spasojević, S., Labus Zlatanović, D., Dramićanin, M., Pećanac, M., Janjatović, P., Šiđanin, L., Rajnović, D., Baloš, S.

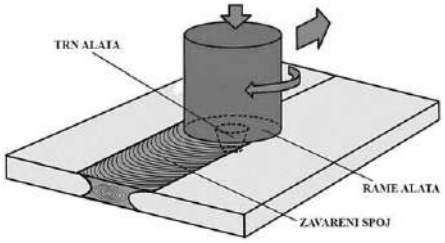
UTICAJ GEOMETRIJE ALATA I PARAMETARA ZAVARIVANJA TRENJEM SA MEŠANJEM NA OSOBINE SPOJEVA OD AL 5052

Rezime: *Zavarivanje trenjem sa mešanjem spada u grupu zavarivanja trenjem koji je patentiran krajem 1991. godine na Britanskom institutu za zavarivanje (eng. The Welding Institute). U ovom radu izvršeno je zavarivanje ploče od legure aluminijuma sa oznakom Al 5052, debljine 5mm. Ključna razlika je u geometriji alata tj. u odsustvu rezervoara i u drugom slučaju, sa prisutnim rezervoarom. Rezultati ispitivanja su pokazali na ne samo pozitivan uticaj prisustva rezervoara prilikom eliminacije greške već ujedno i na pojavu boljih mehaničkih karakteristika zavarenog spoja.*
Ključne reči: *Zavarivanje trenjem sa mešanjem, parametri procesa, rezervoar alata, tunel*

1. UVOD

Zavarivanje trenjem sa mešanjem (ZTM) predstavlja postupak zavarivanja u čvrstom stanju, odnosno zavarivanja pritiskom, bez upotrebe dodatnog materijala i zaštitnih gasova, upotrebom rotirajućeg alata koji obezbeđuje visokokvalitetan zavareni spoj, slika 1 [1]. Najveća prednost ovog postupka jeste što radna temperatura iznosi oko 80% od temperature topljenja materijala [2].

Alat ulazi između blisko prislonjenih ploča ili limova koji predstavljaju radni komad i vrši translatorno kretanje duž čitavog spoja radnih komada. Kretanje alata omogućava pojavu trenja između radnog komada i alata, omekšavanje osnovnog materijala i spajanje.



Sl. 1. Princip rada ZTM [3]

Važnu ulogu na pojavu grešaka imaju alat, najviše njegova geometrija i parametri postupka kao npr. brzina obrtanja, brzina translatornog kretanja, dubina prodiranja i pritisna sila alata.

U ovom radu je data uporedna analiza zavarenih spojeva dobijenih ZTM različitim parametrima i gasnim postupkom zavarivanja.

2. EKSPERIMENTALNI RAD

Osnovni materijal predstavlja leguru aluminijuma Al 5052 debljine 5 mm i dimenzija 200 × 65 mm. Hemijski sastav je određen optičkim emisionim spektrometrom (OES) ARL3580, tabela 1. Ispitivanje zatezanjem je izvršeno na mehaničkoj kidalici WPM ZDM 5/91, tabela 2.

Tabela 1**.** Hemijski sastav legure Al 5052 (mas.%)

Cu	Mn	Mg	Si	Fe	Zn	Ti
0,09	0,09	2,78	0,24	0,38	0,046	0,015

Tabela 2. Mehaničke osobine legure Al 5052

$Rp_{0,2}$ [MPa]	Rm [MPa]	A [%]	Tvrdoća HV10
123,8	193,4	21,7	60

Uređaj korišćen za zavarivanje je vertikalna glodalica Prvomajska UHG 200. Namenski pribor pomoću kojeg je osnovni materijal pozicioniran i stegnut je bio dimenzija 400×370×35 mm. Sastoji se iz žleba sa gornje strane pribora dimenzija 130×5mm u koji se postavljaju prethodno pripremljene ploče i šapa za stezanje ploča osnovnog materijala. Zavarivanje je vršeno pomoću dva alata, jedan sa rezervoarom a drugi bez rezervoara, prikazanih na slici 2.

Sl. 2. Izgled alata

Materijal od kojeg su alati izrađeni je alatni čelik X38CrMoV5-1 (Č 4751, UTOP MO1), predviđen za rad na toplo [4]. Hemijski sastav alata određen pomoću OES uređaja ARL3580 je prikazan u tabeli 3, a tvrdoća je bila 60 HRC.

Tabela 3. Hemijski sastav čelika za alat

C	Si	P	S	Cr	Mo	V
0,37	1,01	0,017	0,0005	4,85	1,23	0,32

Parametri zavarivanja su prikazani u tabeli 4. Ugaona brzina alata je bila konstantna za sve uzorke, dok su brzine zavarivanja varirane.

Tabela 4. Parametri zavarivanja

Alat	Redni broj uzorka	Brzina obrtanja alata n [o/min]	Brzina zavarivanja s [mm/min]
Bez rezervoara	1.	925	125
	2.	925	91
	3.	925	46
	4.	925	17
Sa rezervoarom	5.	925	91
	6.	925	46
	7.	925	17

Ispitivanje zateznih karakteristika šava vršeno je kao i za osnovni materijal, prema ASTM E-8M standardu [5]. Savijanje zavarenog spoja je vršeno takođe na istom uređaju. Ispitivanje je vršeno do pojave prve prsline, a zatim i do ugla od 180°, pri čemu se utvrđuje da li je došlo do loma.

Tvrdoća zavarenog spoja je merena na uređaju VEB HPO 250 sa opterećenjem od 10 kg, prema standardu EN ISO 25239-2:2020 [6]. Rastojanje između otisaka je bilo 1,5 *mm*, kroz sve zone zavarenog spoja, po sredini metalografski pripremljenog uzorka. Makroskopska i mikroskopska ispitivanja vršena su na svetlosnom mikroskopu Leitz Orthoplan, nakon standardne pripreme uzoraka (isecanje, montiranje, brušenje, poliranje i nagrizanje 10% fluorovodoničnom kiselinom).

Radi poređenja izvršeno je i gasno zavarivanje dodatnog uzorka pod rednim brojem 8, istog osnovnog materijala identičnih dimenzija, sa žicom dodatnog materijala tipa 5356 (4,5 – 5,5 % Mg).

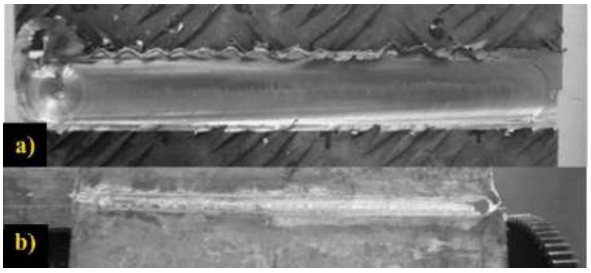
3. REZULTATI

3.1. Vizuelna kontrola

Vizuelna kontrola zavarenog spoja ukazala je na to da datim uzorcima nemamo vidljivih tunela, kao ni prslina, neprovara ili deformacija. Izgled lica i korena šava uzorka 6 prikazani su na slici 3.

3.2. Rezultati ispitivanja zatezanjem

Rezultati zateznih karakteristika zavarenih spojeva prikazani su u tabeli 5. Na osnovu rezultata iz tabele zaključuje se da uzorak 8 poseduje najmanje vrednosti zatezne čvrstoće, a dobijen je gasnim zavarivanjem. S druge strane, uzorak 7 ima najveću vrednost zatezne čvrstoće, koja je gotovo dva puta veća u odnosu na uzorak 8. Uzorak 7 koji nam je pokazao najbolje rezultate dobijen je sa najmanjom brzinom zavarivanja. U poređenju sa osnovnim materijalom, zavareni spoj uzorka 7 pokazuje bolje mehaničke osobine, tačnije veću zateznu čvrstoću.



Sl. 3. Izgled šava uzorka 6: a) lice; b) koren

Tabela 5. Rezultati zateznih karakteristika

Alat	R. br. uzorka	**$Rp_{0.2\%}$ [MPa]**	**Rm [MPa]**
Bez rezervoara	1.	132	184,2
	2.	154,8	189,4
	3.	140,3	189,7
	4.	129,7	178,9
Sa rezervoarom	5.	127,6	148,7
	6.	134,2	157,2
	7.	153,2	207,5
Gasno	8.	98,5	119,1

3.3. Rezultati ispitivanja savijanjem

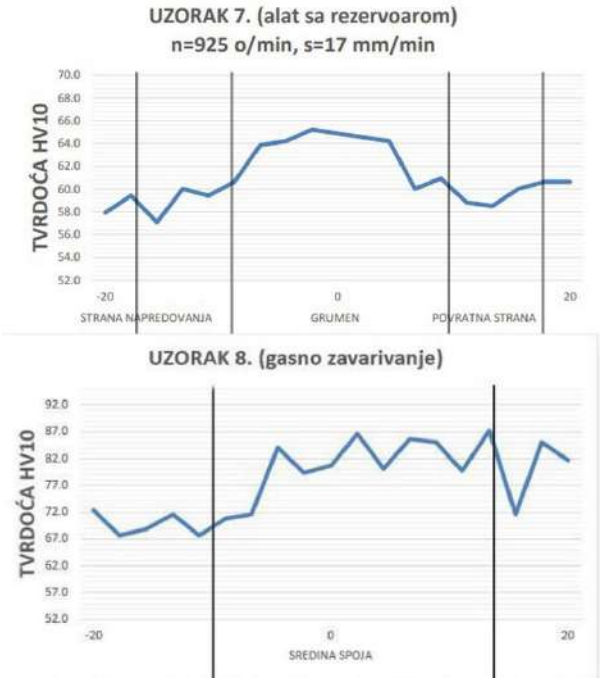
Rezultati ispitivanja savijanjem prikazani su u tabeli 6. Na osnovu rezultata iz tabele 6 se može konstatovati da su svi uzorci izdržali savijanje do vrednosti 180° bez loma materijala osim uzorka 8 dobijenog gasnim zavarivanjem i kod kog je došlo do preloma pri uglu od 68°46`. Najbolje rezultate pokazuje uzorak 7, sa pojavom prve prsline pri uglu od 55°.

Tabela 6. Rezultati ispitivanja savijanjem

Alat	Redni broj uzorka	Ugao pri nastanku prve prsline	Ugao preloma (180^0)
Bez rezervoara	1.	19^0	Nema loma
	2.	$42^0\ 50'$	Nema loma
	3.	$22^0\ 50'$	Nema loma
	4.	$12^0\ 50'$	Nema loma
Sa rezervoarom	5.	$17^0\ 50'$	Nema loma
	6.	$7^0\ 50'$	Nema loma
	7.	55^0	Nema loma
Gasno	8.	24^0	$68^046`$

3.4 Rezultati ispitivanja tvrdoće

Raspodela vrednosti tvrdoće po Vikersu (HV10) uzoraka 7 i 8 su prikazani na slici 4. Kod uzorka 7, tvrdoća u zoni grumena je veća nego kod osnovnog materijala, što je rezultat deformacionog ojačavanja i usitnjavanja urna dejstvom trna alata. S druge strane, kod gasno zavarenog uzorka, tvrdoće su veće zbog upotrebe više legiranog dodatnog materijala. Osim toga, širina metala šava kod ovog uzorka je veća nego kod ZTM zavarenih uzoraka, te su veće tvrdoće dobijene na celoj razmatranoj širini.



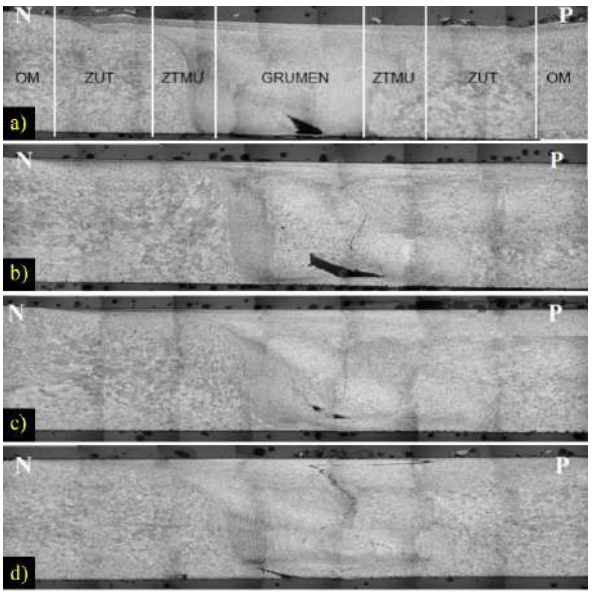
Sl. 4. Vrednosti tvrdoće uzorka 7 i 8

3.5. Rezultati metalografskog ispitivanja

Makro uzoraka zavarenih alatom bez rezervoara su prikazani na slici 5, dok su makro uzora zavarenih alatom sa rezervoarom prikazani na slici 6. Makro prikaz strukture gasno zavarenog uzorka je prikazan na slici 7.

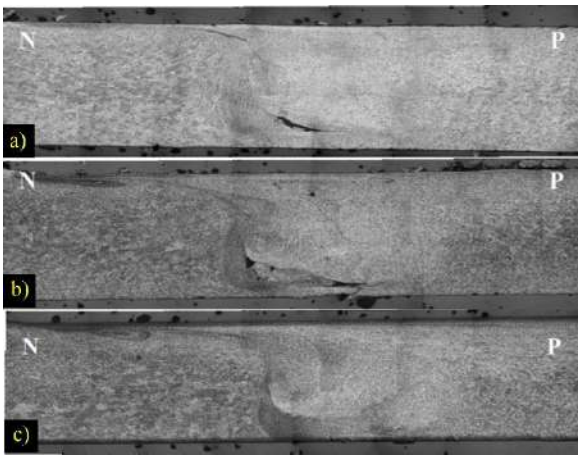
Sa slike 5 je primetno da se kod uzoraka 1, 2, 3 i 4 koji su dobijeni pomoću alata bez rezervoara javila greška u vidu tunela. Kod uzoraka 5 i 6 koji su dobijeni pomoću alata sa rezervoarom javio tunel, ali manjih dimenzija, dok kod uzorka 7 nema prisustva greške, primetno na slici 6. Tunel se javlja u grumenu ili na strani grumena prema termomehaničkoj zoni na strani napredovanja.

Kod uzorka 8, dobijenog gasnim zavarivanjem primetna je pojava pora, što se vidi na slici 7.



OM- osnovni materijal
ZUT- zona uticaja toplote
ZTMU - zona termomehaničkoj uticaja

Sl. 5. Uzorci dobijeni alatom bez rezervoara: a) uzorak 1, b) uzorak 2, c) uzorak 3, d) uzorak 4



Sl. 6. Uzorci dobijeni alatom sa rezervoarom: a) uzorak 5, b) uzorak 6, c) uzorak 7

Sl. 7. Uzorak 8 dobijen gasnim zavarivanjem

4. DISKUSIJA

Na osnovu ispitivanja se može uvideti prednost ZTM u odnosu na gasno zavarivanje. Na to ukazuju skoro duplo veće vrednosti zatezne čvrstoće kod uzoraka dobijenim ZTM postupkom, kasniju pojavu loma pri ispitivanju savijanjem i odsustvo pora kod uzoraka 1-7, za razliku od uzorka 8 dobijenim gasnim postupkom.

Na osnovu zateznih katakteristika uzoraka u poređenju sa zateznim karakteristikama osnovnog

materijala, dobijene su vrednosti efikasnosti zavarenih spojeva, tabela 7. Vidi se da najveću vrednost efikasnosti po naponu tečenja i po zateznoj čvrstoći poseduje uzorak 7. Ovaj uzorak je dobijen alatom sa rezervoarom i sa najmanjom brzinom zavarivanja. Ovo je u odličnoj korelaciji sa rezultatima ispitivanja savijanja i makro ispitivanja. Naime, uzorak 7 je jedini koji nema grešku tipa tunela. Od uzoraka dobijenih ZTM postupkom, relativno niske mehaničke osobine, zajedno sa prisustvom tunela i prslina, kao i najniže zatezne karakteristike pokazali su uzorci 4 i 6.

Tabela 7. Efikasnost zavarenog spoja

Alat	Redni broj uzorka	Po naponu tečenja [%]	Po zateznoj čvrstoći [%]
Bez rezervoara	1.	106,6	95
	2.	125	98,1
	3.	113	98
	4.	104,7	92,5
Sa rezervoarom	5.	103	77
	6.	108	81
	7.	123,7	107
Gasno	8.	79,5	61,5

Najnižu vrednost efikasnosti spoja je pokazao uzorak 8 koji je dobijen gasnim zavarivanjem. U osnovi, tokom ZTM dolazi do ojačavanja materijala mehanizmom ojačavanja granicama zrna, nasuprot pretapanju i kristalizaciji kod gasnog zavarivanja. U takvim uslovima, dolazi do formiranja pora i segregacije, što ne pogoduje postizanju visokih mehaničkih osobina i u pogledu zateznih karaketeristika i savijanja.

Na osnovu parametara zavarivanja, vidimo da je najmanja brzina zavarivanja u vrednosti od 17mm/min najbolja za eliminaciju tunela i dobijanja najboljih mehaničkih karakteristika.

Kada je alat u pitanju, prednost daje alat sa prisutnim rezervoarom. Dokaz svih prethodnih tvrdnji je uzorak 7 sa odsustvom greški i najboljim osobinama spoja.

5. ZAKLJUČCI

Na osnovu istraživanja i predstavljenih rezultata u ovom radu mogu se izvući sledeći zaključci:

Zavarivanje trenjem sa mešanjem daje zavarene spojeve boljih mehaničkih osobina od gasnog zavarivanja, gde presudni ogrnaičavajući faktor predstavlja poroznost i segregacija.

Najbolje mehaničke osobine pokazao je uzorak 7 dobijen ZTM postupkom alatom sa rezervoarom i sa najmanjom vrednošću brzine zavarivanja (17 mm/min). To je brzina koja se pokazala kao najbolja za eliminaciju pojave grešaka u vidu tunela.

ZAHVALNOST

Ovaj rad je rezultat rada autora u okviru projekta pod naslovom „Inovativni materijali i tehnologije spajanja“ Laboratorija za ispitivanje materijala i Laboratorije za zavarivanje, Departmana za proizvodno mašinstvo, Fakulteta tehničkih nauka.

6. LITERATURA

[1] Baloš S., Šiđanin L., Rajnović D., Vučić V.: Zavarivanje trenjem sa mešanjem: XIX konferencija KOMIM-a, Užice 2013, str 1-7.

[2] Mihajlov D.; Zavarivanje trenjem sa mešanjem legure aluminijuma 5052 alatom sa zavojnicom, Master rad, Novi Sad, 2012 god.

[3] Veljić D., Sedmak A, Rakin M., Radović N., Popović N., Dașcău H., Bajić N.: Prednosti zavarivanja trenjem sa mešanjem u odnosu na elektrolučno, zavarivanje - zaštita zdravlja i životne sredine i bezbednost na radu: Structural integrity and life (2015) 15/2, 111–116.

[4] Veljić D., Radović N., Sedemak A., Perović M.: Tehnologija zavarivanja aluminijumskih legura postupkom zavarivanja trenjem mešanjem, Zavarivanje i zavarene konstrukcije 1/2010, str.13-20

[5] https://www.astm.org/Standards/E8.htm

[6]https://iss.rs/sr_Cyrl/project/show/cen:proj:61227

***Autori*: Ana Brdar, Katarina Ilić, Stanko Spasojević, dr Danka Labus Zlatanović, dr Miroslav Dramićanin, Milan Pećanac, Petar Janjatović, prof. Emiritus dr Leposava Šiđanin, vanr. prof. dr Dragan Rajnović, red. prof. dr Sebastian Baloš,** Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2339, Fax: +381 21 454-495.

Email:anab@uns.ac.rs
katailic@uns.ac.rs
spasojevics@uns.ac.rs
danlabus@uns.ac.rs
dramicanin@uns.ac.rs
pecanac.milan@uns.ac.rs
janjatovic@uns.ac.rs
lepas@uns.ac.rs
draganr@uns.ac.rs
sebab@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Ilić, K., Brdar, A., Spasojević, S., Dramićanin, M., Pećanac, M., Janjatović, P., Labus Zlatanović, D., Rajnović, D., Baloš, S., Šidjanin, L.

NAVARIVANJE LEGURA STELITA SA INFILTRIRANIM NANOČESTICAMA

Rezime: *U radu je elaborirana problematika primene nanočestica TiO_2 pri navarivanju tvrdih, hemijsko otpornih legura na bazi kobalta. Primenjeno je različito vreme infiltracije nano čestica, i rezultati su upoređeni sa navarenim slojem dobijenim nemodifikovanim elektrodama. Navarivanje je izvršeno u dva sloja, međusloj je navaren elektrodom na bazi nikla, nakon koga je nanesen završni sloj eletrodom na bazi kobalta (Stelit 6) bez i sa infiltracijom TiO_2 nano čestica. Izvršena su ispitivanja tvrdoće, otpornosti na habanje kao i metalografska ispitivanja. Ustanovljeno je da je u navarenim slojevima dobijenim modifikovanim elektrodama došlo do promene mikrostrukture, kao i promene tvrdoće i otpornosti na habanje. U mikrostrukturi primećena je promena razdaljine između dendrita, kao i otvorenosti karbidne mreže. Došlo je do formiranja titanijum oksida, koji zajedno sa postojećim kompleksnim karbidima povećava otpornost na habanje i smanjuje pad tvrdoće po dubini navarenih slojeva dobijenih modifikovanim elektrodama u poređenju sa navarenim slojevima dobijenim nemodifikovanim elektrodama.*

Ključne reči: *navarivanje, legure na bazi kobalta, otpornost na habanje*

1. UVOD

Legure na bazi kobalta poseduju visoku otpornost na habanje, koroziju, i na visoke temperature [1]. Legure Co-Cr-W-C poznatije kao steliti sadrže oko 30 % hroma, 4 % - 17 % volframa kao i 1 % - 3,2 % ugljenika koji gradi složene karbide u metalnoj osnovi. Izuzetna otpornost na habanje ove legure potiče od tvrdih karbidnih faza koje su rasprostranjene u osnovi zasnovanoj na čvrstom rastvoru hroma i volframa u kobaltu [2]. Postoji niz stelitnih legura, pogodnih za različite primene i različita okruženja. Zahvaljujući dobroj otpornosti na habanje i koroziju, dobroj žilavosti i toplotnoj postojanosti Stelit 6 je najrasprostranjenija od svih legura kobalta [3]. Dakle stelitni sloj se dobija u vidu navara, kao odlivak, i prisutna je interakcija čvrsto-tečno. Jedan od načina poboljšavanja svojstava slojeva dobijenih navarivanjem elektrodama od Stelita 6 predstavlja infiltriranje nanočesticama TiO_2, kao što je predloženo u [4]. U radovima [5-7] pokazano je da dodavanje TiO_2 omogućava stvaranja kompleksnih oksidnih jedinjenja, koji dovode do promene mikrostrukture i imaju pozitivan uticaj na mehanička svojstva.

Cilj ovog istraživanja predstavlja dobijanje navara poboljšanih mehaničkih osobina uz pomoć elektroda sa infiltriranim nanočesticama. U radu je takođe ispitan uticaj vremena infiltracije nanočestica na svojstva navarenog sloja.

2. EKSPERIMENTALNI DEO

U cilju eksperimentalnog ispitivanja izvršeno je navarivanje na uzorcima od konstrukcionog čelika tipa S235JR (EN10025-2:2020), feritno-perlitne mikrostrukture [8]. Korišćena su četiri uzorka, dimenzija 100×50×20 mm. Navarivanje je izvšeno postupkom ručno-elektrolučnog navarivanja, aparatom Iskra E10. Korišćena su dva tipa elektroda. Za međusloj korišćena je elektroda na bazi nikla, proizvođača Boehler, oznaka Fox Nirbas 70/20 Ø3,2 mm. Naneta debljina podloge je bila oko 2,5 mm. Kod kontrolnog uzorka, sa rednim brojem jedan, završni sloj je navaren nemodifikovanom elektrodom Stelit 6 oznake FSH Selectarc Co6. Na ostalim uzorcima nanet je završni sloj istom elektrodom kao kod kontrolnog uzorka ali sa infiltriranim nano česticama TiO_2 nominalnog prečnika 20 nm. Elektrode su postavljene u ultrazvučnu kadu tipa EMAG Emmi-5, potpuno potopljene u rastvor od 5 % TiO_2 nano čestica u destilovanoj vodi. Za tri uzorka korišćena su tri različita vremena infiltracije, tako da je na uzorak broj dva navarena elektroda koja je infiltrirana 30 s, na uzorak broj tri elektroda infiltrirana 4 min, i na četvrti uzorak je navarena elektroda infiltrirana 8 minuta. Nakon infiltracije, izvršeno je sušenje elektroda u peći u vremenskom intervalu od jednog časa na temperaturi 100 °C. Nakon navarivanja izvršena su metalografska i mehanička ispitivanja kao i ispitivanje hemijskog sastava. Od mehaničkih ispitivanja izvršeno je

ispitivanje na habanje i merenje tvrdoće uzoraka po debljini. Ispitivanje na habanje je izvršeno u vremenskom intervalu od trideset sekundi na adaptiranom aparatu za automatsko poliranje tipa Struers DP-U2 pri čemu je umesto platna za poliranje postavljen abrazivni papir granulacije P500. Ispitivanje habanjem je ponovljeno tri puta, a vrednost gubitaka mase je izražena kao aritmetička sredina tri merenja. Tvrdoća je izmerena na uređaju za ispitivanje tvrdoće po Vikersu oznake VEB HP-250, sa opterećenjem od 5 kg, od površine poprečnog preseka navarenog uzorka prema unutrašnjosti, sa rastojanjem između otisaka od 0,5 mm, po standardu SRPS EN ISO 6507-1:2011 [9]. Za metalografsko ispitivanje uzorci su pripremljeni standardnom tehnikom metalografske pripreme uzoraka: brušenje u nekoliko koraka brusnim papirom granulacije od P80 do P2500, poliranje dijamantskom pastom sa veličinom čestica 6, 3 i 1 μm i na kraju nagrizanje nitalom (osnovni materijal) carskom vodom (navar). Metalografsko ispitivanje je izvršeno na svetlosnom mikroskopu tipa Leitz Orthoplan. Ispitivanje hemijskog sastava izvršeno je energetskom disperzivnom spektroskopijom (Energy-dispersive X-ray spectroscopy - EDX). Ispitivanje je izvršeno na skenirajućem elektronskom mikroskopu tipa JEOL JSM 6460LV, a pre ispitivanja na uzorke je naneta zlatna prevlaka na uređaju Bal-Tec SCD-005.

3. REZULTATI ISPITIVANJA

3.1 Rezultati ispitivanja habanjem

Rezultati ispitivanja na habanje, odnosno gubitak mase uzoraka nakon habanja prikazani su u tabeli 1.

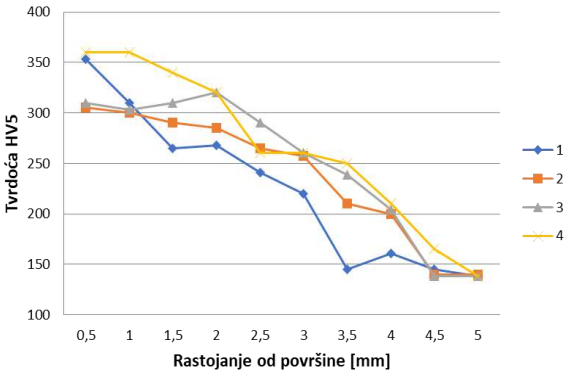
Tabela. 1. Rezultati ispitivanja na habanje

Uzorak	Vreme infiltracije TiO_2 [min]	Gubitak mase [mg]	Standardna devijacija
1	0 (kontrolni uzorak)	43,6	± 4,3
2	0,5	44,0	± 5,1
3	4	43,8	±5,3
4	8	39,8	±4,6

Na osnovu rezultata ispitivanja habanjem uočava se da je kod uzorka četiri, koji je navaren elektrodom sa najdužim vremenom infiltracije habanje najmanje intenzivno, i ono je oko 9% manje u odnosu na prvi, kontrolni uzorak. Kod uzoraka 2 i 3, gubitak mase je gotovo jednak kao kod kontrolnog uzorka i može se smatrati statističkom greškom.

3.2 Rezultati ispitivanja tvrdoće

Raspodele tvrdoće ispitivanih uzoraka date su na slici 1. Kod svih navarenih uzoraka se uočava pad tvrdoće po dubini. Sa slike 1 se može uočiti da je kod kontrolnog uzorka pad tvrdoće po dubini najviše izražen, dok najveću tvrdoću blizu površine poseduje četvrti uzorak kod koga je vreme infiltracije elektroda bilo najduže.



Sl. 1. Rezultati ispitivanja tvrdoće po dubini navarenog uzoraka

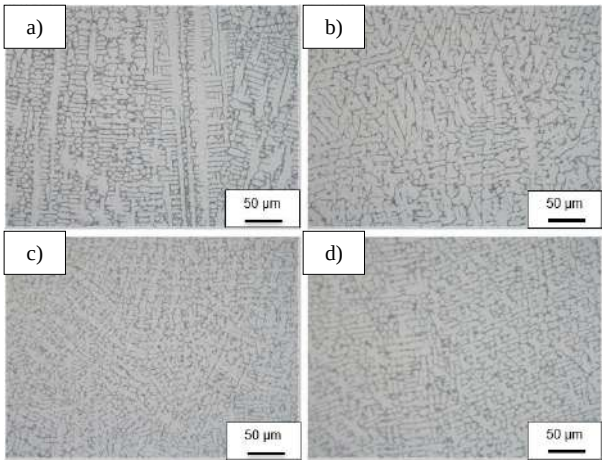
3.3 Rezultati metalografskog ispitivanja

Slika 2 prikazuje mikrostrukturu poprečnog preseka u završnom sloju navarenih uzoraka. Kod svih uzoraka prisutna je osnova na bazi kobalta sa karbidima po granicama dendrita nastalih tokom očvršćavanja navara, što je tipično za legure tipa stelit. Sa slike 4 mogu se uočiti određene morfološke razlike. Uočava se veća razdaljina između dendrita kod uzorka navarenog nemodifikovanom elektrodom (uzorak 1) od uzoraka sa modifikovanim elektrodama (uzorci 2, 3, 4). Takođe karbidna mreža uzorka 1 je otvorenija od drugih uzoraka, pogotovu u poređenju sa uzorkom 4 gde je karbidna mreža skoro kompletno zatvorena. Kod uzorka 1 primećena je i izrazita paralelnost karbidne mreže za razliku od uzoraka 2 do 4.

3.4 Rezultati ispitivanja na skenirajućem elektronskom mikroskopu

Rezultati ispitivanja hemijskog sastava uzorka 1 EDX analizom tvrdih faza u osnovi legure kobalta površinskog navarenog sloja prikazani su na slici 3. Na datoj slici uočljivi su karbidi tipa M_6C (Cr_6C), modifikovani sa W koji su uobičajeni za leguru Stelit 6 [10]. Rezultati ispitivanja hemijskog sastava EDX analizom za uzorak broj 4, koji su prikazani na slici 4., pokazuju da tvrde faze pored elemenata koji su prisutni u odgovarajućim fazama u uzorku 1, sadrže Ti i O.

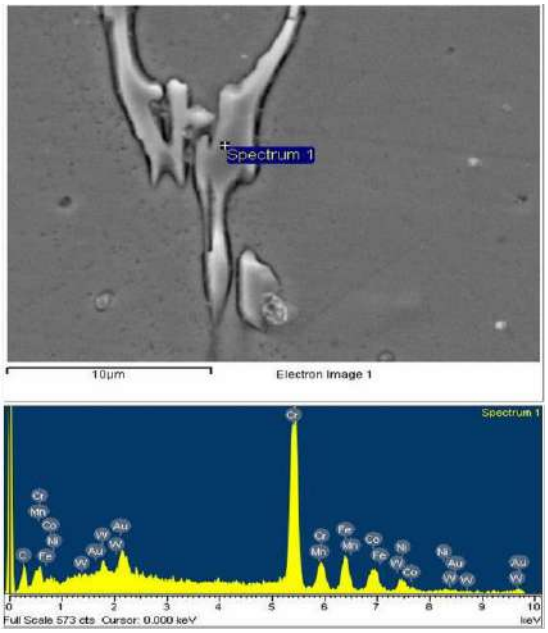
Sa slike se vidi da se pored karbida koji su uobičajni za leguru Stelit 6 tipa M_6C javljaju i oksidi titana. Morfološki analizirana faza se razlikuje u odnosu na fazu tipa M_6C što dovodi do premise da prisustvo ovih faza pozitivno utiče na povećanje otpornosti na habanje uzorka 4.



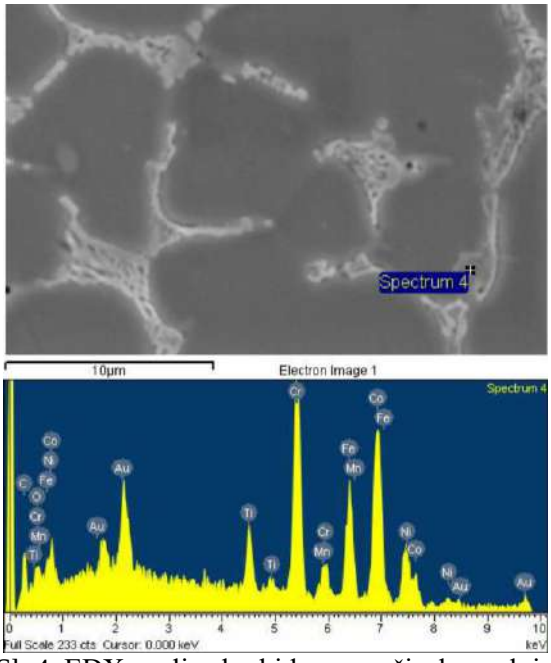
Sl. 2. Mikrostruktura završnog navarenog sloja legure kobalta; a) 1- kontrolni uzorak, b) 2- uzorak dobijen sa vremenom infiltracije 30 s , c) 3 – uzorak dobijen sa vremenom infiltracije 4 min, d) 4 - uzorak dobijen sa vremenom infiltracije 8 min

4. DISKUSIJA

Infiltracija nano čestica u konvencionalnu elektrodu za navarivanje rezultira povećanom otpornošću na habanje. Ovo se može pripisati uticaju nekoliko različitih efekata. Prvi efekat predstavlja pojava titanijum oksida, drugi smanjenje razdaljine između dendrita, treći zatvaranju karbidne mreže i kao četvrti smanjenje pada tvrdoće po dubini. Povećanje tvrdoće uzorka broj 4, može se objasniti prisustvom najveće količine oksida titana infiltrirane u elektrodu, koji nastaje tokom hlađenja nakon navarivanja. Tokom navarivanja, javlja se visoka temperatura koja dovodi do disocijacije nano čestica TiO_2. Prilikom hlađenja navarenog sloja dolazi do oksidacije titana. Oksidi titana očvršćavaju na relativno visokim temperaturama: Ti_2O_3 na 2130 °C a TiO_2 na 1843 °C [11]. Kod uzorka broj 4, prvo nastaje Ti_2O_3 koji predstavlja centar kristalizacije za dalje očvršćavanje navara. Prilikom daljeg hlađenja dolazi do kristalizacije osnove na bazi kobalta u tipičnoj dendritnoj morfologiji na temperaturi od oko 1410 °C. Konačno, karbidi tipa M_6C, tipični za Stelit 6, nastaju između dendrita na temperaturama od 760 do 980 °C, obrazujući strukturu navarenog sloja dobijenog modifikovanim elektrodama [12].



Sl. 3. EDX analiza karbida u površinskom sloju uzorka 1



Sl. 4. EDX analiza karbida u površinskom sloju uzorka 4

Na taj način, može da se objasni manje usmerena mikrostruktura dendrita (uzorak 4) u poređenju sa uzorkom broj 1 kod koga je navarivanje izvršeno nemodifikovanim elektrodama. Iz ovoga se nameće konstatacija da titanijum oksidi imaju uticaj na povećanje tvrdoće, kao i na povećanu otpornost na habanje navarenih slojeva. Povećanjem vremena infiltracije dolazi do povećanja količine infiltriranih nanočestica, veća količina nano čestica znači da je i sadržaj unesenog titana odnosno oksida veći, što uzrokuje i povećavanje količine Ti_2O_3 u mikrostrukturi. Zbog toga je kod uzorka sa najdužim vremenom infiltracije (uzorak 4) najbolja otpornost na

habanje i najveća tvrdoća u površinskom sloju. Kao predlog za dalja istraživanja, može da se navede infiltracija u još dužem vremenu.

5. ZAKLJUČAK

Na osnovu dobijenih rezultata, mogu se izvući sledeći zaključci:

- Infiltracijom nano čestica TiO_2 u elektrode tipa Stelit 6, povećava se tvrdoća navarenih slojeva, naročito po dubini.
- Uzorak navaren elektrodom koja je infiltrirana 8 minuta (uzorak 4) ima najveću otpornost na habanje u odnosu na ostale uzorke, sa kraćim vremenima infiltracije kao i u odnosu na kontrolni uzorak.
- Nanočestice TiO_2 doprinose usitnjavanju, a samim tim i zatvaranju karbidne mreže u odnosu na morfologiju karbidne mreže uzorka navarenog nemodifikovanim elektrodama Stelita 6.
- Oksidi titana, koji prvi očvršćavaju pri hlađenju navarenog sloja doprinose povećanju tvrdoće i otpornosti na habanje, a primećena je i finija, zatvorenija mreža karbida tipa M_6C.

6. LITERATURA

[1] Kuzucu, V., Ceylan, M., Celik, H., Aksoy, I., *Microstructure and phase analyses of Stellite 6 plus 6 wt.% Mo alloy*, Journal of Malerials Processing Technology, 69, 1996, 257-263, 13 2 1996.

[2] Zhu, Z., Ouyang, C., Qiao, Y., Zhou, X., *Wear Characteristic of Stellite 6 Alloy Hardfacing Layer by Plasma Arc Surfacing Processes*, Hindawi, Volume 2017, 20.11.2017.

[3] Delero Wear solutions GmbH, *Hardfacing alloys* [online]. https://www.deloro.com/fileadmin/users/redakteur/006_Downloads/Product_Information/Hardfacing_Alloys_eng.pdf (pristupljeno 2.11.2021.)

[4] Balos, S.; Sidjanin, L.; Dramicanin, M.; Labus Zlatanovic, D.; Pilic, B.; Jovicic, M. *Modification of cellulose and rutile welding electrode coating by infiltrated TiO2 nanoparticles*, Met. Mater. Int. 2016, 22, 509–518

[5] S. Hossein Nedjad and A. Farzaneh, *Formation of fine intragranular ferrite in cast plain carbon steel inoculated by titanium oxide nanopowd*e, Scr. Mater. 57 (2007) 937-940

[6] M. Kiviö, L. Holappa, T. Iung, *Addition of dispersoid titanium oxide inclusions in steel and their influence on grain refinement*, Metall. Mater. Trans. B 41 (2010) 1194–1204

[7] M. Fattahi, N. Nabhani, M.R. Vaezi, E. Rahimi. *Improvement of impact toughness of AWS E6010 weld metal by adding TiO2 nanoparticles to the electrode coating*, Mater. Sci. Eng. A, 528 (2011) 8031–8039

[8] Institut za Standardizaciju Srbije. *SRPS EN 10025-2:2020* [online]. https://iss.rs/sr_Cyrl/project/show/iss:proj:57300 (pristupljeno 4.11.2021.)

[9] Institut za Standardizaciju Srbije. *SRPS EN ISO 6507-1:2011* [online]. https://iss.rs/sr_Cyrl/project/show/iss:proj:33088 (pristupljeno 4.11.2021.)

[10] Rothaman, M:F., Zordan, R.D. *Role of refravtory elements in cobalt-base alloys*, Cabot Corporation, Kokomo, 1984.

[11] Greenwood N., Earnshaw A., *Chemistry of the Elements*, Butterworth-Heinemann, Woburn, 1997.

[12] Grupa autora, *Alloying: Understanding the basics*, ASM International, Materials Park, 2001., 512

ZAHVALNICA

Ovaj rad predstavlja rezultat rada autora u okviru projekta pod naslovom „Inovativni materijali i tehnologije spajanja“ Laboratorija za ispitivanje materijala i Laboratorije za zavarivanje, Departmana za proizvodno mašinstvo, Fakulteta tehničkih nauka.

Autori: **dipl. inž. Katarina Ilić, dipl. inž. Ana Brdar, dipl. inž. Stanko Spasojević, Doc. dr Miroslav Dramićanin, Mast. inž Milan Pećanac, Mast. inž Petar Janjatović, Doc. dr Danka Labus Zlatanović, Vanr. prof. dr Dragan Rajnović, Prof. dr Sebastian Baloš, Prof. emeritus dr Leposava Šiđanin.** Univerzitet Novi Sad, Fakultet Tehničkih Nauka, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2350, Fax: +381 21 454-495.

E-mail: katailic@uns.ac.rs
anab@uns.ac.rs
spasojevics@uns.ac.rs
dramicanin@uns.ac.rs
pecanac.milan@uns.ac.rs
janjatovic@uns.ac.rs
danlabus@uns.ac.rs
draganr@uns.ac.rs
sebab@uns.ac.rs
lepas@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE**
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Matin, I., Štrbac, B., Vukelić, Đ., Kulundžić, N., Hadžistević, M.

THE ADVANCED MOLD DESIGN METHOD

Abstract: *The authors present quick method for mold design using advanced CAx software. This proposed method is fast, easy to use, and comfortable in solving problems related to mold design. The method is consists of numerical simulation of plastic injection molding necessary for initial and final mold design phases.*
Key words: *plastic injection molding, CAx, mold design*

1. INTRODUCTION

Injection molding is a popular process for plastic parts manufacturing. Computer-aided technologies (CAx) is the use of computer technology to aid in the design, analysis, and manufacture of products. Nowadays, the development of a CAx injection mold design software is becoming a focus of world wide research. CAx software could be a possible solution for plastic injection molding process and mold design. The mold is an essential, responsible for the manufacturing of quality plastic parts. Based on approach of the injection process, a procedure for determination of the molding parameters has been proposed. The procedure has been implemented through an integrated CAx system.

Many authors used numerical simulations and integrated CAE software for determinate the relevant injection molding parameters needs for mold design [1-5].

The cooling quality analyze is crucial for selection of a cooling system. The calculated cycle time includes the injection time, packing time, cooling time, holding time and the clamp opening time. The calculated cycle time is primarily based on cavity geometry. The cooling time is time for 90% of simulation model thickness frozen [3].

Computers have been playing more and more important roles in engineering practices. CAx is use of computer technology to aid in the geometry design, analysis, and manufacture of mold. The evolution of CAx systems has been driven by both the needs for efficient design processes and high-quality representation of products, and the advancement of computing technologies and methodologies related to design practices [3, 6].

Mok et al. [5] build a general procedure of mold design. The procedure starts with analyze of the general items such as costs, delivery dates, geometry and machine data. Next phase is decision of number of cavities and parting surfaces and runner system. Next phases are cooling, mechanical system design, and ejector system design. The market of commercial CAD/E systems is dominated by several large software developers who intend to offer complete solutions for the industry. Though academic research is still very active in the field of CAx systems, there are indications that the conventional system development resources will sooner and later become exhausted. A new paradigm might be necessary to provide additional support for the industry, to cope with the complexity of products, processes, and data/knowledge, and to open new opportunities for researchers, innovators, system developers, system integrators, and end users [3, 7, 8, 9, 10, 11].

The following software such as MoldFlow Part Advisor, PTC Pro/Plastic Advisor, Moldex 3D, AutoDesk Mold Flow Advisor and Sigmasoft are the most widely used software for numerical simulation of plastic injection molding process.

2. MATERIALS AND METHODS

The basic features of an injection mold consist of cavity number and layout, runner system, cooling system, ejection system and remaining mold construction. A mold design project normally starts with economic considerations, namely the question of how many parts can and should be produced in one mold in one shot in order to meet the delivery date and other requirements. This is followed by consideration of the arrangements of the cavities in the mold frame, which might directly include thoughts on the ease of ejection and subsequently, the connection between moldings and runners and, part quality (number, position, and shape of gates). The runner system accommodates the molten plastic material coming from the injection nozzle of the molding machine and distributes it into each cavity. To

remove the heat from the molding, it is necessary to provide the mold with an adequate cooling system. After the molding has solidified and cooled down, it has to be removed from the mold by the ejection system. Mold is generally designed by stacking several mold plates to form a rigid body. Mold design normally involves the selection of mold bases and standard mold parts [9-18].

In the in view of the above authors proposed flowchart of mold design process, that is presented in Fig. 1.

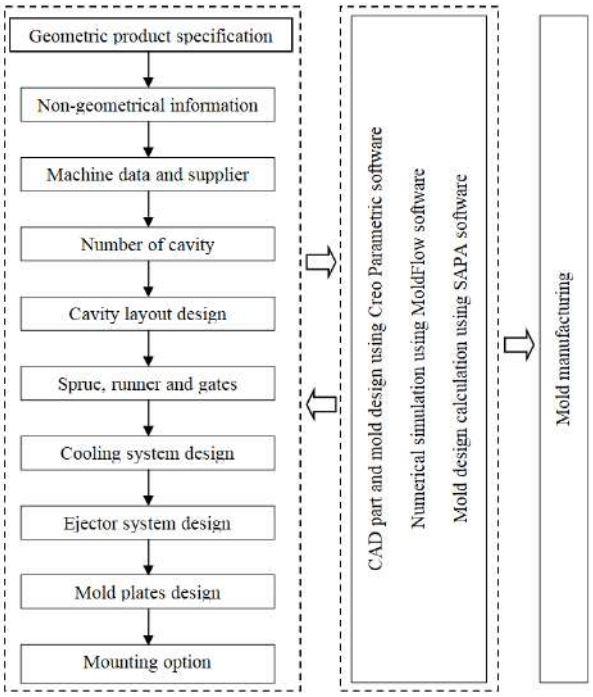


Fig. 1. Flowchart of mold design phases

Geometric product specification is consists of dimensions and tolerances. Non-geometrical information is: Number of manufacturing products per year, total number of production and material specifications. The mold designer should verify that the mold would fit in the available molding machine(s). Machine data contains name of injection molding machine and its manufacturer, type of drive power, distance between tie bars, clamping force, specification of injection unit (acc. to EUROMAP standard), maximum injection pressure, maximum pressure drop, ejector force, screw circumferential speed, maximal screw torque, maximal nozzle contact force, maximal retraction stroke, screw length, screw diameter, heating capacity, maximal shot weights, cooling medium etc. Number of cavities is determining by purchaser or by designer according to number of products. Cavity layout design, assessment of the parting surface, assessment of sprue, runner and gate types and, its sizing, are the central phases of the mold design. The goal of cavity layout design is to produce a mold design that is compact, is easy to manufacture, and provides molding productivity. Cavity layout design also includes core and insert design. Cooling system design is important because cooling phase is the higher phase in the cycle. Conformal cooling channel design is the solution to the problem, which "conforms" to the shape of cavity in the molds. Concerning the injection cycle, the cooling phase is the more important phase of the overall cycle time. Furthermore, it has a strong influence on plastic part's final properties and, therefore, cooling should be as efficient as possible. The cooling system design is, therefore, highly dependent on the compromise between temperature uniformity and the duration of the injection molding cycle. Ejector system design is determining according to runner system type and way of the ejection. Mold plates design includes selection of the mold plates using specialized knowledge-based system called "SAPA". The mounting option included standard mold assembly design using CAx applications.

3. RESULTS AND DISCUSSION

The holder is used in the following case study. The part material is Polypropylene PP001 that has a crystalline structure. The technical drawing of the holder is presented in Fig. 2.

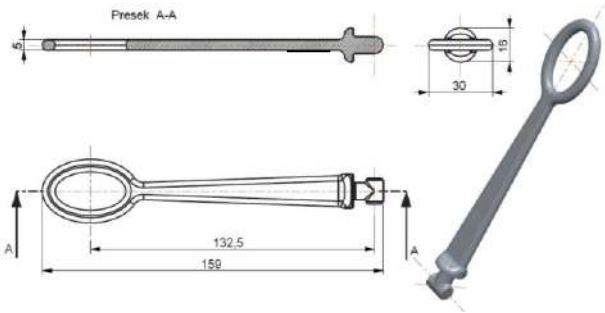


Fig. 2. Technical drawing of the holder

"Creo Parametric" software is used to simulation model design, mold design, and cooling system design. Autodesk Moldflow Advisor Premium is used for numerical simulation of injection molding process. A balanced linear layout is selected, because the cavities are all uniformly filled at the same time under the same injection molding parameters. The simulation model is generated using iterative redesign procedure. The appropriate simulation model consists of the runner subsystem and four plastic parts. The runner system further consists of sprue gate, main runner, sub runners, cold slug and gates. The gates need to be designed for automatic trim of the runner system during ejection. The

simulation model with appropriate cooling system is presented in Fig. 3.

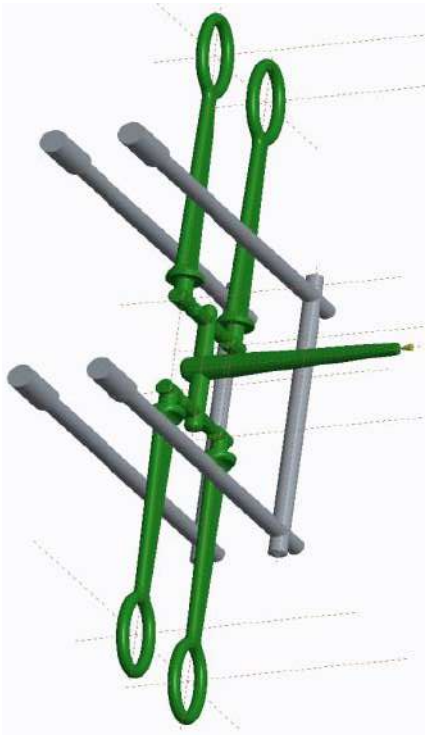


Fig. 3. The simulation model with model of cooling system

The U-channel is the simplest and most applicable cooling system. A water compound with 20% ethyl glycol is used for cooling.

The cooling quality analyze by AutoDesk MoldFlow is also presented in Fig. 3. The cooling quality of the simulation model is high, because all zones in the model are green without yellow and red zones. The red zone cools five times longer than the green zone. This simulation result is important because cooling time is the most significant role in the calculated cycle time. The calculated cycle time is 22 s. The diameter of the cooling channel (waterline) is 8 mm. The position of the cooling channels is determinate by software "SAPA". The initial diameter is also determinate using SAPA, and the optimal value is verified by numerical simulation.

The estimated sink marks are 0,086 mm to 0,018 mm. The injection-molding machine must also provide sufficient clamping force to hold the two halves of the mold together when pressurizing the polymer melt. If the molding machine does not provide sufficient clamping force, then the mold will open during operation and the melt will flow across the parting plane and shut-offs. If the molding machine provides too much force to undersized mold, however, the mold maybe damaged by the imposed compressive stresses. Maximal clamping force is 11.08 MPa.

Based on the dimensions of the simulation model and the type and size of cooling system, the mold assembly serial code "N3050" is selected. The mold assembly is normal type according to D-M-E standard. The assembly is composed of the following standard mold plates:

- top clamping plate N03,
- clamping plate N04,
- fixed plate N10A,
- movable plate N10B,
- support plate N20,
- risers N30,
- ejector retainer plate N40 and
- ejector plate N50.

There is no insert into both fixed plate and movable plate. The length and width of the mold in the parting surface plane is 496 x 296 mm. The SAPA is used for selecting all the remaining mold elements such as, ejector pin, locating ring, guide pin bush, sprue bush, return pins, and screw.

4. CONCLUSIONS

This paper presented a practical approach to determine mold design phases using both commercial CAx software and specialized modular software "SAPA". It will help in reducing the working time in the field of mold design and manufacturing of cavity.

The cooling channels are generated very fast and easy. As a result, comfortable conventional cooling was obtained. This research assumes that the plastic part has been cooled, within a mold, rigid enough to withstand the ejection force and no plastic deformation happens during the ejection process.

The sink marks results are guaranteeing high geometrical precision of the product. There are no essential weld lines and no air traps in the part.

The advanced mold design method has proven to be very successful and effective, so as such it can be used by the most demanding tasks set for the industry 4.0. This method also saves time in the mold design process because it removes redundant work. This is important for the mold-making industries since the lead-time for mold making is decreasing.

Future studies should conduct experiments with data from more different analysis areas, which include influence of the cooling water compound to the cycle time depending on the ratio of water and ethyl glycol in mixture. Next future efforts should be focused on analyze of time need for numerical simulation of injection molding process using several contemporary hardware configuration.

5. REFERENCES

[1] Hodolič, J., Matin, I., Hadžistević, M., Vukelić, Đ.: *Development of integrated CAD/CAE system of mold design for plastic injection molding*, Materiale Plastice, Vol. 46, No. 3, p.p. 236–242, 2009.

[2] Tan, C., Wang, D., Ma, W., Chend Shijin Chen, Y., Chen, S., Yang, Y., Zhou, K.: *Design and additive manufacturing of novel conformal cooling molds*, Materials and Design, Vol. 196, p.p. 109–119, 2020.

[3] Farouq, , Y., Nicolazo, C., Sarda, A., Deterre, R.: *Temperature measurements in the depth and at the surface of injected thermoplastic parts*, Measurement, Vol. 38, No. 1, p.p. 1-14, 2005.

[4] Khan, M., Afaq, K., Ullah Khan, N., Ahmad, S.: *Cycle Time Reduction in Injection Molding Process by Selection of Robust Cooling Channel Design*, Hindawi Publishing Corporation, https://doi.org/10.1155/2014/968484, 2014.

[5] Mok, C. K., Chin, K.S., Lan, H.: *An Internet-based intelligent design system for injection moulds*, Robotics and Computer-Integrated Manufacturing, Vol. 24, p.p. 1–15, 2008.

[6] Matin, I., Štrbac, B., Ranisavljev, M., Vukelić, Đ., Hadžistević, M.: *Mold cavity layout design*, Proceedings of XI International Conference Industrial Engineering and Environmental Protection, p.p. 112–116, October 07–08, Zrenjanin, Serbia, 2021.

[7] Matin, I., Štrbac, B., Hadžistević, M., Ranisavljev, M.: *The advanced design and manufacture of the plastic part*, Proceedings of 38th International Conference on Production Engineering, p.p. 109–113, Faculty of Technical Sciences, University of Kragujevac, October 14–15, Čačak, Serbia, 2021.

[8] Zeng, Y.: *Fundamentals of next generation CAD/E systems*, Computer-Aided Design, Vol. 44, p.p. 875–878, 2012.

[9] Fu, J., Ma, Y.: A *method to predict early-ejected plastic part air-cooling behavior towards quality mold design and less molding cycle time*, Robotics and Computer Integrated Manufacturing, Vol. 56, p.p. 66–74, 2019.

[10] Baldi-Boleda, T., Sadeghi, E., Colominas, C., Garcia-Granada, A.: *Simulation approach for hydrophobicity replication via injection molding*, Polymers, Vol. 13, No. 13, 2021.

[11] Wang, Y., Yu, K. M., Wang, C. L.: *Spiral and conformal cooling in plastic injection molding*, Computer-Aided Design, Vol. 63, p.p. 1–11, 2015.

[12] Lin, A. C., Quang. N. H.: *Automatic generation of mold-piece regions and parting curves for complex CAD models in multi-piece mold design*, Computer-Aided Design, Vol. 57, p.p. 15–28, 2014.

[13] Liu, Y., Gehde, M.: *Evaluation of heat transfer coefficient between polymer and cavity wall for improving cooling and crystallinity results in injection molding simulation*, Applied Thermal Engineering, Vol. 80, p.p. 238–246, 2015.

[14] Szabo, F., Suplicz, A., Kovacs, J. G.: *Development of injection molding simulation algorithms that take into account segregation*, Powder Technology, Vol. 389, p.p. 368–375, 2021.

[15] Obregon, J., Hong, J., Jung, J. Y.: *Rule-based explanations based on ensemble machine learning for detecting sink mark defects in the injection moulding process*, Journal of Manufacturing Systems, Vol. 60, p.p. 392–405, 2021.

[16] Mahshid, R., Zhang, Y., Hansen, H. N., Slocum, A. H.: *Effect of mold compliance on dimensional variations of precision molded components in multi-cavity injection molding*, Journal of Manufacturing Processes, Vol. 67, p.p. 12–22, 2021.

[17] Guo, W., Yu, Z., Wei, W., Meng, Z., Mao, H., Hua, L.: *Effect of film types on thermal response, cellular structure, forming defects and mechanical properties of combined in-mold decoration and microcellular injection molding parts*, Journal of Materials Science and Technology, Vol. 92, p.p. 98–108, 2021.

[18] Tang, S. H., Kong, Y. M., Sapuan, S. M., Samin, R., Sulaiman, S.: *Design and thermal analysis of plastic injection mould*, Journal of Materials Processing Technology, Vol. 171, p.p. 259–267, 2006.

Authors: **Dr Ivan Matin, Assist. Prof. Dr Branko Štrbac, Prof. Dr Đorđe Vukelić, MSc Nenad Kulundžić, Prof. Dr Miodrag Hadžistević,** University of Novi Sad, Faculty of Technical Sciences, Department of Production Engineering, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Phone.: +381 21 485 2332, Fax: +381 21 454 495.

E-mail: matini@uns.ac.rs
strbacb@uns.ac.rs
vukelic@uns.ac.rs
kulundzic@uns.ac.rs
miodrags@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Spasojević, S., Ilić, K., Brdar, A., Dramićanin, M., Labus Zlatanović, D., Pećanac, M., Janjatovi, P., Rajnović, D., Baloš, S., Šiđanin, L.

UTICAJ NANOČESTICA METALNIH OKSIDA NA MEHANIČKE OSOBINE AUSTENITNOG NERĐAJUĆEG ČELIKA ZAVARENOG A-TIG POSTUPKOM

Rezime: *Zavarivanje austenitnih nerđajućih čelika se najčešće izvodi postupkom zavarivanja u zaštiti inertnog gasa netopljivom elektrodom (TIG). Ovaj postupak ima mnoge prednosti od kojih je jedna od najznačajnijih zavarivanje širokog spektra materijala. Međutim, upotreba mu je ograničena zbog niske produktivnosti izazvane malom dubinom uvara i brzinom zavarivanja. Ovaj problem se može prevazići korišćenjem premaza koji znatno povećavaju dubinu uvara. U ovom radu su korišćeni premazi sa SiO_2 i TiO_2 oksidnim nanočesticama u različitim odnosima. Za karakterizaciju mehaničkih osobina zavarenih spojeva izvršeno je ispitivanje zatezanjem i energije udara. Ustanovljeno je da premaz deluje na povećanje dubine uvara bez značajnog pada mehaničkih osobina.*

Ključne reči: *A-TIG zavarivanje, nanočestice, mehaničke osobine*

1. UVOD

Austenitni nerđajući čelici poseduju otpornost na koroziju u atmosferskim, hemijskim i vodenim sredinama zbog čega imaju veliku upotrebu u petrohemijskoj, farmaceutskoj i prehrambenoj industriji. Pored hemijske postojanosti imaju mašinsku obradivost i dobru zavarljivost određenim postupcima zavarivanja. Kako se u ovakvim industrijskim sistemima zahteva visok kvalitet zavarenog spoja, kao adekvatno rešenje se nameće zavarivanje u zaštiti inertnog gasa netopljivom elektrodom (TIG - Tungsten Inert Gas) [1]. Upotreba TIG postupka je ograničena debljinom uzorka, odnosno dubinom uvara, što rezultira malom brzinom zavarivanja i smanjenom proizvodnošću. Postoji više različitih metoda za povećanje produktivnosti TIG postupaka. Većina njih se zasnivaju na povećanju dubine uvara. Jedan od tih načina je upotreba aktivnog premaza (topitelja) koji se sastoji od metalnih oksida rastvorenih u odgovarajućoj suspenziji npr. aceton ili etanol. Ovi premazi se mogu nanositi četkicom ili u vidu spreja [2,3].

Upotrebom ovakvih premaza dolazi do značajnog povećanja proizvodnosti jer nema potrebe za pripremom V-žleba. Na taj način se smanjuje broj prolaza radi popune žleba i potrošnja gasa. Sve ovo zajedno takođe rezultira i smanjenjem troškova [4]. Pored povećanja dubine aktivni premazi imaju uticaj i na zatezne karakteristike zavarenog spoja.

U radu koji je napisao Chern [5] objavljen 2011 godine ispitivane su mehaničke osobine zavarivanih uzoraka (AISI 2205) TIG postupkom sa i bez premaza. Rezultati koji su dobijeni prilikom ispitivanja ukazuju da su zatezne karakteristike kod uzoraka zavarivanih pomoću premaza veće ili jednake od uzoraka koji su zavarivani bez premaza. Dok su duktilnost i procentualno izduženje pokazali blago smanjenje kod uzoraka zavarivanih pomoću premaza.

Cilj ovog rada je odabir adekvatnog aktivnog premaza koji bi prilikom nanošenja na površinu zavarivanog spoja povećao dubinu uvara i omogućio zavarivanje većih debljina austenitnih nerđajućih čelika bez pripreme šava. Ustanovljene su zatezne i udarne karakteristike zavarenih spojeva dobijenih različitim tipovima nanočestica.

2. EKSPERIMENTALNI DEO

U radu je izvršeno zavarivanje dve ploče od nerđajućeg austenitnog čelika AISI 304L. Hemijski sastav i mehaničke osobine osnovnog materijala (standardom propisane vrednosti i stvarne vrednosti) date su u tabelama 1 i 2 respektivno. Ploče dimenzija 200×50×10 mm su bile postavljene sučeono bez zazora.

Tabela 1. Hemijski sastav AlSl 304L u procentima

C	Si	Mn	Cr	Ni	P	S	Fe
0.02	0.042	1.55	18.63	8.23	0.032	0.0004	osnova

Premazi koji su korišćeni u ovom ispitivanju su napravljeni od mešavine nanočestica SiO_2 veličine 40 nm i TiO_2 veličine 20 nm i etanola u odnosima: 5% TiO_2 (5Ti), 4% TiO_2 +1% SiO_2 (4Ti1Si), 3% TiO_2 + 2% SiO_2 (3Ti2Si), 2% TiO_2 + 3% SiO_2 (2Ti3Si), 1% TiO_2 + 4% SiO_2 (1Ti4Si), 5% SiO_2 (5Si) Mešanje je izvršeno magnetnim mešačem Tehtnica mm530 (slika 1). Premazi su nanošeni

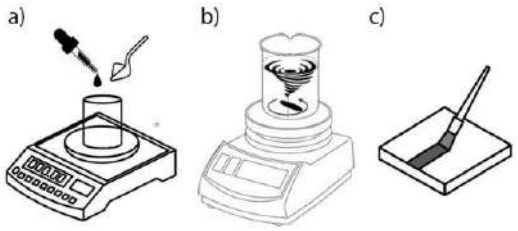
četkicom u širini od 20 mm i debljini 10 μm preko ivice pripojenih ploča odnosno budućeg šava, a debljina premaza je merena pomoću uređaja Tehtnica Type 2615.

Tabela 2. Mehaničke osobine osnovnog materijala i standardom propisane vrednosti za čelik AISI 304L

Mehaničke osobine	Napon tečenja Re [MPa]	Zatezna čvrstoća Rm [MPa]	Izduženje A [%]	Procentualno suženje Z [%]	Ukupna energija udara [J]
Uzorak	474	697	57	60	273
Standardne vrijednosti za 304L materijal	>170	>485	>40	-	>100

Kako bi se eliminisao uticaj zavarivača i ostvarila konstanta brzina zavarivanja gorionik je postavljen na zavarivački traktor Lorch koji se kretao brzinom od 40 mm/min. Korišćena je elektroda od volframa sa 2% torijum oksida prečnika 3,2 mm sa uglom vrha 60˚ i keramičke mlaznice prečnika 12,7 mm. Jačina struje na aparatu za zavarivanje je podešena na 250 A, a kao zaštitni gas korišćen je argon čistoće 99,999% i protokom od 12 l/min. Rastojanje od vrha elektrode do čelične poloče iznosilo je 1 mm.
Ispitivanje zatezanjem izvršeno je na hidrauličnoj kidalici Schenck hydropuls PSB u skladu sa standardom SRPS ISO 4136:2013 [6]. Uzorci su pripremljeni tako što su iz svake zavarene ploče uzete po dve epruvete, sa početka i sa kraja zavara.

Ispitivanje energije udara urađeno je na instrumentiranom Šarpijevom klatnu Jinan JTW 450 J po standardu SRPS EN ISO 148:2011 [7]. Prilikom ispitivanja energije udara korišćene su standardne epruvete dimenzija 10 × 10 × 55 mm sa zarezom.



Sl. 1. Priprema aktivnog premaza a) odmeravanje, b) mešanje c) nanošenje na ploče [8]

3. REZULTATI I DISKUSIJA

3.1 Rezultati ispitivanja zateznih karakteristika

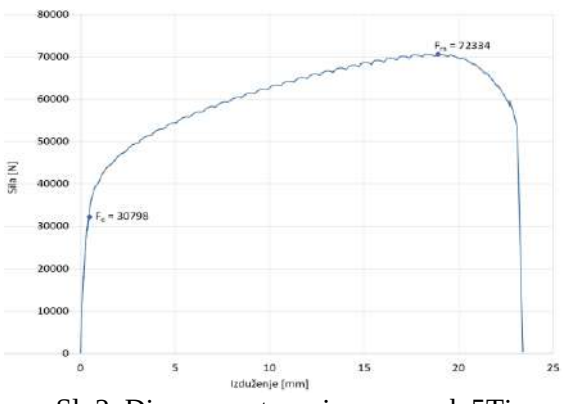
U tabeli 3 su prikazani rezultati zateznih karakteristika zavarenih uzoraka. Iz tabele 1 se može konstatovati da su dobijene vrednosti zateznih karakteristika veoma slične, kao i rezultati koji su dobijeni sa uzoraka koji su uzeti sa početka i sa kraja zavarene ploče. Najveća zatezna čvrstoća (632 MPa) i napon tečenja (275 MPa), kao i najveće zabeleženo izduženje (50%) i suženje (69%) su dobijeni kod uzorka 1K (1% TiO_2 i 4% SiO_2) koji je uzet sa kraja ploče. Svi zavareni spojevi imaju niže zatezne karakteristike u odnosu na osnovni materijal, ali su veće u odnosu na standardom propisane vrednosti za čelik AISI 304L.

Tabela 3. Mehaničke osobine zavarenih uzoraka (U oznaci uzoraka slovo P označava da je uzorak uzet sa početka ploče dok slovo K označava da je uzorak uzet sa kraja ploče)

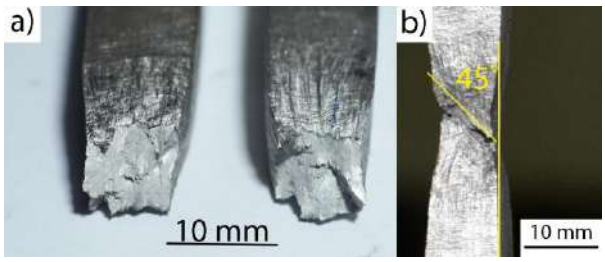
Uzorak		Re [MPa]	Rm [MPa]	Srednje vrednosti Rm	Izduženje A [%]
5P	5Ti	273	603	600,5	48,5
5K		257	598		47,5
4P	4Ti 1Si	254	583	588,5	46,5
4K		272	594		44,5
3P	3Ti 2Si	274	592	602,5	42,5
3K		261	613		45,5
2P	2Ti 3Si	268	599	606,5	43,5
2K		253	614		47,0
1P	1Ti 4Si	257	615	623,5	46,0
1K		275	632		50,0
0P	5Si	270	616	618,5	44,0
0K		230	621		49,5

Vidi se da najnižu srednju zateznu čvrstoću (588,5 MPa) ima uzorak 4Ti1Si, a najveću (623,5 MPa) uzorak 1Ti4Si.

Na osnovu prikupljenih podataka sa kidalice dobijen je dijagram zatezanja sila – izduženje prikazan na slici 2. Ovaj reprezentativni dijagram je dobijen prilikom zatezanja prvog uzorka koji je uzet sa početka ploče, zavarene premazom 5Ti. Dijagram ovog oblika je karakterističan za duktilne materijale, s obzitom da se nakon maksimalne sile Fm, vrednosti sila smanjuju sve do loma.



Sl. 2. Diagram zatezanja za uzorak 5Ti



Sl 3. Prelomljena površina metala šava a) vidljivi vlaknasti tragovi b) lom pod uglom od 45˚

Nakon dostizanja zatezne čvrstoće na epruvetama nastaje suženje na mestu gde dolazi do loma. Kod svih epruveta je došlo do pojave vrata prilikom zatezanja što je karakteristika duktilnih materijala. Na prelomljenom metalu šava su uočljivi vlaknasti tragovi tečenja metala kao i lom pod uglom od oko 45˚(slika 3b). Kod svih uzoraka, lom se desio u metalu šava.

3.2 Rezultati ispitivanja energije udara

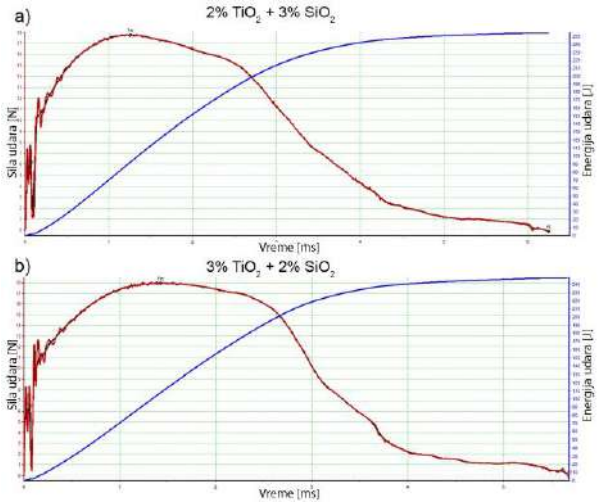
Vrednosti energije udara koja je potrebna za stvaranje i širenje prsline su date u tabeli 4, kao i ukupna energija udara ispitanih uzoraka. Iz tabele 4 se može videti je najveća ukupna energija udara dobijena kod uzoraka 1Ti4Si i 2Ti3Si koja iznosi 253 J, a najmanja energija udara je dobijena kod uzorka 4Ti1Si i iznosi 227 J.

Tabela 4 Rezultati ispitivanja energije udara u metalu šava

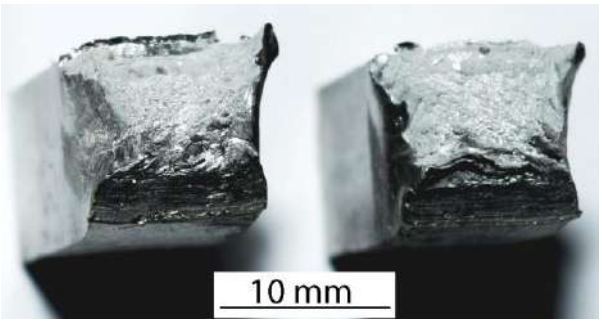
Uzorak	Epruveta	Energija za stvaranje prsline [J]	Energija za širenje prsline [J]	Ukupna energija udara KV [J]
5Ti	1	94	156	250
	2	100	150	250
	3	96	146	242
	Srednja vr.	**97**	**151**	**248**
4Ti1Si	1	98	117	215
	2	90	153	243
	3	99	125	223
	Srednja vr.	**96**	**132**	**227**
3Ti2Si	1	100	152	252
	2	100	131	231
	3	108	141	248
	Srednja vr.	**102**	**141**	**244**
2Ti3Si	1	92	162	254
	2	86	152	238
	3	100	165	265
	Srednja vr.	**93**	**160**	**253**
1Ti4Si	1	94	168	262
	2	97	154	251
	3	95	150	245
	Srednja vr.	**95**	**157**	**253**
5Si	1	102	137	239
	2	93	125	219
	3	102	148	250
	Srednja vr.	**99**	**137**	**236**

U poređenju sa osnovnim materijalom kod koga ukupna energija udara iznosi 273 J, primetno je da postoji mali pad energije udara od 8 do 20%. Može se videti da su energije za širenje prsline veće u odnosu na energije za stvaranje prsline kod svih uzoraka.

Na slici 6, prikazani su dijagrami energije udara. Crvena kriva predstavlja zavisnost sile od vremena, na kojoj se može uočiti maksimalna sila (Fm), odnosno momenat u kom dolazi do stvaranja prsline. Površina ispod krive do tačke Fm predstavlja rad utrošen na stvaranje prsline, dok površina ispod krive nakon tačke Fm predstavlja rad utrošen na rast (širenje) prsline. Priraštaj energije udara u zavisnosti od vremena predstavlja plava kriva. Na slici 6 su prikazani dijagrami energije udara na kojima se može videti razlika između uzoraka 2Ti3Si (slika 4a), i uzorka 3Ti2Si (Slika 4b), jer je energija udara površina ispod krive sila – vreme. Standardom SRPS SN 10088-2:2003 [9] najmanja propisana vrednost energije udara na sobnoj temperaturi sa zarezom postavljenim u položaj VWT po standardu SRPS ISO 9016:2013 [10] je 100 J. Na osnovu ovog standarda svi uzorci višestruko prelaze propisane vrednosti



Sl 4. Dijagrami energije udara: a) uzorak zavaren sa aktivnim premazom 2% TiO_2 + 3% SiO_2, b) uzorak zavaren sa aktivnim premazom 3% TiO_2 + 2% SiO_2



Sl 5. Prelomljena površina uzorka 1Ti4Si

Na slici 5 je prikazana površina loma uzorka

1Ti4Si prilikom ispitivanja energije udara. Na njemu su vidljivi tragovi plastične deformacije nastali prilikom loma. Kod svih ispitivanih uzoraka uočljivi su tragovi plastične deformacije što je karakteristika duktilnih materijala.

4 ZAKLJUČCI

Na osnovu istraživanja i rezultata opisanih u ovom radu mogu se izvesti sledeći zaključci:

- Iz dobijenih rezultata prilikom ispitivanja zateznih karakteristika uzoraka zavarivanih sa različitim premazima uočljivo je da svi dobijeni rezultati zadovoljavaju propisane standardne vrednosti osnovnog materijala, koje su date u tabeli 2.
- Kod ispitivanja energije udara zavarivanih uzoraka sa različitim premazima, ustanovljeno je da svi uzorci zadovoljavaju zahtevane standardne vrednosti.
- Na osnovu datih rezultata može se ustanoviti da sa premazom 1Ti4Si su dobijeni rezultati koji su najpribližniji osnovnom materijalu i da je to premaz koji daje najbolje osobine zavarenog spoja.

5. LITERATURA

[1] K.-H. Tseng, C.-Y. Hsu, *Performance of activated TIG process in austenitic stainless steel welds*, J. Mater. Process. Tech. 211, pp. 503–512, 2011

[2] Huang H.-Y., *Argon–hydrogen shielding gas mixtures for activating flux-assisted gas tungsten arc welding*, Metall. Mater. Trans. A Phys. Metall. Mater. Sci. 41 (2010)

[3] K.-H. Tseng, N.-S. Wang, *Welding activated flux for structural alloy steels*, US Patent 20160167178A1, 2016.

[4] P.J. Modenesi, E.R. Apolinário, I.M. Pereira, *TIG welding with single-component fluxes*, J. Mater. Process. Technol. 99, pp. 260–265, 2000.

[5] T.-S. Chern, K.-H. Tseng, H.-L. Tsai, *Study of the characteristics of duplex stainless steel activated tungsten inert gas welds*, Materials & Design. 32 (2011) 255–263

[6] BS EN ISO. "BS EN ISO 4136*: Destructive Tests on Welds in Matallic Materials – Transverse Tensile Test* (ISO 4136:2012)," 2013, 1-20.

[7] UNI EN ISO 148-1-2011 *Charpy Part 1 Test Method.*

[8] Dramićanin M. *Uticaj aktivnog premaza na dubinu uvara pri zavarivanju nerđajućeg čelika netopljivom elektrodom u zaštiti inertnog gasa*, Disertacija, Novi Sad, 2019

[9] EN 10088-2-2005(2014)-*Nerđajući Čelici — Tehnički Zahtevi Za Isporuku Limova i Traka Od Čelika Otpornih Na Koroziju-Technical Delivery Conditions for Sheetplate.Pdf*,"

[10] EN ISO 9016 – *Destructive test on welds in metallic materials – Impact tests – Tests specimen location, notch orientation and examination* (ISO 9016:2012)

ZAHVALNOST:
Ovaj rad rezultat rada autora u okviru projekta pod naslovom „Inovativni materijali i tehnologije spajanja" Laboratorija za ispitivanje materijala i Laboratorije za zavarivanje, Departmana za proizvodno mašinstvo, Fakulteta tehničkih nauka.

Autori: **dipl. inž. Stanko Spasojević, dipl. inž. Katarina Ilić, dipl. inž. Ana Brdar, , Doc. dr Miroslav Dramićanin, Mast. inž Milan Pećanac, Mast. inž Petar Janjatović, Vanr. prof. dr Dragan Rajnović, Prof. Dr Sebastian Baloš.** Univerzitet Novi Sad, Fakultet Tehničkih Nauka, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2350, Fax: +381 21 454-495.
E-mail: spasojevics@uns.ac.rs;
katailic@uns.ac.rs;
anab@uns.ac.rs;
dramicanin@uns.ac.rs;
danlabus@uns.ac.rs
pecanac.milan@uns.ac.rs;
janjatovic@uns.ac.rs:
draganr@uns.ac.rs;
sebab@uns.ac.rs
lepas@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Terek, V., Miletić, A., Kovačević, L., Škorić, B., Bobić, Z., Panjan, P., Terek, P.

AFM ANALYSIS OF SURFACE TOPOGRAPHY AND GRAIN MORPHOLOGY OF NANOSTRUCTURED TiAlSiN COATING

Abstract: *Among other properties, grain morphology and surface micro/nano topography have a great influence on mechanical properties and tribological and corrosive behavior of hard coatings. Atomic force microscopy is a technique that has already proven useful in characterization of hard coatings. In this study, AFM was employed for analysis of surface topography and grain morphology of nanolayered TiAlSiN coating deposited on five different substrate materials. The coating was prepared in industrial magnetron sputtering unit using 1-fold, 2-fold, and 3-fold rotation during deposition. Both substrate material and rotation has shown great influence on the results.*
Key words: *AFM, surface topography, grain morphology, nanolayer coating, magnetron sputtering*

1. INTRODUCTION

TiAlSiN is one of the most advanced protective coatings due to its extraordinary properties, such as high hardness, thermal stability, oxidation resistance, etc. [1,2]. It is mostly used for protection of cutting tools, forging tools, high pressure die casting tools and others. However, due to its chemical inertness and high corrosion resistance it is also applied on biomedical implants and devices. Wide range of applications of this coating requires its deposition on wide range of different substrate materials. However, when it is deposited on different substrate materials, different coating properties might be expected even in the same deposition batch. Additionally, in order to apply coating on complex tools and elements, multiple substrate rotation during deposition is required.

Both, the substrate material, and rotation during deposition have a great impact on coating topography and grain morphology, which are important for tribological behavior and mechanical properties of coatings [3,4]. Our motivation for this study was to broaden still scarce information about the effects of substrate material and rotation during deposition on coating topography and grain morphology.

2. MATERIALS AND METHODS

In this study, nanolayered TiAlSiN coating was deposited on five different substrate materials. The coating was deposited on disk shaped samples (Ø32 x 5 mm) made of quenched and tempered cold-working tool steel (EN X153CrMoV12), hot-working tool steel (EN X37CrMoV5-1), plasma nitrided hot-working tool steel, hot rolled surgical stainless steel (EN X2CrNiMo18-15-3), and cemented carbide (WC/Co). Prior to deposition samples were ground and polished (3 µm diamond paste) and degreased and cleaned in ultrasonic baths.

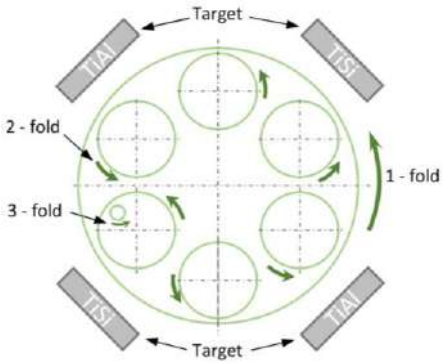


Fig. 1. Schematic of deposition unit in top view and position of targets.

The deposition was performed using industrial magnetron sputtering unit (CC800/9, Cemecon). The unit consists of four unbalanced magnetron sources placed in the corners of the chamber and has ability of planetary rotation (Figure 1). Cold-working tool steel was coated employing 1-, 2-, and 3-fold rotation while all other substrate materials were coated with only 2-fold rotation during deposition. However, all samples were deposited in a single deposition batch. Samples designation used in this study is shown in table 1. Deposition parameters and other details about process can be found in [2].

Coating's mechanical properties were determined using Fisherscope H100C tester equipped with Vickers diamond indenter. Coating hardness and modulus of elasticity on hot-work tool steel substrate was 2301 $HV_{0.005}$ and 289.62 GPa, respectively. Coating thickness for 1-fold, 2-

fold and 3-fold rotation was 6.38 μm, 3.6 μm and 2.6 μm, respectively.

Table 1. Designation of samples

Rotation	1-fold	2-fold	3-fold
Cold-work tool steel	CW-1	CW-2	CW-3
Hot-work tool steel	-	HW	-
Plasma nitrided tool steel	-	PN	-
Surgical stainless steel	-	SS	-
Cemented carbide	-	CC	-

Surface topography was evaluated using 3D stylus profilometry (Talysurf, Taylor Hobson) and atomic force microscopy (AFM; CP-II di, Veeco). Scanning area for profilometry was 1 x 1 mm, while areas scanned by AFM were 90 x 90, and 5 x 5 μm. Surface roughness parameters and size of columnar grains were determined using image analysis software (SPIP, Image Metrology A/S). Additionally, the number of coating growth defects (islands) was determined using a detection threshold of 0.5 μm.

3. RESULTS

3.1 Coatings topography on different substrates

Figure 2 shows representative 3D topography images of stainless steel (SS) and plasma nitrided (PN) samples. Nodular growth defects, typical for magnetron sputtered coatings, can be observed as a spike-like features on the surface. More defects are present on SS sample than on PN, but the defects on SS seem smaller.

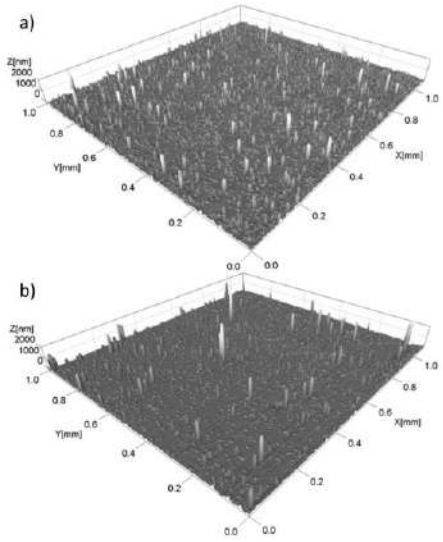


Fig. 2. 3D topography profilometry images of 1 x 1 mm areas: a) SS; b) PN.

Surface roughness parameter Sa, and defect density is for different samples presented in Figure 3. The highest roughness (Sa = 76.7 nm) was determined for SS sample, while other samples showed similar and considerably lower Sa ranging from 44.7 to 53.5 nm. Similar trends were also observed for density of growth defects, with SS sample having 338 defects per mm^2, while considerably lower defect density was determined for other samples (ranging from 96 / mm^2 to 166 / mm^2). Additionally, it was found that SS sample has the lowest overall volume of defects (V_{ss} = 14.8 μm^3), while volume for CC, HW, CW-2 and PN samples was 28.6, 29.3, 38.7, and 44.4 μm^3, respectively.

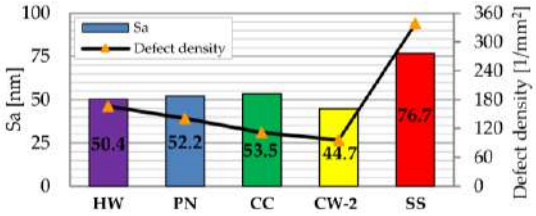


Fig. 3. Sa parameter and defect density of different samples, on area of 1 mm^2.

Surface topography images of SS and PN samples, obtained by AFM on areas of 90 x 90 μm, are presented in Figure 4. In these higher resolution images, higher defect density for SS sample can be visually confirmed, but also the topographical features between the nodular defects seem smaller. Sa parameter is for these images presented in table 2. When compared with profilometry, different trends of Sa parameter were observed. This is a consequence of random selection of small scanning areas that resulted in fluctuation of defect density on sample's surface.

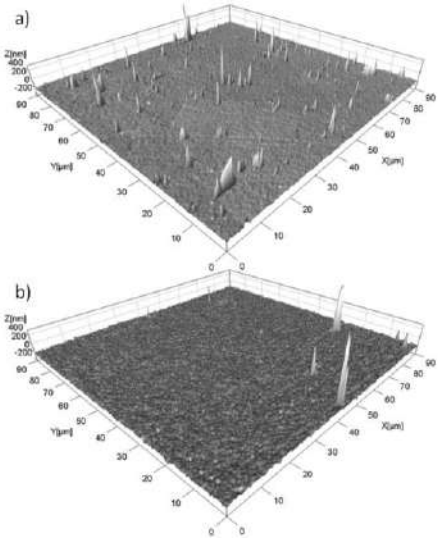


Fig. 4. 3D topography AFM images of 90 x 90 μm areas: a) SS; b) PN.

Nano-topography between the nodular defects was studied on the areas of 5 x 5 μm, which were scanned by AFM. Sa parameter is shown in table

2. In accordance with previous postulation that smoother surface is observed between defects, significantly lower values of Sa parameter were observed for SS sample.

Table 2. Sa parameter of different samples and areas scanned by AFM

Area	HW	PN	CC	CW-2	SS
90 x 90 μm	15.0	15.0	28.1	27.2	14.0
5 x 5 μm	16.2	15.1	16.8	20.8	7.9

In order to evaluate the influence of substrate material on coating grain size, grain analyses were performed on 2D AFM images of 5 x 5 μm. SS sample displayed the largest number of grains (1580), which consequently means that this sample has smallest grains. Mean diameter of grains for SS sample was 125 nm. Other samples showed similar and significantly lower number of grains, ranging from 490 to 614, while mean grain diameter for these samples ranged from 211 to 236 nm.

3.2 Coatings topography using different rotations during deposition

Figure 5a presents surface roughness parameter Sa and defect density obtained by profilometry for CW samples. Almost the same roughness was determined for CW-2 and CW-3 samples, while roughness for CW-1 sample was considerably higher. Overall, decrease of Sa parameter and defect density with increased degree of rotation during deposition was observed.

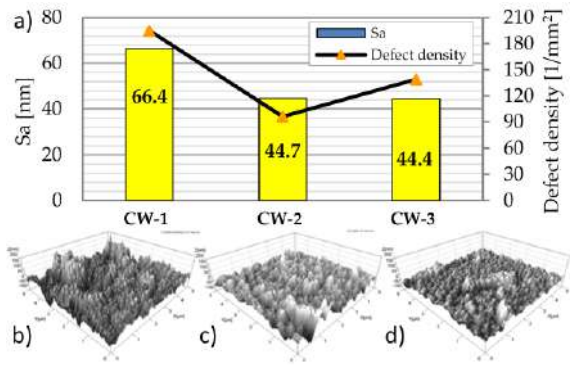


Fig. 5. CW samples: a) Sa and defect density on area of 1 mm^2; b) – d) Surface topography of 5 x 5 μm areas of CW-1, CW-2, and CW-3 sample.

3D surface topography images of zones between defects (5 x 5 μm), of CW samples, are presented in Figure 5 b-d. Decrease of surface roughness with increase in number of rotations is observed once more. Additionally, uneven surface and grain agglomerations were present on coating deposited with 1-fold rotation, while coating deposited with 2- and 3-fold rotation displayed less pronounced agglomerations and more uniform surface. Accordingly, the Sa parameter was highest for CW-1 sample (Sa_{CW-1} = 41.0 nm) and decreased for CW-2 and CW-3 samples (Sa_{CW-2} = 20.8 nm; Sa_{CW-3} = 15.3 nm).

Grain analyses of CW samples were performed on 2D AFM images of 5 x 5 μm. The largest number of grains was detected for CW-1 (1376), while 607 and 1060 grains was detected for CW-2 and CW-3, respectively. Consequently, mean grain diameter determined for CW-1, CW-2 and CW-3 was 136, 213 and 162 nm, respectively.

4. DISCUSSION

4.1 Coatings topography on different substrates

In this study, differences in surface topography and roughness were detected among coated investigated materials. Lower roughness and less defects were determined for coating deposited on tool materials (HW, PN, CW, and CC), while high roughness and high number of defects were found on coated stainless steel (SS), Figure 3. It is known that carbides in material (as in tool steel) can significantly increase number and size of coating growth defects due to the shadowing effect during deposition [5]. But since stainless steel does not have carbides in its microstructure, nodular defects have different origin [6]. It is suggested that, due to its lowest hardness among tested materials, grinding and polishing of stainless steel creates large number of deformed asperities on the surface. Additionally, diamond paste or sandpaper particles can easily embed into the surface. Both effects cause increase in number of coating growth defects on SS sample.

Surface topography on macro level of all samples is dominated by nodular defects and therefore appears quite similar. However, nano-topography between the nodular defects is considerably different for coating deposited on stainless steel. SS sample displayed the smallest grains and more uniform surface which resulted in the lowest Sa parameter (table 2). However, considering that all samples were prepared in the same batch under the same conditions, the observed difference in grain size might be the consequence of different microstructures of substrate materials. Microstructure of stainless steel consists of austenite, while other substrates mostly contain tempered martensite [6]. Therefore, it is suggested that coatings grow with smaller grains and smoother surface on substrates with austenite microstructure. Additionally, since size of grains directly correlates with mechanical properties and crack propagation resistance, coating deposited on SS substrate is expected to

show better properties from this point of view.

4.2 Coatings topography using different rotations during deposition

It was found that Sa parameter and defect density decreased with higher degree of rotation (Figure 5a). However, thickness of the coating also follows the same trend [7]. Additionally, it is postulated that nodular defects for thicker coatings, such as 1-fold, may easily grow higher and above detection threshold. Therefore, it is suggested that influence of rotation on coating roughness and defect density should be evaluated using coatings of the same thickness.

Analysis of 5 x 5 μm AFM images showed that coating deposited with 1-fold rotation displayed the smallest grains, but surprisingly the highest roughness. This unexpected behavior is a result of pronounced agglomerations and uneven surface morphology of the coating. With higher degree of rotation (2- and 3-fold) ion bombardment of the growing film increases and deposition rate decreases [7]. Low ion bombardment and high deposition rate for 1-fold rotation induced low adatom mobility that resulted in coating grain agglomerations and consequently high Sa parameter. Therefore, no specific correlation between grain size and degree of rotation was observed.

5. CONCLUSIONS

From presented study several conclusions can be drawn:

- It was found that coating surface roughness parameter Sa and number of coating growth defects are directly correlated.
- Substrate materials of lower hardness may suffer from larger number of defects due to formation of micro and nano asperities and embedment of sandpaper and diamond paste particles during sample preparation.
- Size of coating columnar grains highly depends on microstructure of substrate material.
- Decrease of surface roughness for higher degree of rotation is a combined effect of rotation and coating thickness.
- High deposition rate and low ion bombardment for coating deposited with 1-fold rotation induced grain agglomerations and higher Sa parameter.
- No clear relationship between coating grain size and degrees of rotation was observed.
- Additional study is required to fully understand the influence of rotation during deposition and substrate material microstructure on coating grain size and surface topography.

6. REFERENCES

[1] Sui, X., Li, G., Qin, X., Yu, H., Zhou, X., Wang, K., Wang, Q., *Relationship of microstructure, mechanical properties and titanium cutting performance of TiAlN/TiAlSiN composite coated tool*, Ceramics Intertnational, 42, p.p. 7524–7532, 2016.

[2] Miletić, A., Panjan, P., Škorić, B., Čekada, M., Dražič, G., Kovač, J., *Microstructure and mechanical properties of nanostructured Ti-Al-Si-N coatings deposited by magnetron sputtering*, Surface and Coatings Technology, 241, p.p. 105–111, 2014.

[3] Panjan, P., Drnovšek, A., Kovač, J., *Tribological aspects related to the morphology of PVD hard coatings*, Surface and Coatings Technology, 343, p.p. 138-147, 2018.

[4] Luo, Q., Lewis, D.B., Hovsepian, P.Eh., Münz W-D., *Transmission electron microscopy and x-ray diffraction investigation of the microstructure of nanoscale multilayer TiAlN/VN grown by unbalanced magnetron deposition*, 19, p.p. 1093-1104, 2004.

[5] Panjan, P., Drnovšek, A., Gselman, P., Čekada, M., Panjan, M., *Review of Growth Defects in Thin Films Prepared by PVD Techniques*, Coatings, 10, p.p. 447, 2020.

[6] Davis, J.R., *Asm Specialty Handbook: Stainless Steels*, ASM International, 1994.

[7] Panjan,M., *Influence of substrate rotation and target arrangement on the periodicity and uniformity of layered coatings*, Surface and Coatings Technology, 235, p.p. 32–44, 2013.

Authors: **M.Sc. Vladimir Terek**, **Assoc. Prof. Lazar Kovačević, Full Prof. Branko Škorić, M.Sc. Zoran Bobić, Assist. Prof. Pal Terek**, University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia, Phone: +381 21 450 810.
E-mail: vladimirterek@uns.ac.rs
lazarkov@uns.ac.rs
skoricb@uns.ac.rs
zoranbobic@uns.ac.rs
palterek@uns.ac.rs

Researcher Aleksandar Miletić, Polytechnique Montreal, Department of Engineering Physics, Quebec H3T 1J4, Canada, Phone.: +1 514 340 4711.
E-mail: aleksandar.miletic@polymtl.ca

Research Counselor Peter Panjan, Jožef Stefan Institute, Department of Thin Films and Surfaces, Jamova 39, Ljubljana, 1000, Slovenia, Phone.: +386 1 477 39 00.
E-mail: peter.panjan@ijs.si

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Živković, T., Movrin, D., Milutinović, M., Ranđelović, S., Stefanović, Lj.

ISPITIVANJE DEFORMACIJA TANKIH DELOVA IZRAĐENIH SLA TEHNOLOGIJOM

Rezime: *Aditivne tehnologije (ili 3D štampa) danas predstavljaju jednu od popularnijih tehnologija koje su svoju primenu našle u svim granama industrije ali i u svakodnevnom životu. Jedna od najpopularnijih aditivnih tehnologija danas jeste Stereolitografija (SLA) koja se bazira na očvršćavanju tečnog fotopolimera pod dejstvom UV svetlosti. Na tržištu se može pronaći veliki broj fotopolimera koji se razlikuju po mehaničkim karakteristikama izrađenih delova. Kroz rad je prikazano eksperimentalno određivanje i poređenje deformacija tankih delova izrađenih SLA tehnologijom upotrebom štampača Form 2 i dva fotopolimera (Grey i Durable).*

Ključne reči: *Aditivne tehnologije, SLA, deformacije, fotopolimer*

1. UVOD

U ranom razvoju aditivnih tehnologija, zbog ograničenosti u mehaničkim karakteristikama izrađenih delova, primena im je bila ograničena samo na izradu prototipova. Poslednjih godina došlo je do ubrzanog razvoja kako samih tehnologija, tako i materijala, čime je postignuto da se ovim tehnologijama danas izrađuju funkcionalni delovi i alati, a moguća je i izrada malih serija proizvoda.

Danas jedan od rasprostranjenijih aditivnih procesa jeste stereolitografija (Stereolithography - SLA), kojim se mogu izraditi polimerni delovi visokog kvaliteta površine i tačnosti, kao i dobrih mehaničkih svojstava. Visok kvalitet, tj. niska hrapavost površine se postiže zahvaljujući korišćenju tečnih fotoosetljivih polimera, i visokom rezolucijom (malom debljinom sloja; 0.025-0.2 mm) uređaja. Manje debljine sloja omogućavaju dobijanje delova složenije geometrije i veće tačnosti i preciznosti izrade, ali povećavaju vreme i cenu izrade, dok za veće debljine slojeva važi suprotno.

Međutim, kao i svaka tehnologija i SLA ima određeni niz nedostataka, a najveći nedostatak predstavlja potreba za naknadnom obradom (postprocesiranjem) izrađenih delova u UV komorama. U nekim slučajevima, kao što je izrada tankih delova, pri određenim parametrima postprocesiranja može doći do neželjenih deformacija delova, što je nepovoljno sa stanovišta tačnosti.

Kao osnovni materijal za izradu delova primenom stereolitografije koriste se tečni fotoosetljivi polimeri. Prvi fotopolimeri koji su se našli u upotrebi za osnovu su imali akrilate, a izrađeni delovi su imali loše mehaničke karakteristike i tačnost im je bila niska zbog velikog skupljanja pri polimerizaciji (5-20%). Takođe, zbog načina generisanja sloja, gde laserski zrak prodire i do prethodnog sloja, dolazi do problema duplog osvetljavanja prethodno osvetljenog sloja, što izaziva dodatno skupljanje [1, 2]. Većina današnjih fotopolimera kao osnovni monomer koristi akrilate uz dodatak različitih aditiva kako bi se umanjile negativne osobine akrilata, kao što je visok procenat skupljanja prilikom procesa polimerizacije.

Tokom SLA procesa ne dolazi do potpune polimerizacije radnih delova, već unutar dela, između slojeva, ostaje deo materijala koji nije polimerizovan. Za potpunu polimerizaciju potrebno je naknadno izlaganje delova UV zracima u odgovarajućim komorama, ponekad i na povišenim temperaturama.

U radovima više istraživača mogu se pronaći istraživanja povezana sa problematikom skupljanja delova izrađenih akrilatnim fotopolimerim. Tako na primer Karalakes i ostali su izvršili uporednu analizu skupljanja dva različita fotopolimera, EXACTOMER 2202SF koji je u osnovi akrilat i SOMOS 7110 koji je baziran na epoksidnoj formulaciji. Poređenjem zaostalih napona i veličina deformacija utvrdili su da akrilatni fotopolimeri imaju veću tendenciju ka skupljanju i pojavi većih unutrašnjih napona od fotopolimera na bazi epoksida [3].

U svom istraživanju Zhang i ostali [4] su primenom teorije, metode konačnih elemenata i eksperimentalnom verifikacijom određivali veličinu ugla krivljenja delova kod struktura oblika češlja izrađenih DLP tehnologijom. S obzirom da je za razliku od SLA tehnologije, pri DLP štampi moguće varirati vreme ekspozicije svakog pojedinačnog sloja, autori su ovaj

parametar varirali u dva nivoa, 2s i 7s i pokazali značajan uticaj ovog parametra na krajnji oblik, tj. vrednost ugla krivljenja dela.

Različite tehnike postprocesiranja i njihov uticaj na mehaničke karakteristike, kao i na promenu dimenzija kroz svoja istraživanja su prikazali Zhao i drugi [5]. Umesto standardne UV komore za postprocesiranje, autori su koristili i običnu peć kao i mikrotalasnu komoru. Kroz istraživanja je pokazano da najveći uticaj na promenu dimenzija delova ima UV komora, dok je mikrotalasna komora pokazala najmanju promenu dimenzija. Sa druge strane, ako se posmatra zatezna čvrstoća, ipak je postprocesiranje u UV komorama nezamenljivo i daje veće rezultate u odnosu na druga dva načina .

Katheng i ostali su varirali temperaturu i vreme zadržavanja delova u UV komori i na taj način pratili dimenzionu promenu i stepen polimerizacije dentalnih protetičkih elemenata. Kao polazni fotopolimer korišćen je fotopolimer Clear proizvođača Formlabs, i varirane su tri različite temperature i dva vremena zadržavanja u UV komori. Dimenziona promena je praćena stereomikroskopom i na taj način je utvrđeno da pri temperaturi od 40^0C i vremenu zadržavanja u komori od 15 minuta dolazi do najmanjih dimenzionih promene, tj. tada je deo najtačniji [6].

2. EKSPERIMENTALNA ISTRAŽIVANJA

2.1 Izbor materijala i parametara procesa

Izbor materijala za eksperimentalna istraživanja izvršen je po tri kriterijuma:

1. Oblast primene - inženjerstvo;
2. Dostupnost na domaćem tržištu;
3. Kompatibilnost sa dostupnim uređajem Form2 (proizvođač Formlabs, USA).

Kao reprezentativni fotopolimeri za eksperimentalna istraživanja izdvojeni su Grey i Durable fotopolimer. Grey fotopolimer je izabran zato što predstavlja formulaciju koja daje najbolje kvalitet površine i odnos brzine izrade dela u odnosu na mehaničke karakteristike. Durable fotopolimer za razliku od Grey ima dobru elastičnost i žilavost, a po svojim osobinama najsličniji je Polipropilenu. Oba fotopolimera u svom sastavu sadrže metakrilat monomera, metakrilat oligomera, fotoinicijatore i aditive. Primer delova izrađenih upotrebom ova dva fotopolimera prikazan je na slici 1.

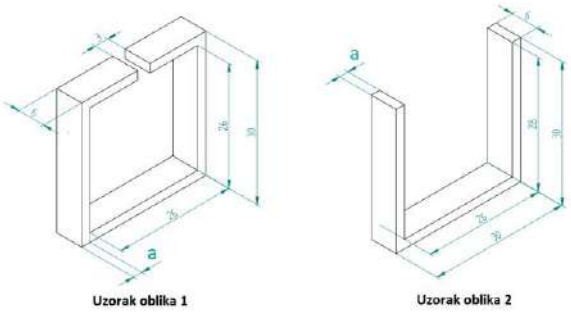
Uzorci testirani u eksperimentalnim istraživanjima su izrađeni na štampaču Form 2 sa rezolucijom (debljinom sloja) 0.1 mm.

Sl. 1. Deo izrađen fotopolimemorom Grey (levo) i Durable fotopolimerom (desno)

2.2 Izbor oblika uzoraka

Uvidom u postojeća istraživanja određivanja veličine deformacija i tačnosti delova izrađenih SLA postupkom, nije moguće naći jedinstven oblik uzorka za ispitivanje. U zavisnosti od korišćene opreme za merenje, pojedinačnih ideja istraživača kao i očekivanih rezultata, u literaturi se mogu pronaći uzorci oblika kružne pločice, ravne četvrtaste ploče, oblika češlja i dr.[3, 4, 5, 6]

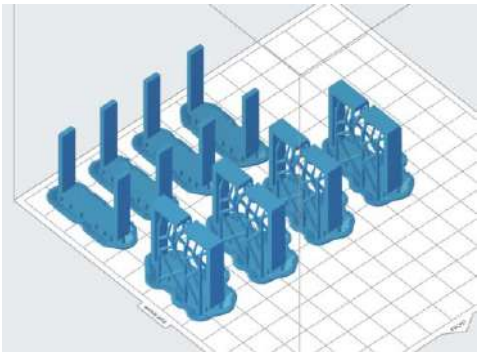
S obzirom da ovo ispitivanje nije obuhvaćeno ISO/ASTM standardom, u istraživanju su korišćena dva modela uzorka do kojih se došlo na osnovu izmena standardnog modela za ispitivanje toplotnog skupljanja materijala pri termičkoj obradi. Na osnovu takvog standardnog modela izvršena je korekcija, tj. prilagođavanje uzoraka SLA tehnologiji i na osnovu prethodnih istraživanja u Laboratoriji za aditivnu i virtuelnu proizvodnju, došlo se do dva najoptimalnija rešenja koja su sa dimenzijama prikazana na slici 2. Merne zone predstavljaju zazor od 3 mm kod oblika 1, tj. dimenzija od 26 mm kod oblika 2.



Sl. 2. Geometrija test uzoraka

Glavna razlika između usvojena dva oblika je u položaju potpora koje je potrebno postaviti na model kako bi štampa bila uspešna (slika 4), a koje mogu uticati na krajnju tačnost modela. Potpore najčešće generiše softver štampača, automatski, na osnovu ugrađenog algoritma i one predstavljaju oslonac pri izradi konzolnih elementa ili elemenata oblika grede, kako bi njihova izrada bila moguća. Nakon štampe one se skidaju i deo poprima konačan oblik.

Orijentacija uzorka na radnom stolu štampača, kao i generisane potpore prikazani su na slici 3, gde je izabran način orjentacije koji eliminiše potrebu za potporama duž cele visine uzorka oblika 2.



Sl. 3. Položaj i orijentacija uzoraka na radnom stolu SLA uređaja

Uzorci oba oblika nakon štampe, sa potporama, prikazani su na slici 4. Od svake serije uzoraka izrađena su po 4 komada, a za vrednost deformacije su se uzimale prosečne vrednosti merenja sva četiri.

Sl. 4. Uzorci nakon štampe sa potporama

2.2 Izbor temperature i vremena postprocesiranja

Svaki fotopolimer, bilo kog proizvođača, ima jedinstvenu preporuku o vremenu i temperaturi na kojoj je potrebno izvršiti postprocesiranje. U nekim slučajevima je postprocesiranje moguće vršiti na sobnoj temperaturi, dok kod se nekih fotopolimera javlja potreba za postprocesiranjem na povišenoj temperaturi. Takođe, vremena zadržavanja delova u UV komorama su veoma različita i kreću se od par minuta do par sati. Veća vremena su potrebna kod SLA postupka i kreću se između 60 i 120 minuta, dok se nakon DLP postupka delovi u komorama zadržavaju znatno kraće vremena, do nekoliko minuta.

Za delove izrađene na uređaju Form 2 temperaturni rang postprocesiranja je od 40-80^{0}C, dok se vreme kreće od 30 minuta pa do 2 sata, u zavisnosti od vrste fotopolimera.

Za Grey fotopolimer preporuka za vreme potrebno za potpuno postprocesiranje pri kom se dobija maksimalna zatezna čvrstoća je 60 min. Za Durable fotopolimer je takođe ista vrednost preporučenog vremena od 60 min. Preporuka za oba fotopolimera je da se postprocesiranje vrši na 60^{0}C [7].

S obzirom na sve navedeno, za realizaciju eksperimentalnih istraživanja postprocesiranje je izvedeno po vrednostima vremena i temperature datim u tabeli 1.

Tabela 1. Parametri postprocesiranja

Tip fotopolimera (intenzitet zračenja 30 LED sijalica po 20.7 mW/cm^2)	**Vreme [min]**	**Temperatura [^{0}C]**
Grey	60	60
Durable	60	60

Postprocesiranje je vršeno u UV komori BB Cure proizvođača Meccatronicore, Italija, koja ima precizno setovanje temperature kao i tajmer za isključivanje nakon zadatog vremena.

3. REZULTATI

Nakon izrade uzoraka, za svaki fotopolimer, izvršeno je merenje karakterističnih dimenzija i to:

- pre postprocesiranja – Bez UV,
- nakon postprocesiranja sa potporama – UV+P,
- nakon postprocesiranja bez potpora – UV-P,
- nakon sedam dana – 7D.

Dimenzione (Δ [mm]) i procentualne (Δ [%]) deformacije uzoraka u zavisnosti od stepena postprocesiranja, potpora i vremena (Bez UV, UV+P, UV-P, 7D), oblika uzorka i vrste materijala su prikazane u tabeli 2 za Grey i tabeli 3 za Durable fotopolimer. Pozitivne vrednosti promene dimenzije Δ [mm] predstavljaju povećanje dimenzija, dok negativne vrednosti predstavljaju smanjenje dimenzije.

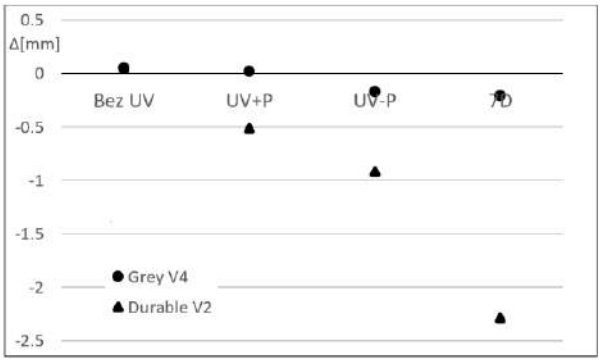
Tabela 2. Deformacije Grey fotopolimera

	Oblik 1	Oblik 2	Oblik 1	Oblik 2
	Δ[mm]	Δ[%]	Δ[mm]	Δ[%]
Bez UV	0,054	1,8	0,02	0,076
UV+P	0,019	0,633	-0,430	-1,657
UV-P	-0,17	-5,667	-0,444	-1,711
7D	-0,207	-6,9	-0,533	-2,053

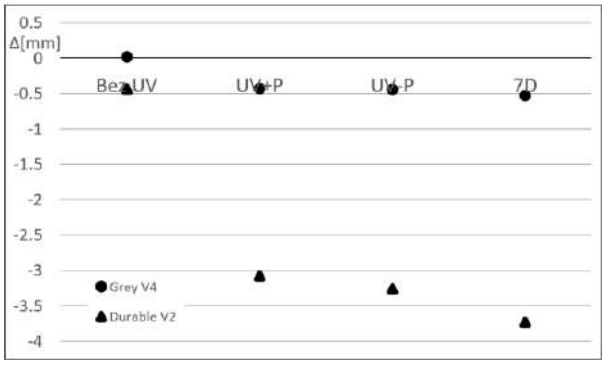
Tabela 3 Deformacije Durable fotopolimera

	Oblik 1	Oblik 2	Oblik 1	Oblik 2
	Δ[mm]	Δ[%]	Δ[mm]	Δ[%]
Bez UV	0,0515	1,716	-0,438	-1,684
UV+P	-0,513	-17,1	-3,077	-11,836
UV-P	-0,918	-30,6	-3,264	-12,553
7D	-2,287	-76,233	-3,733	-14,357

Radi lakše analize rezultata, svi tabelarni rezultati su prikazani dijagramski na slikama 5 (Oblik 1) i 6 (Oblik 2).



Sl. 5. Rezultati merenja za oblik uzorka 1



Sl. 6. Rezultati merenja za oblik uzorka 2

4. DISKUSIJA I ZAKLJUČAK

U istraživanju su prikazana ispitivanja uticaja parametara postprocesiranja na deformacije tankih delova izrađenih SLA postupkom u zavisnosti od njihove geometrije i oblika.

Ispitivanjem deformacija dve vrste fotopolimera, može se uočiti da su deformacije znatno više izražene u slučaju fotopolimera Durable V2, kao i da su manje u slučaju uzoraka oblika 2, tj. u slučaju korišćenja manjeg boja potpora. Takođe, u slučaju ovog fotopolimera deformacije su najveće nakon sedam dana od postprocesiranja, jer dolazi do naknadnog umrežavanja polimera i nakon kraja procesa. Stoga se može zaključiti da ovaj fotopolimer nije pogodan za primenu kod delova gde je potrebna konstantnost dimenzija prilikom eksploatacije jer se procentualna promena pojedinih dimenzija kreće i preko 70%.

Merenjem deformacija fotopolimera Grey V4, može se uočiti da, i u slučaju uzoraka oblika 1 i uzoraka oblika 2 nakon postprocesiranja dolazi do deformacija ali su one značajno manje u odnosu na prethodni fotopolimer (max 7%), pa se može zaključiti da je pogodan za primenu prilikom izrade preciznih delova.

Dalja istraživanja iz ove problematike bi se odnosila utvrđivanje tačnog vremena nakon kog delovi ne pokazuju tendenciju ka deformacijama, tj. trenutak završetka polimerizacije u zapremini delova.

5. REFERENCE

[1] Gibson I, Rosen DW., Stucker B *Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing*, Springer, New York, 2010

[2] Quan H., Zhang T., Xu H., Luo S. Jun Zhu N.X., *Photo-curing 3D printing technique and its challenges*, Bioactive Materials, Vol. 5, No.1, pp 110-115, 2020.

[3] Karalekas D., Rapti D., Gdoutos E.E., Aggelopoulos A., *Investigation of Shrinkage-induced Stresses in Stereolithography Photocurable Resins*, Experimental Mechanics, Vol. 42, No. 4, pp. 439-444, 2002.

[4] Zhang Q., Wenga S., Hamel C.M., Montgomery S.M., Wua J., Kuang X., Zhou K., Qi H.J, *Design for the reduction of volume shrinkage-induced distortion in digital light processing 3D printing*, Extreme Mechanics Letters, Vol. 48, pp. 1-11, 2021.

[5] Zhao j., Yang Y., Lia L., *A comprehensive evaluation for different post-curing methods used in stereolithography additive manufacturing*, Journal of Manufacturing Processes, Vol. 56, pp. 867-877, 2020.

[6] Katheng A., Kanazawa M., Iwaki M., Minakuchi S., *Evaluation of dimensional accuracy and degree ofpolymerization of stereolithography photopolymer resin under different postpolymerization conditions: An in vitro study*, The Journal of prosthetic dentistry, Vol.125, No. 4, pp. 695-702, 2021.

[7] Pagac M., Hajnys J., Ma QP., Jancar, L. Jansa J, Stefek P., Mesicek J. *A Review of Vat Photopolymerization Technology: Materials, Applications, Challenges, and Future Trends of 3D Printing*, Polymers, Vol. 13, No. 4, pp. 598-617. 2021.

Autori: **MSc Tomislav Živković[1], Doc. dr Dejan Movrin[2], Van. prof. dr Mladomir Milutinović[2], Red. prof. dr Saša Ranđelović, MSc Ljiljana Stefanović[2], asistent,** [1]JP "ELEKTROPRIVREDA SRBIJE" BEOGRAD Ogranak TE-KO Kostolac, Kostolac, [2]Univerzitet Novi Sad, Fakultet Tehničkih Nauka, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2350, Fax: +381 21 454-495, [3]Mašinski fakultet u Nišu, Univerzitet u Nišu, Aleksandra Medvedeva 14, 18106 Niš, Tel +381 18 500 627.
E-mail: tomislav.zivkovic1@gmail.com
movrin@uns.ac.rs
mladomil@uns.ac.rs
sassa@masfak.ni.ac.rs
ljiljanastefanovic@uns.ac.rs

INTERNATIONAL SCIENTIFIC CONFERENCE ETIKUM 2021

PROCEEDINGS

Session 2:

METROLOGY AND QUALITY CONTROL IN THE BIOMEDICAL ENGINEERING

Novi Sad, 02 – 04 December 2021

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE**
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Bednarčíková, L., Michaliková, M., Staško, R., Živčák, J.

EFFECT OF BRACE THERAPY ON SCOLIOSIS TREATMENT

Abstract: *The aim of the article is monitoring the effectiveness of brace therapy applied to influence the scoliotic curve. The group consists of 34 subjects, an "S" type curve occurs with a dominant segment of curvature in the Th region. Subjects were indicated for orthosis therapy based on the Cobb angle and were observed for 1 to 4 years. The results show that brace therapy has a significant benefit in stabilizing or regressing the scoliosis, which was confirmed in 61.7% of subjects. It is necessary to monitor the development of the curve throughout the application, as its changes in adolescent age can be quite dynamic.*
Key words: *scoliosis, brace, treatment, Cobb angle*

1. INTRODUCTION

Children with deforming dorsopathy, the most prevalent spinal deformity, are more likely to be found recently. This spinal disease affects children, especially those aged five to fifteen years. Idiopathic scoliosis is the most common form of the disease, diagnosed in 3% of the total population. Idiopathic scoliosis is mostly prevalent in girls, for no apparent reason. Currently, the National Center for Health Information of Slovakia is reporting that children and adolescents are facing a rise in diseases of the musculoskeletal system. In Slovakia, 23,148 patients aged 3-18 years were registered for these diseases in 2016.

During growth, when there is a possibility of significant tissue remodeling, therapeutic orthopedic aids - orthoses are used as a means of treating congenital or acquired deformities of the musculoskeletal system. The total amount of prosthetic and orthopedic devices used in 2014 was more than 12.000 spinal orthoses [1]. Over 86% of the total cost of treating the most common spinal deformities in 2016 was spent on scoliosis treatment.

Its primary purpose is to prevent scoliosis from progressing during growth, enabling non-surgical treatment of scoliosis. The scoliotic treatment process is ilustrated in Fig. 1. The treatment itself is initiated if the curve is at high risk of progressing. The use of corset therapy is generally indicated for patients with curvatures of 20 to 40 degrees of Cobb and the progression of the curve is cease in 50% of cases, the curvature is improved in 30% of cases, and the curve remains unstable in 20% of cases. Surgical treatment is recommended if the curve exceeds 40 to 45 degrees.

To produce torso orthoses, the goal is always to make the greatest correction possible. Cobb angles reduced by 30% are considered successful, while Cobb angles reduced by 50% are considered excellent. We discovered that torso orthoses are typically used for the treatment of scoliosis relatively late in the treatment process after reviewing professional articles, literature and research. The problem is that diagnosis is often late.

The correction of individual parts of the skeleton by orthoses is achieved by either the force of their three-point action or by the action of several three-point correction systems for correcting spatial deformities and by the action of moments for correcting torsional deformities. A correction orthosis causes remodeling of the skeleton and surrounding tissues with its force effects, according to biomechanical laws. A physiotherapy or orthotic treatment will systematically load the viscoelastic skeleton and connective tissues for a long period. [2]

Orthosis of the spine are most effective in curves of the spine that lie in the middle region (Th6 to L3) and they are also effective in curves that are less than 30 or 40 degrees of Cobb. Peaks outside these limits usually pose a challenge to effective treatment.

It is essential to wear an orthosis or corset long-term for a healing process to occur, specifically remodeling of connective tissues. In empirical experience, torso braces are often used for 23 hours a day - often overnight - when an hour is spent for personal hygiene and physiotherapy without a torso brace. It has been shown that in 75-85% of cases, the progression of the condition can be prevented by close monitoring of the patient and regular use of a corset [3]. A corset is effective on many curves,

but it must be worn honestly and according to prescription. The average orthopedic treatment lasts between three and four years. Treatment involves not only physical changes to the human skeleton, but also changes to the orthopedic equipment. As a result, orthoses or corsets need to be adjusted according to technical specifications during treatment in order to maintain their effectiveness. [4]

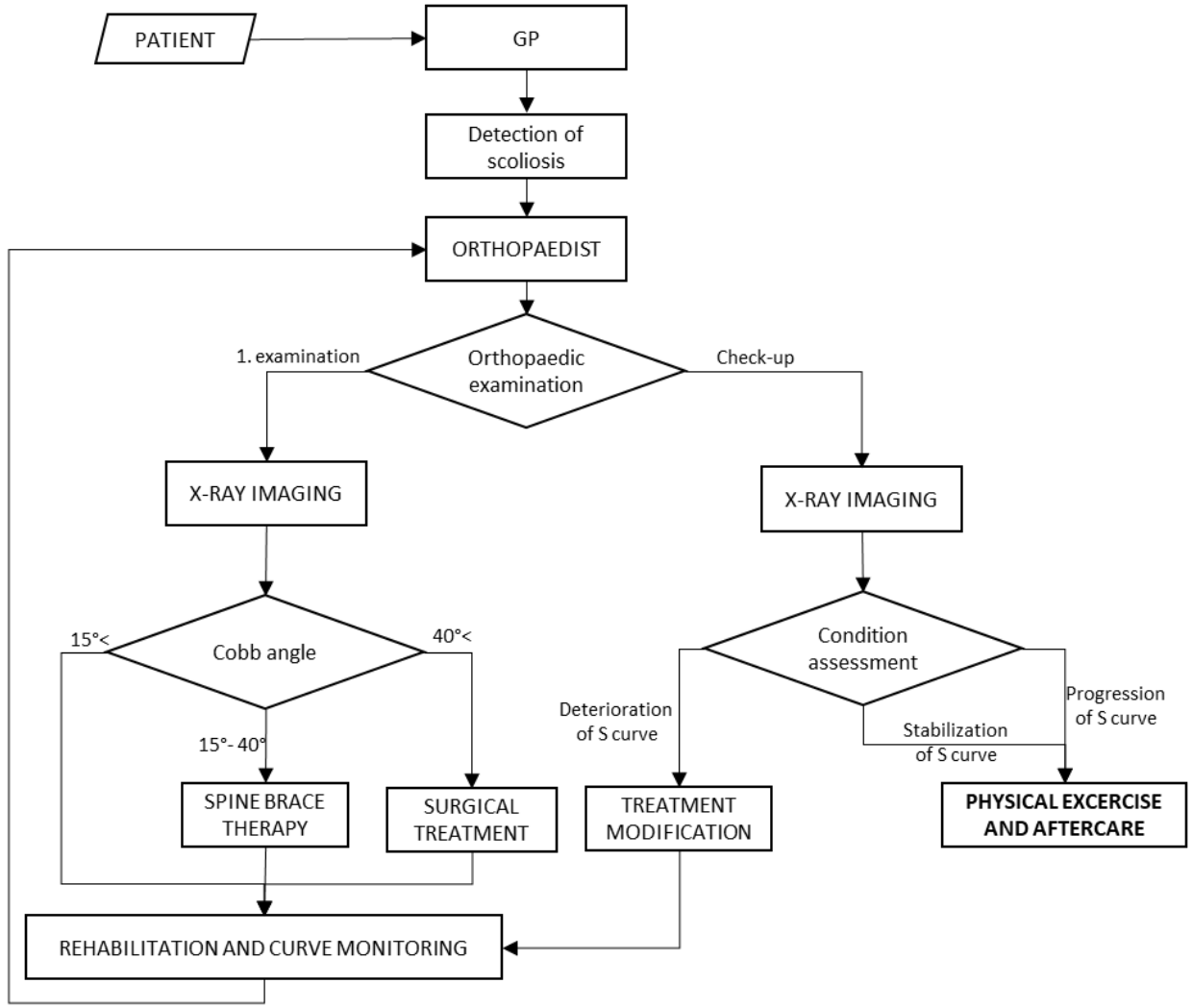


Fig. 1. Scoliotic treatment process.

According to the above information, the effective duration of an orthosis' correction is usually between 3 to 6 months. After the patients reach the end of their growth phase, the human body parts do not change significantly; thus, torso orthoses age and lose their therapeutic effectiveness. [5] It is appropriate to examine any shape changes and the possibility of further corrective adjustments after 9 to 12 months. In many cases, the orthosis is used correctly after one year at the end of its service life. [5]

2. MATERIAL AND METHODS

The study participants included 34 orthopedically treated children and teenagers aged 9-17. The average age of the monitored group was 14 years old. In the study group, 32 female and 2 male patients are diagnosed with idopathic scoliosis. A total of 34 subjects were analyzed, with 27 suffering from S-type scoliosis, 6 suffering from dextroconvex and 1 suffering from sinistroconvex, with the Th segment having the greatest incidence of curvature.

X-rays of the whole spine standing with the head and pelvis captured were utilized to determine whether corset therapy should be provided to all subjects in the monitored group. In both anteroposterior and lateral projections, images were used for determining the individual curves, their apexes, cranial and caudal vertebrae ends. In addition, a Cobb angle was measured, and a treatment plan was created based on the

measurement. In symptomatic therapy, the focus is on inhibiting the progression of the curves using a corset (torso orthosis) in conjunction with physical therapy. Depending on prognostic factors, such as the cause, size and topography of the curve, skeletal age, growth rate, sex, and degree of development of sexual characteristics, treatment methods must be selected. There were 18 subjects prescribed the TLS spine brace, 8 Chenau, 4 Caens night corsets, 3 CBW, and 1 Milwakee spine brace. Regular radiological examinations are needed approximately every 3 to 6 months, with the possibility of repeated radiological evaluations to monitor the progress of the curve and effectiveness of therapy.

3. RESULTS

There are 34 patients in the monitored group with scoliosis, out of which 94.12% are female. The predominant type of scoliosis is sigmoidal with a maximum involvement inTh segment.

During the first year of the dispensary of thirty-four patients, the curve worsened in nine of them, the condition stabilized in fifteen, and improved in ten patients, and treatment was discontinued. In the following year, the remaining twenty patients from the original group were examined, of whom seven had worsened, thirteen had improved, and three were stabilized. Ten patients who did not improve in their previous year were checked in the third year. Three years after diagnosis, the condition improved in seven and deteriorated in three patients. Three out of three patients improved in the fourth year after diagnosis. All data are listed in Fig. 2.

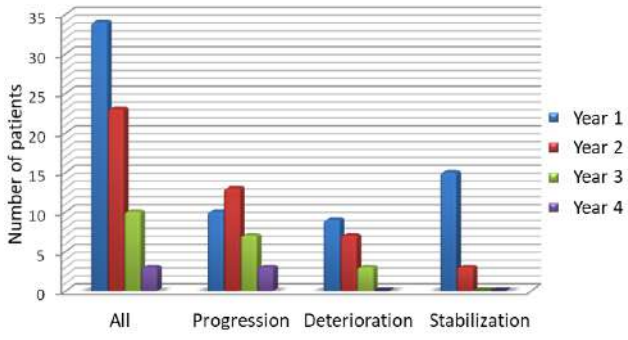


Fig. 2. Treatment monitoring

The above results show that an orthotic device (corset) was applied within the monitored group and that the Cobb angle was reduced in 61.7% of all subjects. Degree of correction achieved is an important factor that is closely related to the outcome of corset therapy. The higher the correction, the better the results can be expected, especially when the torso orthosis is used correctly. Generally, a correction of 30% or more is considered a good correction, while reduction of the curve by more than 50% is considered an excellent correction. [6] In the study sample, nine subjects had scoliosis angles reduced by at least 30%, and in three, the angles were reduced by 50%, which can be considered excellent.

Table 1. Monitored group with scoliosis

Subject	Age	Cobb angle (°)		Status (%)	
		Start of therapy	End of therapy	Progression	Deterioration
1	9	17	25	-	50
2	9	21	24	-	35
3	9	23	17	25	-
4	11	27	30		12
5	10	29	25	12	-
6	10	17	12	40	-
7	11	23	18	25	-
8	10	32	48	-	50
9	10	31	23	25	-
10	12	28	28	-	-
11	10	18	22	-	25
12	11	20	16	-	25
13	11	32	35	-	12
14	13	40	-	-	-
15	13	19	21	-	10
16	12	36	22	45	-
17	11	28	18	40	-
18	14	29	27	10	-
19	9	16	7	55	-
20	10	37	27	25	-
21	10	29	24	20	-
22	13	18	13	25	-
23	11	27	18	35	-
24	12	26	28	10	-
25	12	39	45	-	12
26	11	24	17	25	-
27	10	18	8	45	-
28	14	30	28	8	-
29	14	17	14	20	-
30	12	25	14	47	-
31	14	42	52	-	25
32	15	19	12	40	-
33	14	35	40	-	12
34	15	16	8	50	-

As a result of scoliosis treatment utilizing a torso orthosis, the demands for monitoring and overall patient care are increased, because sudden changes in curves can occur, especially in adolescents, which require a change in approach. There were 4 subjects in the monitored group who were required to undergo surgical treatment due to

insufficient compensation with torso orthosis due to a worsening curve (Cobb angle greater than 40°).

4. CONCLUSION

Problems relating to pathological curvatures of the spine are still relevant today. The average number of children affected by spinal curvature is six out of 1,000, and orthopaedic treatment is necessary for each of them. There are 80-85% of cases that are idiopathic, meaning the cause is unknown. Despite the skepticism of some authors about the effectiveness of spinal orthoses, the above data clearly demonstrates that they are an effective non-operative solution for controlling scoliosis. In scoliotic patients, corsets certainly contribute, if not to improvement, then at least to stabilization.

The results themselves are influenced by the time a spine orthosis is worn. Those that are worn for at least 12 hours each day have a significantly higher success rate. Age is also a factor in the success rate (skeletal maturity).

In cases of subjective symptoms that can confirm that a patient has scoliosis, correct diagnosis and treatment should be initiated as soon as possible. If the patient is already suffering from pain due to the pathological curvature of his or her spine, the angle of curvature is generally quite large. Treatment becomes complicated when the deviation from the norm is great. As a result, scoliosis needs to be diagnosed as soon as possible, while the level of involvement is not yet so severe. An effective treatment is wearing a corset. Nevertheless, this treatment should be supplemented with exercise and rehabilitation. The scoliotic regimen cannot be effective if the patient ignores or does not comply with it.

ACKNOWLEDGEMENT

The manuscript has been supported by research grants: Cultural and educational grant agency of the Ministry of Education, Science, Research and Sports of the Slovak Republic: KEGA 041TUKE-4/2019, Research and Development Support Agency APVV-19-0290.

5. REFERENCES

[1] http://data.nczisk.sk/statisticke_vystupy/Spolocne_vysetrovacie_liecebne_zlozky/Cinnost_spolocnych_vysetrovacich_a_liecebnych_zlozieok_v_SR_2014.pdf

[2] Černý P.: *Idiopatická skolióza a možnosti konzervativní léčby*, Vox Pediatrae, ISSN 1213-2241, Volume 12. p.p. 17-20, 2012. (in Czech)

[3] Chaloupka, R., Motyčka, J.: *Infekční komplikace po operacích skolióz.* 15. národní kongres ČSOT, Praha, 18.-21.5.2011.

[4] Cerny, P.: *Silové působení končetinových a trupových ortéz: možnosti přesné verifikace*, Ortopedicka protetika, Volume 18, ISSN 1212-6705, p.p. 19-20, 2012. (in Czech)

[5] Černý, P.: *Technické možnosti konzervativní léčby skolióz*, In: Ortopedie, č. 4, p.p. 160-167, 2008. (in Czech)

[6] Dungl, P. a kol: *Vybrané kapitoly z ortopedie*, Grada Publishing, Praha, 2004. (in Czech)

Authors: **Ing. Lucia Bednarčíková, PhD., Ing. Monika Michaliková, PhD., MUDr. Richard Staško, Dr.h.c., mult.prof. Ing. Jozef Živčák, PhD., MPH,** Technical university of Košice, faculty of Mechanical engineering, Department of Biomedical engineering and Measurement, Letná 9, 040 02 Košice, Slovakia, Phone.: +421 55 602 2382.

E-mail: lucia.bednarcikova@tuke.sk
monika.michalikova@tuke.sk
richard.stasko@campus-nes.de
jozef.zivcak@tuke.sk

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Michaliková, M. Ondrejová, B., Štefanovič, B., Barcalová, M., Živčák, J.

DESIGN OF A VARIABLE ANATOMICAL MODEL OF THE HEAD FOR EDUCATIONAL PURPOSES

Abstract: *This article is focused on the design and creation of an educational head model with the possibility of replacing chosen anatomical parts with different individual models. The variable head model can be obtained from an individual 3D scan of the subject's head or from freely available general models. In this study an approach with selected models representing both man and woman gender was chosen. Single removable facial parts with different variants were designed in Autodesk Meshmixer software. Subsequently, a database of various shape modifications of the anatomical models was created which is as a visual and practical teaching equipment for educating students.*
Key words: *additive manufacturing, head model, modeling, facial differences*

1. INTRODUCTION

The methods of education are various, and they are constantly improved by new educational methods, which also include various teaching equipment and objects. The model, which is the subject of this work, is primarily intended for educational purposes. It serves not only as a visual but also a practical teaching equipment for the education of pupils, students, teachers but also professionals such as doctors. This method of education helps to process information faster and more efficiently, improves interest and attention, facilitates the perception of information by improving the idea of the shape and function of individual parts of the equipment [1]. It significantly helps to shape and develop a memory, thinking, senses, creativity, clarifies the issue, or complements unspoken information. The proposed model can be easily modified so that its use is extended to more professional areas of education.

The peculiarity of each person is their unique appearance. The face and its parts are different with their various shapes, sizes, and proportions. The head is also specific with its visible differences such as skin color, eye color, hair, and facial hair, which are often variously modified. These specific characteristics can be classified into certain groups of people that depend on the gender or social origin of the population [2].

Head models can be obtained by several ways. One way is to download a paid or freely available database model or to 3D scan a subject's head with a subsequent adjustment. The approach using a 3D scanner depends on several criteria such as the purpose of the scan, requirement for certain accuracy, resolution, capturing texture and color [3]. In this work an approach of modifying the head model obtained from freely available databases has been chosen (Fig. 1). There are a numerous 3D models for various uses in several commercial forums and websites. Most authors share their models, allowing others to use, modify, and redesign them for their own purposes. Models are usually available in formats such as OBJ, MAX, FBX, STL, C4D, BLEND and more.

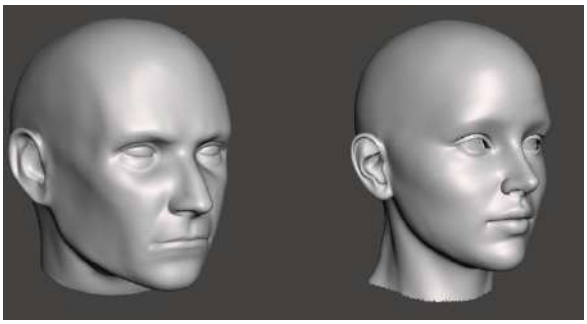


Fig. 1 Selected head model of both genders

2. DESIGN OF A VARIABLE HEAD MODEL

The design of the variable head model itself was made using the Autodesk Meshmixer modelling software (Autodesk, Inc., San Rafael, USA), which is freely available. The basic modifications of the model were performed in this software. The additional elements that were attached to the removable parts of the model were created in the program SolidWorks (Dessault Systems SolidWorks Corporation, Waltham, USA). These parts were intended for inserting the eyes, ears, mouth, and nose into the variable head model.

The design of a removable ear was solved in four different variants, the third of which is the

most suitable for the female head model and the last for the male head model. The first step was creating a removable part by separating the entire external ear. A model of the cylinder from the menu of the program was inserted into the modeling field and the dimensions were adjusted to the size of the ear. These two objects were combined into one. This design of the ear model was insufficient and needed to be modified. The issue was no skewing of the cylinder, which could lead to constant falling out of the head model. The cylinder was inserted into the ear at an angle of approximately 45° compared to the previous design. This design was also insufficient because the holder does not secure the ear against its rotation around the axis of the insertion cylinder. For this reason, a third design was created, in which the shape of the inserted part was changed from a circular cross-section to a triangular one. In the third design, the cylinder-shaped insert was replaced by a triangular prism. This prism was created using a SolidWorks program with the base of an equilateral triangle. The third design was the most suitable for the model of a woman's head, because it better suits the position of the ears and the length of the ear canal. The fourth variant was created for the male head model. To the trimmed part, a triangular prism was attached to the rear flat part of the ear. The part was shorter because in this way insertion was ensured only from the top of the head. The ear and the prism were combined into one unit and saved as a separate object. The model of the man's head is symmetrical, so it was possible to mirror the area of the ear and thus create the same model for the opposite ear.

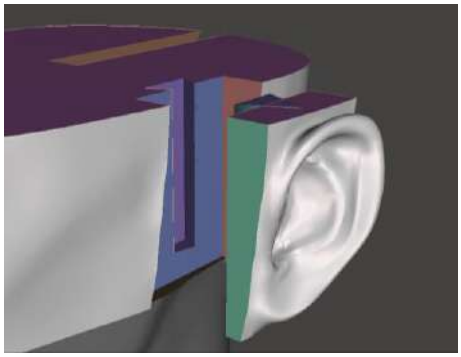


Fig. 2 Creating a removable ear part

Subsequently, the ear with the insertion element was enlarged in each axis by 0.4 mm, and an ear hole was created in the head model with a plug-in component. The same procedure was repeated on the other side with the mirrored part of the ear. After making a hole on the other side of the head, the head model was divided into two parts by a horizontal cut. Additionally, it was necessary to create a plug-in system for the head segments. A triangular prism with adapted dimensions was also attached to the upper part. The model of the head was cut in the transverse plane into three parts, which were inserted into each other (Fig. 2).

The removal of the nasal area was designed in three variants. In the first variant a T-shaped part with a length of 35mm was created in Solidworks. This feature was copied into an unfinished nose model in Meshmixer. The dimensions of the part were also adjusted according to the dimensions of the nose model and after a suitable placement, the two elements were combined.

The nose model with the retractable feature was enlarged in each axis by 0.4mm, and a hole with enlarged nose dimensions was created in the head model. The nose was fixed to the lower part of the head model by first separating the lower part of the head, then inserting the nose from below, which is held in the model by returning the lower half to its place. Therefore, it was necessary to additionally create a system by which the parts of the head were separated and joined. The second variant had a groove and a plug-in feature in the shape of a triangular prism, which was also used in the fourth variant of the design of the ears (Fig. 4). It is a more practical, simpler, and with a less complicated fastening that fulfils the same function. The third variant differs from the previous ones in that it is created entirely by trimming the surrounding surface. It was created by combining the designs of all parts into one model. The angle and direction of the cut depended on the shape of the nose.

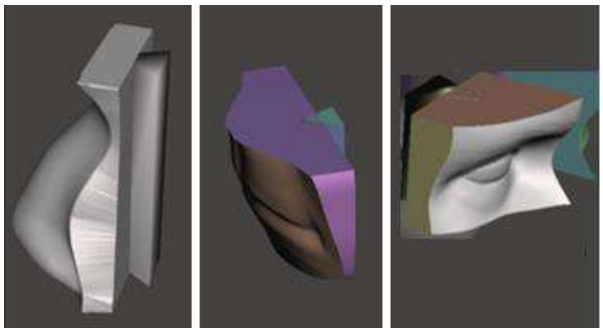


Fig. 3 Triangular shaped element attached to the facial parts models

The mouth retractable model was incorporated into the nasal design, which was created at the bottom part of the retractable head (Fig. 4). The upper border of the mouth was determined by the transversal cut that divided the head into two parts. The procedure for creating the mouth part was the same as for the design of the ears. The design works by extending the lower part of the head model first, the mouth area is inserted, and

then the nose model into the upper part of the model. The nose is retained in the model by sliding the lower part of the head back into place.

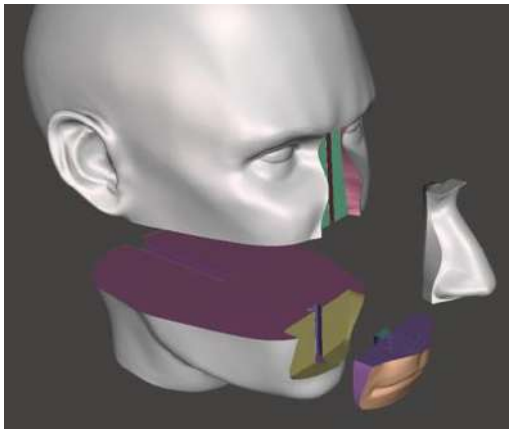


Fig. 4 Removable nose and mouth parts

The eye variant is based on the same principle as previous nose and mouth retractable designs. The design works by first sliding the top of the head forward, inserting the eyes into the holes created, and sliding the top of the head back. (Fig. 5)

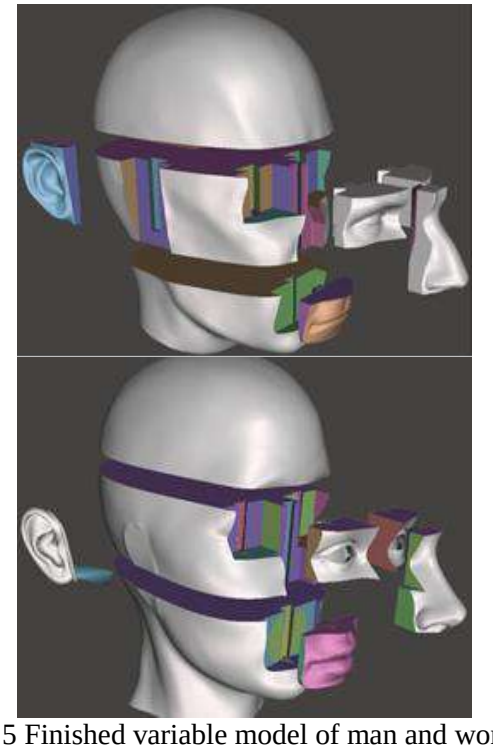


Fig. 5 Finished variable model of man and woman head

4. DESIGN OF A DATABASE OF SELECTED ANATOMICAL ELEMENTS

The database of individual anatomical elements was created based on the original elements, which were modified in various ways. The changes were made using the Meshmixer modeling software, which was also used to create the removable parts of the model described in the previous chapter. The selected anatomical elements such as the eyes, ears, mouth, and nose, were transformed. During the transformation of these parts, it was important, that the result was realistic. At the same time, it was important that the boundaries of the removable parts of the head were not affected in any way. In the Fig. 6, specific designs of individual anatomical parts are shown, as well as the original structures based on which the database was created.

Using the described procedures of separation of individual localities, whether from freely available head models or individually by a 3D scanner of digitized human subjects, it is possible to renew and expand the database of individual elements.

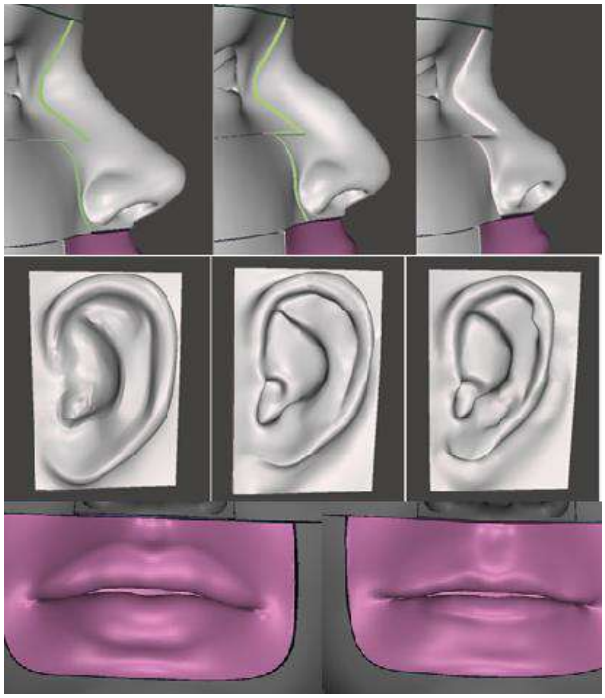


Fig. 6 Samples of the database for man and woman model

5. RESULTS AND DISCUSSION

Based on the described areas of the face and their possible shape changes, a variable anatomical model of the head was created with the possibility of exchanging selected anatomical elements. A 3D model of the head could be obtained using 3D scanning or from freely available database models. From several possible variants of freely available models, shared on the website, exactly two head models representing the gender of a man and a woman were chosen. It was necessary to choose exactly one model for each gender, because the creation of variable replacements of selected anatomical elements of

the face is specific for each gender. The models were suitable due to sufficient representation of the gender and their individual facial features. Subsequently, the models were individually modified in the Meshmixer software. A fastening system was created, operating on the principle of inserting a triangular prism into openings of the same shape. The offset between the insertion element and the hole was in all cases approximately 0.4 mm. The prism was mounted on preselected anatomical elements, which are the eyes, nose, mouth, and ears. The head model as a fastening system is divided into three main parts into which the individual elements are inserted. Using SolidWorks, a triangular prism and other fastening features were created. The replaceable anatomical parts were subsequently modified several times, based on which variable replacements were created. These spare parts differ from each other by changes in the sizes and shapes of the given shape areas. The final model was produced by additive technology, assembled and then it was possible to combine the created parts in various ways. This procedure can change the overall appearance of the model.

Fig. 7 Produced and assembled final model

The resulting model can find application in various areas and industries and fulfil its presentation and especially educational purpose. Areas of application of anatomical models of the head generally include disciplines such as anthropometry, criminology, ergonomics, archaeology, reconstruction techniques, art and architecture, healthcare, and fashion industry.

6. CONCLUSION

The main goal of this article was to design an educational head model with the possibility of replacing chosen anatomical parts with different individual models. The basis of the variable head model was obtained from freely available general models. Selected models representing both man and woman gender were chosen. Single removable facial parts with different variants were designed in Autodesk Meshmixer software. Subsequently, a database of various shape modifications of the anatomical models was created which is as a visual and practical teaching equipment for educating students. There are many areas in which the head model can be used and their appearance is mostly adapted to their purpose. They are distinguished based on the shapes, sizes, production materials, and other details.

ACKNOWLEDGEMENT

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-19-0290, project KEGA 041TUKE-4/2019 and KEGA 023TUKE-4/2020.

6. REFERENCES

[1] Vijayalakshmi, M.: *Modern Teaching Techniques in Education*, Educational Technology in Teacher Education in the 21st Century, Government College of Education for Women, Coimbatore, February 2019

[2] Fetter. V., Prokopec, M., Suchý, J., Titlbachová, S.: *Antropologie*. Academia. nadavatelství Československé akadémie věd., Praha, 1967.

[3] Bednarčíková, L., Michalíková, M., Danko, M., Hudák, R., Živčák, J.: *Základy skenovania pre protetické a ortotické aplikácie*, Faculty of Mechanical Engineering, Technical University of Kosice, Kosice, 2019.

Authors: **Ing. Michalíková M., PhD., Ing. Ondrejová B., Ing. Štefanovič B., Mgr. Barcalová M., PhD., Dr.h.c., mult.prof. Ing. Živčák J., PhD., MPH,** Technical university of Košice, faculty of Mechanical engineering, Department of Biomedical engineering and Measurement, Letná 9, 040 02 Košice, Slovakia, Phone.: +421 55 602 2657.

E-mail: monika.michalikova@tuke.sk
bibiana.ondrejova@tuke.sk
branko.stefanovic@tuke.sk
miroslava.barcalova@tuke.sk
jozef.zivcak@tuke.sk

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Milić, L., Qureshi, S., Vejin, M., Stanojević, K., Kojić, S., Petrović, B., Stojanović, G.

AUTOMATION OF MEASUREMENT OF WETTING ANGLE OF HUMAN ENAMEL WITH ANTISEPTIC SOLUTIONS USING MATLAB

Abstract: *The need for simple methods for measuring the contact angle increases in various scientific disciplines. There are algorithms that help users enter the droplet limits themselves, and the algorithm calculates the required data. Interaction with the user introduces uncertainty into the objectivity of the results. The goal was to create an algorithm in Matlab, intuitive to use, automated with minimal user interaction. Data were collected by an experiment that analyzed the enamel wetting with artificial saliva and mouthwashes solutions. The images were taken after complete droplet propagation, transferred to ImageJ software, which calculated the contact angle, and then the contact angle was calculated using an algorithm in Matlab and comparable results were obtained.*
Key words: *contact angle, wetting, Matlab, algorithm*

1. INTRODUCTION

The interaction between saliva and anatomical structures in the mouth is crucial for overall oral health and the maintenance of homeostasis. The surface of biomaterials, enamel or restorative materials, is important in the interaction between enamel and biological conditions prevailing in the oral cavity, where all structures are exposed to the phenomenon of adhesion and plaque removal [1].

The use of antimicrobial agents in cariology has been proposed having in mind the infectious nature of the disease. The goal of this approach is to achieve a caries-preventive effect by suppressing the cariogenic flora. For the purpose of use as mouthwash solutions intended for use in dental health care. American Reference Institutions, American Dental Association (ADA) and the Food and Drug Association (FDA) have adopted guidelines for testing the efficacy and safety of antiseptic agents with significant review by the expert community and formed a consensus that, in addition to fluoride solutions, only products containing chlorhexidine, cetylpyridinium chloride or from the group of approved essential oils (such as Listerine) may be approved in the category of mouthwash and bear the affirmative seal of acceptance [2]. In order to be effective on both smooth and solid structures in the oral cavity, mouthwash solutions should be completely spread on the surfaces, theoretically they should have the lowest possible contact angle [3].

However, the relationship between the chemical composition of the antiseptic solution is not directly correlated with their achieved clinical effect and precisely because of that, the research of physico-chemical properties of antiseptic solutions used in dentistry is increasingly represented.

The measure of the ability of a solid body to be wetted by a liquid is called the contact angle and is denoted by Θ.

The contact angle is actually defined by three different interfacial surfaces: solid-liquid; solid-gaseous; liquid-gaseous, which results in the existence of three different interfacial tensions that meet at one point. The contact angle is the angle between the tangent drawn from that point to the circle that represents the contour of the droplet of the tested liquid and the surface of the solid body that the liquid moistens, which actually represents the solid-liquid interfacial voltage.

The most commonly used technique for measuring the contact angle is the direct measurement of the tangent angle at the three-phase contact point on the profile of the settled droplet [4]. This optical method requires small amounts of liquid and a small surface area of the solid substance. The contact angle of a liquid droplet on an ideal horizontal solid surface is determined by the mechanical equilibrium of the droplet under the action of three intermediate voltages of the liquid

2. MATERIALS AND METHODOLOGY

The labial and buccal surfaces of three human donated intact teeth were cut with a diamond disc and washed under running tap water with abrasive paper of fineness 800 to 1200 and polished with Al2O3 powder in distilled water.

After that, the polished surface was washed with demineralized water. In this research,

artificial saliva based on carboxymethyl cellulose made according to the recipe of the Pharmacy Institution Belgrade (registered under the main preparations of the Republic of Serbia) was analyzed. The glycerine / citric acid solution is prepared separately. For 1 kg of solution, 388 g of glycerine and 25 g of citric acid were used according to the recipe Pharmacy institutions Novi Sad (registered under master preparations of the Republic of Serbia). with four mouthwashes:

1) 0.1% chlorhexidine solution (Eludril Classic, Pierre Fabre Medicament, Bologna, France);
2) Elmex, mouthwash (Gaba International, France) where active ingredients were 100 ppm amine fluoride and 150 ppm sodium fluoride,
3) Listerin (Cool Mint Listerine Johnson & Johnson, New Brunswick, NJ)
4) Dentadent, (the alcohol-free formulation containing a combination of aluminium lactate, sodium fluoride and chlorhexidine (Lilly)

In this study, a total of 14 different solutions (artificial saliva solution, saliva stimulant solution, 4 mouthwash solutions, as well as 8 solutions (1: 1) solution of each mouthwash solution with artificial saliva and saliva stimulant) were tested on the surface of intact enamel.

The wetting angle measurement experiment was performed using the following apparatus and the procedure to be described below. Namely, a tripod is fixed on the anti-vibration surface, both for the camera and for the surface on which the preparation is placed. The camera is adjusted at a level a few cm from the upper limit of the specimen behind which the light source is placed. The camera is connected to a laptop, via a USB port. Drip is performed with an automatic pipette. After the first contact with the substrate, wait 10 s, until the drop subsides.

The system is then photographed three times, adjusting the brightness, contrast and focus on the camera itself (Fig 1). The obtained images were saved, and the drop is wiped from the substrate, then the process is repeated five times, for each solution.

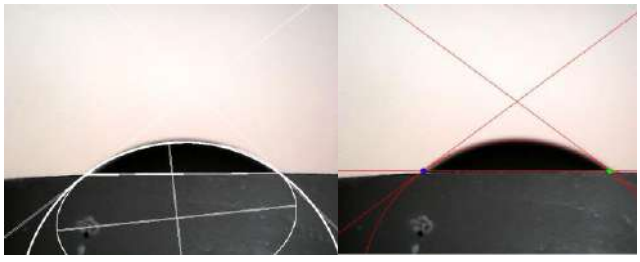


Fig. 1. Wetting angle

All images were divided by solutions and the wetting angle was automatically calculated using the algorithm which is described in detail in our previous work [5], with one change. Due to the amount of images, the algorithm is executed over the entire folder, taking each image from the same and calculating the left and right wetting angles. The improved algorithm is shown in Fig. 2.

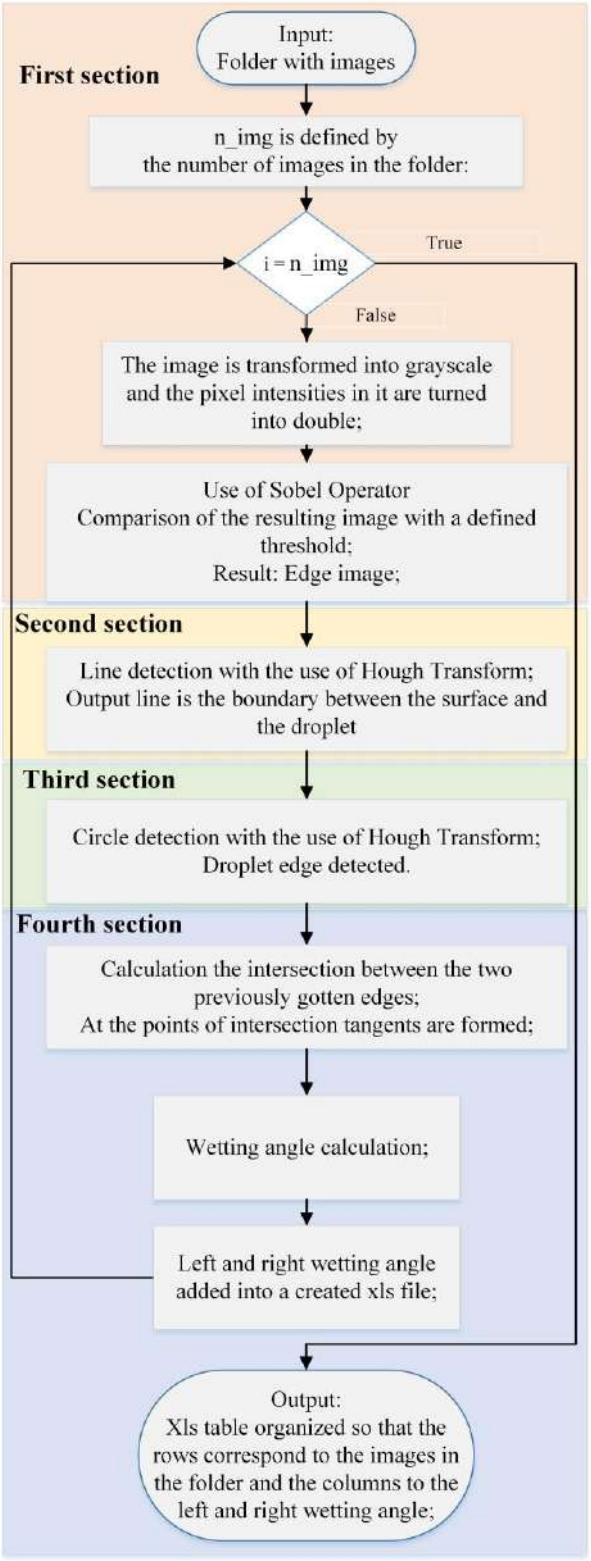


Fig. 2. Main algorithm

When it comes to statistical analyses, the data were presented in the form of mean values and standard deviation. To evaluate how far data were from normality, the Shapiro–Wilk test was used. In cases when data were with disturbed, distribution normality, the significance of the difference between the examined research groups, was tested by the Wilcoxon signed-rank test, while for the data that exhibited normal distribution one-way ANOVA and paired samples T-tests were used. The level of statistical significance was set at 5% ($p < 0.05$). For all statistical calculations Jamovi software (version 0.9.2.8) was used.

3. RESULTS

Fig 3 shows the mean values of the left and right contact angles measured using all three methods used on all 14 tested fluids and the obtained results show mutual agreement (manual, Image J and Matlab measurements included).

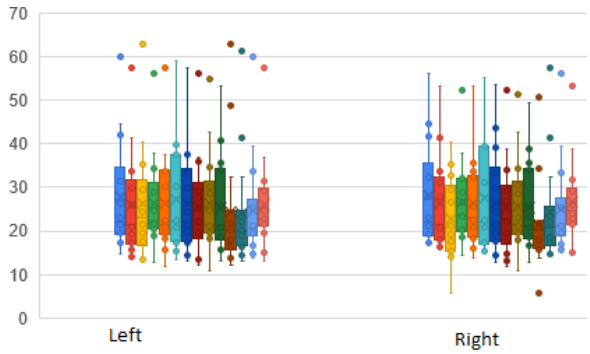


Fig. 3. Right and left contact angles

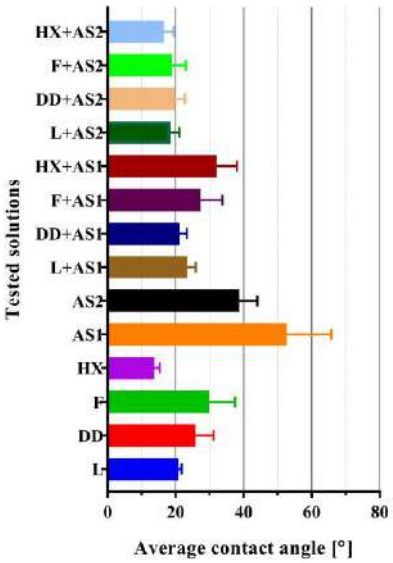


Fig 4. Contact angles – average values

The obtained mean values of the contact angle ranged from 15 degrees (observed with chlorhexidine solution) to 53 degrees with artificial saliva, shown in Fig. 4. A statistically significant difference in the values of the contact angle ($p < 0.05$) was observed between all examined liquids.

In all 4 tested antiseptic solutions, lower values of contact angles were observed during mixing with the saliva stimulant compared to artificial saliva, and this difference was statistically significant ($p < 0.05$).

4. DISCUSSION AND CONCLUSION

There are significantly variable results in the literature when it comes to the values of the contact angle with the enamel. In a significant number of studies, not human but bovine enamel was used, some studies were performed in vivo, some in vitro. The reasons for such a wide range of contact angles of different enamel liquids can be explained by all three components of the experimental design, method of measurement, nature of the liquid being analyzed and preparation of the substrate (enamel) Due to all this, it may be more expedient to monitor the differences in the values of contact angles within one experimental protocol than to compare the obtained values with the absolute values obtained in other studies. Theoretically, the values of the contact angles of antiseptic values should have the lowest possible values, which would justify their role in cleaning tooth surfaces, and the effective bioavailability of the active components of the mouthwash solution.

Indeed, there are reports in the literature about really low values of the contact angle of the mouthwash, significantly lower than those shown in the conducted research. However, in a study conducted by Perdock. and associates published values of contact angles in the range that fully corresponds to the contact angles measured in our study, ranging from 37 to 54 degrees, at pH values from 3.1 to 7.5. Significantly higher values for the chlorhexidine contact angle, even over 50 degrees, have been reported by Alves et al.

It should be noted here that it is not recommended to compare different formulations of the same antiseptic solutions because the real concentrations of active substance in them are extremely low, often not exceeding 0.1%, so the contact angle will not depend on the active substance, but more on detergents, solvents and other substances. present in commercial mouthwashes.

Matlab is a software platform designed specifically for engineers and scientists to analyze and design systems. The basis of Matlab is the

Matlab programming language, which is based on matrices.

This fact is especially important when looking at image processing because each image is, at its core, a matrix. In addition to the fact that the manipulation of the matrix or image value is facilitated due to the very nature of the programming language, Matlab offers many implemented functions that are used for image processing. The methods and functions used gave satisfactory results and proved to be important when it comes to solving problems of this type. It has been shown that it is possible to solve complex problems of image segmentation obtained during a biomedical experiment using built - in Matlab functions.

The algorithm used in this paper can also be used with input images obtained in a different way, ie by changing the experimental setting. The development of software tools that would automate the process of determining the contact angle shows considerable potential.

The development of such a tool would reduce people's subjective influences on results and would also significantly shorten the time required for assessment.

Comparing the add-on to the ImageJ software for calculating the wetting angle and the mentioned algorithm encoded in Matlab, user participation is completely reduced to running the application in Matlab. Namely, due to the large number of images, the algorithm described in [5] has been modified to load all images from folders, unlike the ImageJ plugin for calculating the wetting angle which requires loading each image individually and manually marking the edges of the droplet.

Due to the possibility of blurred edges in the images from the experiment, the variability is further increased by using ImageJ software. On the other hand, when calculating the edges of an image, in Matlab, a step is added that thins it out, in order to reduce the variability introduced by the blurred image.

By loading the whole folder, the lack of low speed of the algorithm from [5] was overcome, because now the application can count in the background and process all the images, while the user is doing something else.

Biomedical engineering encompasses a wide range of scientific areas using different techniques. It is well known that measurements on humans need to be as non-invasive as possible with physical separation of signal acquisition hardware and the rest of the equipment. With this in mind, it is preferred for the measuring processes to be as automated as possible. Thus, the need for automatization in this sphere of research is essential.

5. REFERECES

[1] Auschill, T.M.; Arweiler, N.C.; Brecx, M.; Reich, E.; Sculean, A.; Netuschil, L.: *The effect of dental restorative materials on dental biofilm*, European Journal of Oral Sciences, 110, 48–53, 2002.

[2] Ciancio, S. G.: *Alcohol in mouthrinse: lack of association with cancer*. Biological Therapies in Dentistry 9, 1–2, 1993.

[3] Perdok, J. F., Van der Mei, H. C., & Busscher, H. J.: *Physicochemical properties of commercially available mouthrinses*, Journal of dentistry, 18(3), 147-150, 1990.

[4] Liber-Kneć, A., & Łagan, S.: *Surface Testing of Dental Biomaterials—Determination of Contact Angle and Surface Free Energy*. (2021).

[5] Milic, L., Petrovic, B., Kojic, S., Qureshi, S., Stojanovic, G.: *Using the Hough Transform in the Automatization of Contact Angle Calculation*, Telfor Conference, Belgrade, Serbia, 23-24 November 2021.

ACKNOWLEDGEMENT

This research has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Sklodowska-Curie Grant Agreement No. 872370 and Grant Agreement No. 951747.

Authors: **Lazar Milić[1], dr Saima Qureshi[1], Marija Vejin[1], Ksenija Stanojević[1], Sanja Kojić[1], prof. dr Bojan Petrović[2], prof. dr Goran Stojanović[1]**

[1]University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2350, Fax: +381 21 454-495.

[2]University of Novi Sad, Faculty of Medicine Hajduk Veljkova 3, Novi Sad, Serbia, Tel: +381 21 661 2222.

E-mail: lmilic@uns.ac.rs
saimaqureshi@uns.ac.rs
marija@uns.ac.rs
ksenija@uns.ac.rs
sanjakojic@uns.ac.rs
bojan.petrovic@mf.uns.ac.rs
sgoran@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE**
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Ondrejová, B., Štefanovič, B., Bednarčíková, L., Hudák, R., Živčák, J.

CUSTOM PROSTHETIC SOCKET PRODUCTION USING ADDITIVE TECHNOLOGY

Abstract: *This work was focused on the fabrication of custom prosthetic sockets using additive technology. The aim was to produce, test, and compare 3D printed prosthetic sockets of different materials. Subsequently 3 custom sockets were produced using FFF additive technology which were tested on one subject. Static socket loading, dynamic loading in terms of subject's gait and maximum socket loading per supracondylar area were tested. Proposed sockets failed in the mechanical tests due to unsuitable mechanical properties of selected materials or non-optimized printer parameters. This opens opportunities for further testing and design remodelling.*
Key words: *additive technologies, transtibial socket, 3D printing, FFF technology, prosthetics*

1. INTRODUCTION

The main purpose of lower limb prostheses is to reduce the negative impact of the handicap as much as possible and to try to restore the normal functioning and independency of the amputees. [1] To achieve a functional and comfortable prostheses, great attention must be paid to the design of the sockets. [2] The prosthetic socket represents a critical interface between the user's amputated limb and the actual device. A suitable socket must provide effective attachment, adequate load transfer, stability, and control, which is often a key factor in the success or failure of the prosthesis itself. The shape of the prosthetic socket, its applied materials, and the attachment system are most important, which affect the stability of the residual limb inside the socket. Current developments in additive technologies open new manufacturing possibilities in all areas, including orthopedic prosthetics. [3] This work is focused on the possibilities of prosthetic socket production in an innovative way using 3D scanning, CAD modelling and additive manufacturing. [4] The prosthetic socket was designed for one subject with a transtibial amputation who is included in the highest degree of activity.

2. CUSTOM TRANSTIBIAL SOCKET

Before printing an object, it is necessary to obtain a 3D model, which is then processed into definitive shape. In the orthopedic prosthetics, 3D scanning is a way of obtaining the accurate digital positive of a residual limb. Scanning can be performed with exposed residual limb or with the liner on, but in both cases, areas as the distal end of tibia and the patellar tendon area are marked with reflective elements. Scanning without a liner requires considerable experienced and skilled orthopedic technician. [5] Further processing of the model for additive manufacturing includes postprocessing operations such as smoothening, reduction and artifact removal.

Fig. 1 Representation of important areas marked during scanning, on the distal side the end of the tibia, the proximal center of the patellar tendon

Additive manufacturing (AM) is not only an innovation in the production process, but also supports a new paradigm for design. This principle can be used for medical devices that require a high degree of individual approach. [6] In fact, due to high flexibility in design of models for AM technology, they are suitable for the custom production that should fulfill the requirements of various individual customers or patients. [7] The main stages of lower limb prosthetics production using modern approaches are design, validation and final production of the prosthetic socket. [8]

2.1 Residual limb scanning and socket modeling

The subject was scanned in a sitting position using a Sense (3Dsystems, Rock Hill, California) 3D scanner, where the necessary areas for production were marked on the liner which was put on the residual limb. These points were useful in the next step of processing. It's important that the shape of stump scan approximates the anatomical shape of the residual limb. The amount of mass removed from the digital positive depends mainly on the amount and density of soft tissues of the residual limb. The edge of the prosthetic socket model passes horizontally through the center of the patella and continues proximally to the sides. On the medial side, there is an edge over the area of the supracondylar suspension, which was marked before scanning. (Fig.1)

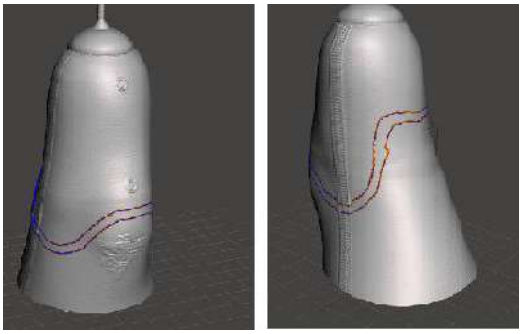


Fig. 2 Boundary delimitation of the shape and height of the edge of the digital socket

On the lateral side, the curve of the edge is similar to the medial side and also at the same height. The horizontal line of the edge on the dorsal surface is located at the level of the center of the patellar tendon at 5° flexion in the knee joint. Subsequently, the virtual mass was lifted proximally to the edge of the designed socket which helped with the visualization. Other important locations on scan were highlighted, such as popliteal area with green color and medial condyle with brown color (Fig. 3). A small amount of material was reduced at patellar tendon area considering to other soft tissues.

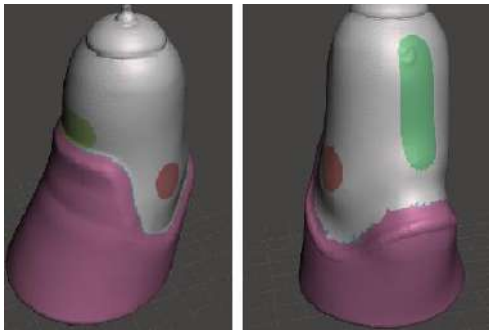


Fig. 3 Popliteal area and patellar tendon area on a digital socket

The modifications were made according to the measurements of residual limb in normal and compressed condition. The area under the patella was rounded and smoothened. Medial area of soft tissue was adjusted for load transfer which was marked with dark green color (Fig. 4). Modification of soft tissue starts under medial condyle of tibia and ends approximately 20mm from the distal end of the residual limb. This area was adjusted to a concave shape from distal to the proximal direction. On medial side of tibia was also reduced a small amount of material, approximately 2 mm, which was marked with purple color. Convex shape in the transverse plane was preserved and the edges were smoothened. The distal end of tibia was marked with yellow color and the tuberosity of tibia was marked with light green color.

Fig. 4 Medial area of the digital socket

For the head of fibula was necessary to add the material about 4 mm, although the shape, was preserved.

2.2 Additive manufacturing of the socket with FFF method

After modelling the digital socket was produced using FFF (Fused Filament Fabrication) technology on a 3D printer from German RepRap X400 (German RepRap GmbH, Feldkirchen, Germany). The socket thickness was set to 3,5 mm with 50% infill. Used nozzle was made from hardened steel, as the carbon fibre polyamide is a highly abrasive filament, the classic brass nozzle would be destroyed after a few hours of printing.

Table 1 3D printing parameters

Height of layer	0,3 mm
Nozzle diameter	0,6 mm
Width of outer layer	0,8 mm
Printing time (1 pcs)	>10 h

2.3 Diagnostic and definitive socket

Three sockets of 3 different materials were manufactured with a magnetic lock system. The virtual positive was designed precisely with an empty space for the lock system. (Fig. 5)

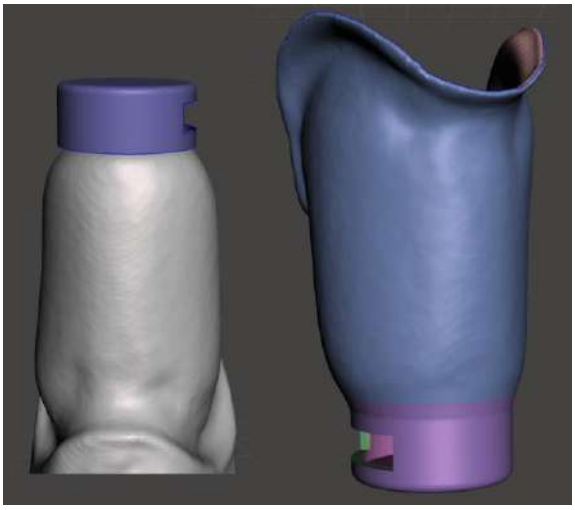


Fig. 5 Attachment of the space for the magnetic lock to the digital socket

These sockets were made from PA (polyamide) material with carbon fibre, PETG (polyethylene terephthalate copolymer) and PC (polycarbonate). All mentioned materials were certified for skin contact. For the cropping and slicing of the model Simplify 3D (Simpily3D, USA, OH, 10805 Indeco Dr, Cincinnati) was used.

Sockets were successfully printed on the first attempt, but it was necessary to remove the support material which filled the gap for the activation and deactivation of the magnetic lock mechanism.

The edges were manually grinded and smoothened out and the magnetic lock mechanism was attached, so the socket was prepared for testing.

2.4 Socket testing

In the beginning, the subject evaluated the AM socket as comfortable and precise. For safety precautions parallel bars were provided for the testing. The testing had three stages: static socket loading, dynamic socket loading and maximum socket loading per supracondylar area in terms of the subject's gait. All static socket loading tests were performed in maximum vertical loading without failing. The dynamic loading in the form of walking was without socket failure. The subject also evaluated the socket as comfortable while walking.

Tests with full loading on the supracondylar area showed a weakness in sockets made by AM technology. All three AM sockets failed in this area under the maximum loading from the subject. The PETG and PC socket did not fail in between layers as expected but have cracked irregularly (Fig. 6).

Fig. 6 PETG socket failure after full load on the supracondylar area

The PA socket failed in between layers (Fig. 7). This probably means that the quality of production of this socket was insufficient.

Fig. 7 Abruption of a socket layer made of PA (polyamide) with carbon fiber

3. ANALYSIS OF RESULTS AND DISCUSSION

Tests have shown that it will be necessary to strengthen the supracondylar area of the socket and improve FFF technology production. These areas are significantly stressed in subjects' active usage. It has been proven that the full loading of the subject caused the failure. Static and walking test were successful and without socket failure. The solution could be to remodel and reinforce this area, as well as to reduce the printing speed which would consequently better bond the layers. An undeniable advantage is virtual modelling, which saves time for orthopaedic prosthetics and, as a result, accelerates the production of the final product. In the future, the 3D model is easier to store digitally than physically, and when the volume of the residual limb is changing, partial remodelling according to a new scan of current condition is possible. This system of production has many advantages, such as faster processes, more precise socket modeling and digital archiving. Another advantage of AM is that it is possible to quickly undo a few steps in the modelling process in CAD software, compared to traditional production where this process would be time-consuming and inaccurate.

4. CONCLUSION

The aim of this work was to produce, test, and compare 3D printed prosthetic sockets of different materials. Proposed sockets failed in the mechanical tests due to unsuitable mechanical properties of selected materials or non-optimized printer parameters. This opens opportunities for further testing and design remodeling.

ACKNOWLEDGEMENT

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-19-0290, project KEGA 041TUKE-4/2019, and KEGA 023TUKE-4/2020.

6. REFERENCES

[1]. Devinuwara, K., Dworak-Kula, A., J.O'Connor, R.: *Rehabilitation and prosthetics post-amputation.* Orthopaedics and Trauma, 32, p.p. 234-240, August 2018.

[2]. Rajťúková, V., Michalíková, M., Bednarčíková, L., Balogová, A., Živčák, J.: *Biomechanics of Lower Limb Prostheses*, Procedia Engineering, 96, p.p. 382-391, 2014.

[3]. Yan Wang, Qitao Tan, Fang Pu, David Boone, Ming Zhang, *A Review of the Application of Additive Manufacturing in Prosthetic and Orthotic Clinics from a Biomechanical Perspective*, Engineering, 6, p.p. 1258-1266, 2020.

[4]. Barrios-Muriel, J., Romero-Sánchez, F., Alonso-Sánchez, F.J., Rodríguez Salgado, D.: *Advances in Orthotic and Prosthetic Manufacturing: A Technology Review*. Materials, 13, p.p. 295, 2020.

[5]. Bednarčíková, L., Michalíková, M., Danko, M., Hudák, R., Živčák, J.: *Základy skenovania pre protetické a ortotické aplikácie*, Faculty of Mechanical Engineering, Technical University of Kosice, Kosice, 2019.

[6]. Vitali, A., Regazzoni, D., Rizzi, C., Colombo, G.: *Design and Additive Manufacturing of Lower Limb Prosthetic Socket*, ASME 2017 International Mechanical Engineering Congress and Exposition, p.p. 7, The American Society of Mechanical Engineers, Tampa, November 3–9, 2017.

[7]. Chen, R.K., Jin, Y., Wensman, J., Shih, A.: *Additive manufacturing of custom orthoses and prostheses—A review*, Additive Manufacturing, 12, p.p. 77-89, 2016.

[8]. Ballit, A.: *Design and manufacturing process optimization for prosthesis of the lower limb*. Biomechanics, Université de Technologie de Compiègne, Compiègne, 2020.

Authors: **Ing. Ondrejová, B., Ing. Štefanovič, B., Ing. Bednarčíková, L., PhD., prof. Ing. Hudák, R., PhD., Dr.h.c., mult.prof. Ing. Živčák, J., PhD., MPH**, Technical University of Kosice, Faculty of Mechanical Engineering, Department of Biomedical Engineering, Letna 9, 04200, Kosice, Slovakia, Phone: +421556022657
E-mail: bibiana.ondrejova@tuke.sk
branko.stefanovic@tuke.sk
lucia.bednarcikova@tuke.sk
radovan.hudak@tuke.sk
jozef.zivcak@tuke.sk

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Plavac, N., Vejin, M., Spajić, K., Kalamković, J., Petrović, B., Kojić, S., Stojanović, G.

STABILITY OF SALIVARY PH AFTER USE OF ORAL ANTISEPTICS AND CARBONATED BEVERAGES

Abstract: *Acid-base balance of saliva is an important factor for oral health because lowering the pH is associated with the development of oral diseases. The physiological value of saliva pH is in the range of 6.2-7.6. A saliva sample was taken before consuming the liquid and four samples at a certain time interval after that, in 10 volunteers. PH was determined using a digital pH meter (Lutron Electronics Enterprise pH meter). The tested liquids lead to an initial decrease in pH which after 2 hours approaches the values before the experiment. Sweetened carbonated drinks have the most significant effect on the pH of saliva.*
Key words: *saliva, pH, acidic beverages, mouthwashes*

1. INTRODUCTION

The normal pH value of the saliva of healthy individuals ranges from 6.2 to 7.6. The concentration of the buffer system is directly related to both the pH level and the degree of saliva secretion. Thanks to it, the pH of all physiological liquids generally remains constant. In this regard, even after consuming acidic foods or applying acidic solutions, with the help of a buffer system, they are neutralized, so the pH of saliva remains relatively stable [1].

Many dental patients report drinking acidic beverages on a regular basis, and their increasing prevalence has made them a source of concern for both dental professionals and the general public [2]. Importantly, recent research has discovered that drinking acidic beverages can lower oral pH below critical level1 of 5,5. Significant research on the effects of acidic beverages on oral pH suggests that the pH drop is greatest immediately after consumption, and that pH returns to pre-exposure levels within a half-hour [3-5].

There are studies in the literature that examined the use of medications before and after exposure to enhance salivary pH neutralization and enamel protection. Turssi et al. found that a calcium lactate pre-rinse followed by a sodium fluoride rinse protected enamel surfaces from citric acid erosion better than sodium fluoride alone [6]. Other study results by Lindquist et al. looked into the effectiveness of post-drink mouthrinses and other products in accelerating the return of salivary pH to acceptable levels [7,8]. The pH-buffering abilities of neutralizing agents such as antacid tablets, chewing gum, and mineral water have been noted by researchers.

Through a series of researches and comparative studies, it has been determined that Listerine, which is used as an additional means of maintaining oral hygiene, has the strongest effect of all antiseptics against the formation of dental biofilm, as well as inflammatory processes. It is effective in preventing supragingival plaque and gingivitis. It is considered that products with essential oils are more suitable for use than chlorhexidine, because, unlike it, they do not cause stains on teeth and that during their long-term daily use, resistant microorganisms and opportunistic microorganisms do not appear [9].

In addition to Listerine, mouthwashes with fluorides have a great advantage, because their local application dissolves the surface layers of enamel and releases various ions [10]. Fluoride ions bind the released calcium ions to form calcium fluoride, which is deposited on the demineralized enamel. When the pH value falls below 5.5, calcium fluoride dissolves and fluoride ions are released, the increased presence of which plays a significant role in forcing the remineralization process and inhibiting the enamel surface demineralization process [11]. It is considered that these solutions should be used in certain concentrations depending on the frequency of application. Thus, if they are applied once a day, it is necessary to use a concentration of 200-300 ppm of fluorine; if applied once a week, a concentration of 1000 ppm fluorine is used; and if applied once every two weeks, a concentration of 2000 ppm fluorine is used [12].

Because of its antimicrobial properties, chlorhexidine (CHX) is a widely used antiseptic mouthwash among dental professionals and the general public. It's also generally biocompatible, popular with dental professionals and the patients using it orally as an antiseptic mouthwash to prevent bacterial biofilm and plaque accumulation [13].

The majority of the mouthrinses are acidic, some with a pH as low as 3 [14].

The aim of this research study is to evaluate accessible options for returning salivary pH to a phzsiological level after acidic exposure.

2. MATERIALS AND METHODOLOGY

In the research, unstimulated saliva of 10 volunteers of different ages was analyzed. 6 male and 4 female volunteers were included, without oral and systemic diseases present. The ethical consent of the Ethics Committee of the Dental Clinic of Vojvodina (01-18 / 22-2020) was obtained for the conducted research.

The sampling method belongs to the passive saliva collection (SalivaBio Passive Drool Method), in this way a sample of mixed saliva is obtained, which is poured directly from the mouth into a plastic tube. This method can collect a small amount of sample. In this way, the collection of high quality samples is ensured, and thus precise analytical results. It is a very simple method of collecting saliva, which makes it suitable for both adults and children. Before collecting the sample, it was advised that the subjects do not consume food and colored drinks, except water, smoking tobacco, as well as brushing their teeth, since all these factors can affect the level of saliva secretion.

During this research, 4 mouthwashes were used: Oral B, Listerine, Denta dent and Perioplus and 3 commercial carbonated drinks: Coca Cola, Coca Cola zero and Fanta.

In all volunteers, saliva sampling was performed as follows. Saliva samples were collected before drinking or rinsing the mouth, and then liquids were used. Subsequently, subjects had given a saliva sample after 15 minutes, half an hour, an hour, and 2 hours after the start of the experiment. The pH value was determined with a pH meter.(Lutron Electronics Enterprise pH meter) (Figure 1).

When it comes to statistical analyses, the data were presented in the form of mean values and standard deviation. To evaluate how far data were from normality, the Shapiro–Wilk test was used. In cases when data were with disturbed distribution from normality, the significance of the difference between the examined research groups, was tested by the Wilcoxon signed-rank test, while for the data that exhibited normal distribution one way ANOVA and paired samples T-tests were used. The level of statistical significance was set at 5% ($p < 0.05$). For all statistical calculations Jamovi software (version 0.9.2.8) was used.

3. RESULTS

Figure 2 and table 1 depict changes in pH compared to baseline values following liquid exposure and post-exposure effect of four post treatment measurements. It can be observed that for the entire sample, initial drop 15 minutes after all liquids consumption has been observed, while pH values uniformly increased 30 minutes after the initial measurement and remained stable untill the end of the experiment. Figure 3 and table 2 depict these results in relation to specific mouthwash and carbonated beverage. It is important to note that Coca Cola demonstrated the highest initial pH decrease following acidic consumption.

Fig. 1. pH measurement

Table 1.Descriptive statistics for the entire sample

	Baseline	**15 min**	**30 min**	**60 min**	**120 min**
Mean	7.62	7.55	7.80	7.74	7.75
Median	7.62	7.74	7.92	7.76	7.74
Standard deviation	0.273	0.700	0.508	0.414	0.363
Minimum	6.99	4.84	5.42	6.17	6.66
Maximum	8.26	8.40	8.35	8.38	8.36
Shapiro-Wilk W	0.985	0.761	0.716	0.899	0.963
Shapiro-Wilk p	0.368	< .001	< .001	< .001	0.010

Since data distribution significantly deviated from normality non parametric tests had been conducted. Table 3 shows that statistically significant diferences were observed betwee baseline measuremnents and the measurement after 15 minutes ($p<0.05$).

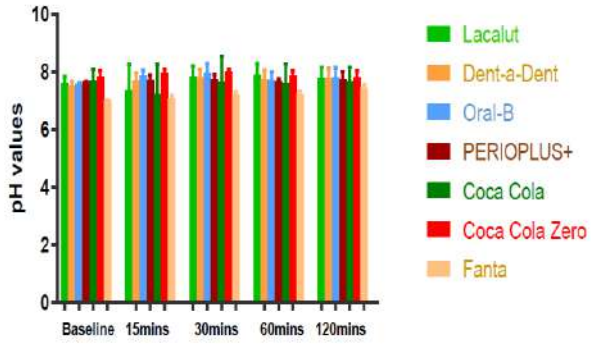


Fig. 2. PH values at the baseline and throughout the experiment

Table 2 pH values in relation to liquids throughout the experiment

Liquid	Baseline	15 min	30 min	60 min	120 min
Coca Cola Zero	7.83	7.97	8.01	7.87	7.8
Coca Cola	7.69	7.24	7.64	7.62	7.66
Dent-a-Dent	7.53	7.69	7 .82	7.76	7.78
Fanta	7.02	7.08	7.19	7.23	7.45
Listerine	7.61	7.37	7.84	7.88	7.78
Oral-B	7.58	7.87	7.96	7.72	7.82
PERIOPLUS+	7.67	7.72	7.76	7.67	7.77

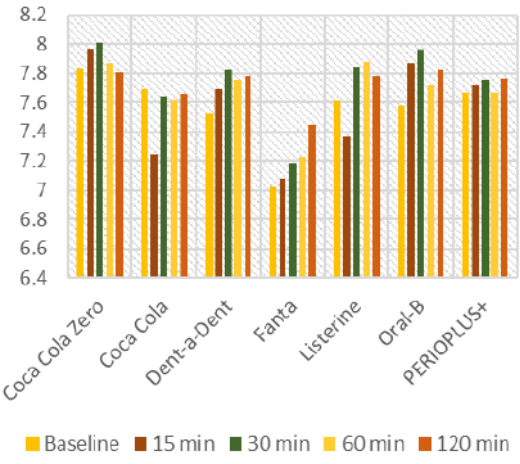


Fig. 3. PH values in relation to solution

The increase in pH values 30 minutes after the baseline measurement was also statistically significant ($p<0.05$, Wilcoxon signed-rank test). After 60 and 120 minutes from the begining of the exoeriment there was no statistically significant diferences ($p>0.05$)

Table 3. Wilcoxon signed-rank test intergroup analysis

	χ^2	Df	P
Baseline	20.55	6	0.002
15 min	16.65	6	0.011
30 min	13.42	6	0.037
60 min	11.28	6	0.080
120 min	4.53	6	0.606

4. DISCUSSION AND CONCLUSION

In the present investigation during this experimental research, data were obtained in order to show how the use of antibacterial mouthwashes on one side, and the use of carbonated beverages, on the other side, affects the level of pH and thus influences the protective role of saliva. The protective role of saliva includes cleaning, lubrication, maintaining the integrity of the oral mucosa, buffering properties, antimicrobial properties, remineralization and assisting in the digestion of food, but the ability to resist the acidic challenge presents one of the most important protective mechanisms [4,7,8].

Based on the obtained results, we determined that the use of various antiseptic agents for rinsing the mouth, as well as the use of carbonated beverages significantly affects the acido-basic salivary balance, which thus can have significant effect on oral health.

While the use of antiseptic solutions has its other mechanisms in maintaining oral health, the initial adverse effect on the acidity of the oral cavity is much lower compared to the frequent use of carbonated beverages. Also, mouthwashes are used according to a strictly defined protocol of oral hygiene and diet upon the advice of a dentist, immediately after brushing teeth, when the pH in the oral cavity is highest and the duration of use of mouthwash is limited to a few minutes. On the other hand, consuming carbonated drinks is a habit that patients can pursue for a longer period of time during the day, in conditions when plaque is already present on tooth surfaces, so the pH drop in this case repeats, lasts longer and certainly has greater clinical significance. In the present investigation, the most frequently used types of active ingredients in mouthwashes had been evaluated (fluoride mouthwash, chlorhexidine and essential oil based mouth rinse), together with most widely used carbonated beverages (Coca Cola and Fanta). In this study, it was shown that saliva has a strong buffering capacity and that the pH values return to the initial values within half an hour after the use of the analyzed solutions. These findings should be taken with caution because completely healthy volunteers, young adults, with extremely low caries activity and no caries lesions participated in this study. These results cannot therefore be directly extrapolated to the general population,

For that reason, it is very important to take into account the extent to which and how often these solutions are used. Since there is a possibility of lowering the pH of the oral cavity below 5.5 when maintaining oral hygiene by brushing teeth and using chemoprophylactic agents, patients should be advised to avoid consuming acidic foods and beverages or use other chemoprophylactic agents to

avoid further lowering the pH. Addy and his coworkers were the first to suggest that mouthrinses could cause dentine smear layer erosion, especially when used in conjunction with mechanical toothbrushing [15].

Many dental patients report drinking a lot of acidic beverages, which is a known and significant health risk for exposed enamel and dentin tooth surfaces. In general, giving dental professionals and patients more information about acidic beverages could help them better educate their patients on how to avoid further erosion and create an oral cavity that is less favorable to unfavorable acidic attack.

5. REFERECES

[1] Podunavac I, Hinić S, Kojić S, Jelenčiakova N, Radonić V, Petrović B, Stojanović GM.: *Microfluidic Platform for Examination of Effect of Chewing Xylitol Gum on Salivary pH, O2, and CO2*, Applied Sciences, 2021 Jan;11(5):2049.

[2] Ehlen, L. A.,Marshall, T. A., et. al. (2008). *Acidic beverages increase the risk of in vitro tooth erosion*. Nutrition Research (New York, N.Y.), 28(5), 299–303. doi: /10.1016/j.nutres.2008.03.001

[3] Hans R., Thomas S., et. al. *Effect of various sugary beverages on salivary pH, flow rate, and oral clearance rate amongst adults*. Scientifica, 2016,

[4] Demir T., Demir H., et al. *The effects of some drinks on saliva pH.* Journal of Interdisciplinary Medicine and Dental Science, 5(4), 216. 2017, doi: 10.4172/2376-032X.1000216

[5] Jha A., Radha G., et. al. *Assessing the acidity and total sugar content of four different commercially available beverages commonly consumed by children and its timedependent effect on plaque and salivary pH*. Journal of Indian Association of Public Health Dentistry, 13, 188-92, 2015.

[6] Turssi C.P., Hara A.T., et. al. *Calciumlactate pre-rinse increased fluoride protection against enamel erosion in a randomized controlled in situ trial*. Journal of Dentistry, 42, 2014.

[7] Lindquist B., Lingstro_mP., et. al.. *Influence of five neutralizing products on intra-oral pH after rinsing with simulated gastric acid.* European Journal of Oral Sciences, 119(4), 301-304. 2011,doi:10.1111/j.1600-0722.2011.00841.x

[8] Belardinelli P.A.,Morelatto R.A., et. al. *Effect of two mouthwashes on salivary pH*. Acta Odontológica Latinoamericana, 27(2), 66-71. 2014.

[9] Ross NM, Charles CH, Dills SS. *Long-term effects of Listerine antiseptic on dental plaque and gingivitis.* The Journal of clinical dentistry. 1989 Jan 1;1(4):92-5.

[10] Rahman B, Alkawas S, Al Zubaidi EA, Adel OI, Hawas N. *Comparative antiplaque and antigingivitis effectiveness of tea tree oil mouthwash and a cetylpyridinium chloride mouthwash: A randomized controlled crossover study*. Contemporary clinical dentistry. 2014 Oct;5(4):466.

[11] Grøn P, Messer AC. *An investigation of the state of carbon dioxide in human saliva*. Archives of oral biology. 1965 Sep 1;10(5):757-63.

[12] Duckworth RM, Morgan SN, Murray AM. *Fluoride in saliva and plaque following use of fluoride-containing mouthwashes*. Journal of dental research. 1987 Dec;66(12):1730-4.

[13] Brookes Z. L.S, Bescos R., Belfield L. A., Ali K, Roberts A., *Current uses of chlorhexidine for management of oral disease: a narrative review*, Journal of Dentistry, Vol. 103, 2020, 103497, https://doi.org/10.1016/j.jdent.2020.103497.

[14] Bhatti SA, Walsh TF, Douglas CW. *Ethanol and pH levels of proprietary mouthrinses*. Community Dental Health. 1994 Jun;11(2):71-74.

[15] M. Addy, T. Loyn, D. Adams *Dentine hypersensitivity—effects of some proprietary mouthwashes on the dentine smear layer: a SEM study* J Dent, 19 (1991), pp. 148-152

ACKNOWLEDGEMENT

This research has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant agreement No. 872370.

Authors: **Nikola Plavac[1], Marija Vejin[1], Jovana Kalamković[1], Kristina Spajić[2], Sanja Kojić[1], prof. dr Bojan Petrović[2], prof. dr Goran Stojanović[1]**

[1]University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2350, Fax: +381 21 454-495.

[2]University of Novi Sad, Faculty of Medicine Hajduk Veljkova 3, Novi Sad, Srbija, Tel.: +381 21 661 2222.

E-mail: plavacnikola@uns.ac.rs
marijavejin@gmail.com
jovanakalamkovic@uns.ac.rs
102774@mf.uns.ac.rs
sanjakojic@uns.ac.rs
bojan.petrovic@mf.uns.ac.rs
sgoran@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Potran, M.

POREĐENJE KONVENCIONALNOG I DIGITALNOG PROTOKOLA IZRADE INDIREKTNIH ZUBNIH NADOKNADA- UTICAJ NA RUBNO ZAPTIVANJE

Rezime: *Indirektna nadoknada zubnih tkiva predstavlja postupak obnavljanja funkcije, intergriteta i morfologije nedostajućih tkiva, koji se vrši na modelu vilice u zubnoj laboratoriji. Ovaj način proizvodnje obezbeđuje potrebno vreme i prostor za manipulaciju tokom izrade. Tačnost izrade se najbolje procenjuje preko marginalne adaptacije. Postupak izrade konvencionalnom-analognom tehnikom sastoji se od dugačkog proizvodnog lanca od kojih svaki korak posredno utiče na rubno zaptivanje. Skraćenjem proizvodnog lanca povećava se stepen kontrole i poboljašava standardizacija postupka. To se postiže implementacijom digitalnih tehnologija, gde glavni činilac postaje materijal i tehnologija koja se koristi. Pregledom literature izvršena je analiza faktora koji utiču na rubno zaptivanje, kod konvencionalnih, kombinovanih i digitalnih postupaka izrade indirektnih zubnih nadoknada.*
Ključne reči: *accuracy, precision, dental impression materials, CAD-CAM, Dental marginal adaptations*

1. UVOD

Izrada indirektnih zubnih nadoknada predstavlja postupak obnavljanja funkcije, intergriteta i morfologije nedostajućih tkiva stomatognatnog sistema. Rekonstrukcja indirektnim zubnim nadoknadama vrši se delimičnim i punim zubnim krunama a tačnost izrade procenjuje se preko marginalne adaptacije [1-3]. Marginalna adaptacija zavisi od više faktora: tehnike brušenja, veličine zrna borera, načina otiskivanja, prisustva vlage, materijala za otiskivanje, ekspanzije gipsa, deformacije rubnog voska, vrste materijala za izradu krune, ekspanzije vatrostalne mase i veštine tehničara [4, 5, 6]. Definisana je kroz nekoliko dimenzija, od kojih marginalni međuprostor (okomito rastojanje između zubne nadoknade i ruba demarkacije) i apsolutni marginalni međuprostor (kosa ravan koja se odnosi na pravu između dve tačke, koje se nalaze na rubu demarkacije i donje ivice zubne nadoknade) najbolje prikazu tačnost naleganja zubne nadoknade [7, 8].

Povećanje međuprostora dovodi do povećane debljine cementnog filma, koji se pod uticajem pljuvačke hidrolitički razgrađuje [9]. Nakon ispiranja cementa nastaje pukotina, koja se teško čisti i dolazi do nesmetane kolonizacje kariogenim bakterijama. Studije rađene in vivo, pokazale su korelaciju između povećanja marginalne pukotine sa plak indeksom i oboljenjima parodoncijuma [10,11]. Specifikacija American Dental Association (ADA) br. 87 ukazuje da debljina cementnog filma ne bi trebalo prelaziti 25 μm, kada se koristi sredstvo za cementiranje tipa I, ili 40 μm kada se koristi sredstvo za cementiranje tipa II [12]. Povećanje marginalne pukotine utiče i na mehaničke karakteristike usled drugačijeg rasporeda opterećenja ispod cementnog filma, rezultirajući lomom keramike [13].

Tačnost adaptacije se različitim metodološkim postupcima ispituje preko 2D i 3D merenja. Dozvoljena granica marginalnog međuprostora u konvencionalnoj stomatologiji iznosi 120 μm [14]. Uz pomoć CAD/CAM sistema, tačnost izrade se stalno povećava a granica marginalnog međuprostora smanjuje [15]. Kompleksni uslovi unutar zubne duplje onemogućavaju standardizaciju merenja in vivo, usmeravajući istraživanja na kontrolisane laboratorijske uslove. Većina dosadašnjih istraživanja rađena je in vitro a merenje marginalnog međuprostora vršeno je dvodimenzionalno, po presecima na mikroskopu [16-21]. Na ovaj način praktično se može uraditi od 4 do 16 preseka, što ne odgovara kompleksnoj geometriji zuba i nadoknade. Prednost trodimenzionalnog merenja nad linearnim nalazi se u velikom broju mernih tačaka i mogućoj proceni lokalnih odstupanja. Potrebno je najmanje 50 tačaka kako bi greška merenja bila ispod 5 μm, nagalašavajući potrebu za trodimenzionalnim modelom [22]. To se postiže savremenim beskontaktnim skenerima, laserom ili kompjuterizovanom tomografijom. Laser skenira oba objekta koji se nakon toga preklope, pri čemu nastaje mapa odstupanja u vidu 3D objekta. Kompjuterizovana tomografija ima dodatnu prednost u vidu direktnog merenja na modelu. Oba načina su konzervativna bez destrukcije modela, čime se pojednostavljuje postupak merenja [2, 3, 23-25].

2. FAKTORI KOJI UTIČU NA TAČNOST OTISKA

Otisak predstavlja reprodukciju intraoralnih tkiva u negativu [otisnim materijalima] ili pozitivu [intraoralnim skenerom]. Otisni materijali koji se koriste u savremenoj praksi spadaju u grupu elastomera, po sastavu su polimeri. Među njima najveću dimenzionu stabilnost imaju adicioni silikoni [26]. Njihovo vezivanje nastaje reakcijom polimerizacije, sa posledičnom volumetrijskom kontrakcijom materijala [27]. Kontrakcija zavisi od količine materijala a izračunava se u odnosu na ukupnu zapreminu mase. Dimenzione promene su veće kada se otiskuje ceo zubni niz u odnosu na jedan zub. Nakon uzimanja otiska treba sačekati najmanje 30 minuta da bi se omogućio viskoelastični povraćaj, što predstavlja elastična i reološka svojstva materijala. Povraćaj nije potpun i zavisi od tehnike otiskivanja i svojstva materijala. Za adicione silikone iznosi 99.5% [28]. Posle toga otisak se izliva u gipsu. Gipsevi koji se danas koriste u fiksnoj protetici su tip 4, sa stopom ekspanzije od 0.15% [28]. Ekspanzija gipsa treba da nadoknadi kontrakciju otiska, ali zbog anizotropne deformacije ne može se očekivati identičan povraćaj u sve tri dimenzije [29]. Gips spada u dimenziono stabilne materijale, sa blagom ekspanzijom zbog sadržaja vode. Utvrđeno je da dimenzione promene nastaju do 96 sati nakon mešanja gipsa [30]. Najveća tačnost je nakon skidanja otiska sa modela, pa je preporuka da se protetski radovi rade ubrzo nakon toga [31]. Kompatibilnost gipsa i otisnih materijala takođe doprinosi reprodukciji detalja, što najviše zavisi od hidrofobnosti otisnog materijala. Hidrofobni materijali sprečavaju tečenje gipsa po otisku i mogu nastati blazne u radnom modelu. Preporuka je da se otisni materijal nakvasi surfaktantom pre izlivanja gipsanog modela [32]. Našim prethodnim istraživanjem utvrđeno je da su dimenzione promene otiska najveće po najdužoj osovini t.j zavise od rastojanja među otiskivanim površinama. Mereno na gipsanom modelu te promene su iznosile do 36 μm transverzalno između molara, sa smanjenjem visine patrljaka (do 15 μm) i konvergencije aksijalnih površina (0.18°) [33].

Kod digitalnog protokola gipsani modeli služe kao osnova za skeniranje pomoću ekstraoralnih skenera i predstavljaju kariku koja spaja konvencionalni sa budućim digitalnim protokolom. Prethodno nastale greške tokom otiskivanja su time uključene u ukupnu grešku marginalne adaptacije zubne nadoknade. Gipsani modeli se u digitalnom protokolu prave od posebne vrste gipsa sa smolom, koja povećava tvrdoću i smanjuje refleksiju površine [34]. Inspekcijom gipsanog modela nastaje oblak tačaka koji se digitalizuje u virtuelni model, služeći kao osnova za dizajn buduće nadoknade. Nedostaci taktilnih ekstraoralnih skenera u vidu nemogućnosti merenja podminiranih mesta, zaobljavanja prelaza između površina i sporosti samog postupka, doveli su do njihove zamene sa beskontaktnim metodama skeniranja [35].

Intraoralni skeneri omogućavaju uzimanje otisaka direktno sa zuba pacijenta. Na taj način izbegnute su sve potencijalne greške koje se javljaju kod izrade radnog modela, no postavlja se pitanje tačnosti skenera u kompleksnim ordinacijskim uslovima. To se odnosi na pomeranja glave pacijenta, prisustvo pljuvačke i ograničene mogućnosti prilaza skeniranom objektu [36]. Jedan od najvećih izazova intraoralnih skenera je registrovanje ruba kod vizuelno nedostupnih područja [37,38]. U tim slučajevima, preporučuje se upotreba konca ili drugih vidova separacije desni [39]. Kod zubnih nadoknada većeg raspona, kao što su semicirkularni mostovi, individualizacija samih nadoknada zahteva postojanje fizičkog modela, najčešće 3D štampom [40]. Postojanost štampanih modela je predmet istraživanja, no trenutno su manje tačnosti od gipsanih [41, 42].

Poređenje tačnosti ekstraoaralnih i intraoralnih skenera predmet je istraživanja još od njihove prve upotrebe. Brojne studije su se bavile ovom tematikom, ali nemoguće je izvesti jasan zaključak. Pokazalo se da tačnost merenja više zavisi od uslova merenja u odnosu na tačnost samog uređaja [2,35,43]. Dodatni problem istraživanja predstavlja nenamenska upotreba intraoralnih skenera u laboratorijskim uslovima, sa očekivano povećanom tačnošću u odnosu na ordinacijske uslove. Upotrebna vrednost intraoralnih skenera raste sa svakom novom generacijom i definitivno predstavljaju budućnost uzimanja otisaka [44]. Visoka cena uređaja je i dalje ograničavajući faktor njihove šire implementacije u stomatološku praksu.

Pregledom dosadašnjih studija, može se zaključiti da ne postoji statistički značajna razlika u tačnosti između konvencionalnog i digitalnog protokola rada [26,44,45]. Najprimetnija razlika je kod otiskivanja punog zubnog niza. Digitalni otisci sa većim brojem preseka skloni su distalnoj deformaciji zubnog luka, dok konvencionalni otisci pokazuju lokalna odstupanja bez distalne deformacije [26,42,44-47]. Na osnovu toga može se reći da je tačnost intraoralnih skenera veća kod otiskivanja kraćih delova zubnog luka, dok su otisni materijali tačniji kod punog zubnog niza

3. DIMENZIONALNA STABILNOST METALNE SUBSTRUKTURE

Konvencionalne tehnike livenja metalnih konstrukcija u stomatologiji zasnovane su na tehnici izgubljenog voska. Metalna konstrukcija počinje izradom modela od voska ili akrilata. Najveći nedostatak tehnike je mala dimenziona stabilnost voštanog modela. Deformacije nastaju usled toplotnih promena i oslobađanja unutrašnjih napona. Povećanje temperature od 20 °C do 36 °C dovodi do ekspanzija voska od 0.7%, dok hlađenje dovodi do kontrakcije od 0.35% [48]. Svaka nova temperaturna varijacija dovodi do anizotropne deformacije koju je teško predvideti. Širi raspon temperature omekšavanja voska, dovodi do pojačanog skupljanja modela kod hlađenja. Najniže temperatura omekšavanja je kod parafina na 37 °C , dovodeći do marginalne deformacije kod pojedinačnih kruna od 7- 110 μm [49]. Samo skidanje voštanog modela sa gipsanog patrljka, koje je neminovno tokom postupka izrade, dovodi do deformacije ruba od 35 μm [50]. Nedostaci manuelne adaptacije voska adresirane su primenom CAD/CAM sistema, štampanjem i frezovanjem voska prema virtuelnom modelu. Tačnost takvih konstrukcija se u većini istraživanja pokazala većom u odnosu na klasičan način ručnog modelovanja [51,52].

Drugi materijal za izradu modela konstrukcije je akrilat, konvencionalnom tehnikom ili 3D štampom. Akrilati su uvedeni da bi nadoknadili nedostatke voska po pitanju dimenzione stabilnosti. Poseduju veću čvrstoću ali se takođe tokom vezivanja jače kontrahuju, sa prisutnom slojevitošću karakterističnom za 3D štampu [53]. Dimenziona stabilnost uslovljena je svojstvom materijala i debljinom zida nadoknade. Akrilatna konstrukcija mora se štampati minimalne debljine od 0,6 mm, što povećava težinu i smanjuje prostor za keramiku. Dodatni problem je nepotpuno sagorevanje akrilata tokom postupka žarenja, što dovodi do defekata u budućoj metalnoj konstrukciji. Pregledom literature nađene su samo dve studije u kojima je merena tačnost rubnog zaptivanja akrilatnih modela, sa izmerenim marginalnim međuprostorom od 36-75 μm, mereno na pojedinačnoj kruni. Slojevito nanošenje materijala uzrokuje porast koeficijenta varijacije iznad 10% [54]. Klinički su primećeni dobri rezultati, sa znatnom uštedom vremena.

Prethodno napravljeni modeli od voska ili akrilata, služe za kasnije kalupljenje u vatrostalnoj masi. Vezivna i termička ekspanzija vatrostalne mase predstavljaju inherentna svojstva materijala, čime se kompenzuje kontrakcija legure. Neujednačenost ekspanzije zajedno sa distorzijom i kompleksnom morfologijom voštanih modela, dovodi do neželjene deformacije odlivaka u sve tri dimenzije [55]. Veće i teže konstrukcije, kao kod semicirkularnih mostova, podložnije su deformaciji [56,57]. To je najzastupljenije kod legura zlata, dok su legure manje težine, kao što je kobalt-hrom, postojanije. Brojni nedostaci tehnike izgubljenog voska izbegnuti su implementacijiom digitalnih tehnologija za proizvodnju i obradu metala, direktnom izradom bez posredovanja kalupa.

4. TEHNOLOGIJA IZRADE METALA

Digitalni protokol izrade zubnih nadoknada završava se pravljenjem fizičkog modela pomoću aditivnih i subtraktivnih metoda. Subtraktivne metode zasnivaju se na sečenju materijala iz preformiranih blokova, dok se u aditivnim model dobija slaganjem materijala sloj po sloj, u vidu 3D štampe. Najčešće aditivne tehnike su stereolitografija (SLA) i selektivno lasersko sinterovanje (SLS).

Sistem laserskog sinterovanja metala koristi metalni prah koji se selektivno sinteriše prema virtuelnom modelu. Integracija slojeva vrši se topljenjem sa laserom, slojevima približne debljine 20 do 60 μm, proizvod čega je fizički model. Prednosti ovog sistema uključuju jednostavnu izradu komplikovanih oblika, štednju materijala, automatizaciju sistema i skraćeno vreme izrade, kao rezultat eliminisanja procedure izrade voštanih modela, ulaganja, žarenja i livenja. Glavni nedostatak sistema je visoka cena opreme [58]. Krunice i mostovi prave se od čestica veličine 3-14 μm. U kombinaciji sa tankim laserskim snopom moguće je praviti čvrste konstrukcije pune gustine 99.9%. Gusto sinterovane krune praktično nemaju poroznost a tačnost izrade je na visokom nivou. Autamatizacija sistema omogućava potpunu kontrolu dizajna, tokom svih faza izrade. Na taj način postiže se standardizacija debljine konstrukcija, cementnog filma i oblika spojnica [59]. Postupak sinterovanja vrši se od dole ka gore, pa je moguća kompenzacija podminiranosti kod fiksnih radova. Kod izlivanja većih konstrukcija tehnikom izgubljenog voska obično dolazi do iskrivljenja konstrukcije, koje je kod laserskog sinterovanja izbegnuto. Predvidljivost samog postupka utiče na potencijalno bolju marginalnu adaptaciju [52].

Tačnost se kod laserskog sinterovanja pokazala boljom u odnosu na tehniku izgubljenog voska [52,60], istom [61], ili manjom [59,62]. Sva istraživanja rađena su na pojedinačnim krunama ili kraćim mostovima. Pregledom literature nisu

nađena istraživanja na semcirkularnim mostovima, gde se očekuje najveća razlika u marginalnoj adaptaciji.

Drugi vid dobijanja fizičkih modela CAD/CAM-om je subtraktivni, mašinskim frezovanjem. Na ovaj način se najviše obrađuje cirkonija i titanijum, ali se koristi i za Co-Cr legure. Nedostatak tehnike je u habanju instrumenata i velika količina otpadnog materijala koji iznosi do 90% [63]. Tačnost frezovanja u poređenju sa tehnikom izgubljenog voska je bila bolja [64], gora [62, 65] ili ista kao navedena [53].

5. ZAKLJUČAK

Zaključak analize je da se konvencionalnom - analognom tehnikom može postići visoka tačnost izrade zubnih nadoknada, poštujući pravila struke i navode proizvođača. Problem je u dugačkom lancu proizvodnje u kom svaka potencijalna greška indirektno utiče na tačnost završne nadoknade, posebno ako se desi na početku. Jednostavnost i smanjenje uticaja ljudskog faktora čini digitalni protokol izrade predvidljivijim i pouzdanijim od konvencionalnog. Glavni činilac postaje materijal i potencijal upotrebljene tehnologije. Standardizacija postupka znatno doprinosi predviđanju potencijalnih problema i omogućava veći stepen kontrole. Digitalne tehnologije predstavljaju budućnost stomatologije a tranzicija ka digitalnoj stomatologiji će doći do izražaja sa smanjenjem cena i udelom većeg broja prozvođača na tržištu.

6. REFERENCE

[1] Boitellea P, Tapieb L, Mawussic B, Fromentind O. *3D fitting accuracy evaluation of CAD/CAM copings – comparison with spacer design settings.*
[2] International Journal of Computerized Dentistry 2016;19[1]:27–43.
[3] Güth J. F, Keul CH, Stimmelmayr M, Beuer F, Edelhoff D. *Accuracy of digital models obtained by direct and indirect data capturing.* Clin Oral Invest [2013] 17:1201–1208.
[4] Kim K.B, Kim J.H, Kim W.C, Kim J.H. *Three-dimensional evaluation of gaps associated with fixed dental prostheses fabricated with new technologies.* J Prosthet Dent 2014;112:1432-1436.
[5] Habib S.R, Al Ajmi M.G, Al Dhafyan M, Jomah A, Abualsaud H, Almashali M. *Effect of margin designs on the marginal adaptation of zirconia copings.* Acta stomatol Croat. 2017;51[3]:179-187.
[6] Jalalian E.A, Mostofi S.N, Shirian A.A, Shamshirgar F, Ghane H.K, Naseri M. *Effect of sloped shoulder and deep chamfer finish lines on marginal adaptation of zirconia restorations.* Journal of Research in Medical and Dental Sciences 2018;6[1]:369-373.
[7] Al-Zubaidi Z.A.K, Al-Shamma A.M.V. *The effect of different finishing lines on the marginal fitness of full contour zirconia and glass ceramic CAD/CAM crowns [an in-vitro study]*. Journal of Dental materials and techniques 2015;4[3]:127-136.
[8] Nawafleh N, Mack F, Evans J, Mackay J, Hatamleh M.M. *Accuracy and reliability of methods to measure marginal adaptation of crowns and FDPs: A literature review.* Journal of Prosthodontics 2013;22:419–428
[9] Papadiochou S, Pissiotis *A.L. Marginal adaptation and CAD-CAM technology: A systematic review of restorative material and fabrication techniques.* J Prosthet Dent 2018;119:545-51.
[10] Ortengren U, Elgh U, Spasenoska V, Milleding P, Haasum J, Karlsson S. *Water sorption and flexural properties of a composite resin cement.* Int J Prosthodont 2000;13:141-147.
[11] Subasi G, Ozturk N, Inan O, Bozogullari N. *Evaluation of marginal fit of two all-ceramic copings with two finish lines.* Eur J Dent 2012;6:163-168.
[12] Mayooran B, Robin S, John R.T. *Dental caries is a preventable infectious disease*. Aust. Dent. J. 2000;45:235–245.
[13] *American Dental Association: ANSI/ADA Specification No. 8 for zinc phosphate cement*. In: Guide to Dental Materials and Devices [ed 5]. Chicago, American Dental Association,1970-1971.]
[14] Wiskott H.W, Belser U.C, Scherrer S.S. *The effect of film thickness and surface texture on the resistance of cemented extracoronal restorations to lateral fatigue loading*. Int J Prosthodont 1999;12:255-62.
[15] McLean J.W, Von Fraunhofer J.A. *The estimation of cement film thickness by an in vivo technique*. Br Dent J 1971;131:107-111.
[16] Boitelle Ph, Tapie L, Mawussi B, Fromentin O. *Evaluation of the marginal fit of CAD-CAM zirconia copings: Comparison of 2D and 3D measurement methods*. J Prosthet Dent 2018;119:75-81.
[17] Laurent M, Scheer P, Dejou J, Laborde G. *Clinical evaluation of the marginal fit of cast crowns – validation of the silicone replica method.* Journal of Oral Rehabilitation 2008;35:116–122.
[18] Juntavee N, Sirisathit I. *Marginal accuracy of computer-aided designand computer-aided manufacturing-fabricated full-arch zirconia restoration*. Clinical, Cosmetic and Investigational Dentistry 2018;10:9–17.
[19] Kim K.B, Kim W. Ch, Kim H. Y, Kim J.H. *An*

evaluation of marginal fit of three-unit fixed dental prostheses fabricated by direct metal laser sintering system. Dental Materials 2013;29:e91–e96.
[20] Pastoret M.H, Krastl G, Bühler J, Weiger R, Zitzmann N.U. *Accuracy of a separating foil impression using a novel polyolefin foil compared to a custom tray and a stock tray technique*. J Adv Prosthodont 2017;9:287-93.
[21] Kokubo Y, Tsumita M, Kano T, Sakurai S, Fukushima S. *Clinical marginal and internal gaps of zirconia all-ceramic crowns.* Journal of Prosthodontic Research 2011;55:40–43.
[22] Suarez M.J.J, Vernimmen F.S, Merchán E.A.R. *Comparison of marginal fit of zirconia copings manufactured with the use of two CAD/CAM systems Cerec InLab [Sirona®]*. Revista Odontológica Mexicana 2015;19[4]:e236-e241.
[23] Groten M, Axmann D, Pröbster L, Weber H. Determination of the minimum number of *marginal gap measurements required for practical in vitro testing*. J Prosthet Dent 2000;83:40-9.
[24] Chul Oh K, Lee B, Park Y.B, Moon H.S. *Accuracy of three digitization methods for the dental arch with Various tooth preparation designs: An in vitro study*. J Prosthodont. 2019;28[2]:195-201.
[25] Persson A, Andersson M, Oden A, Sandborgh-Englund G. *A three-dimensional evaluation of a laser scanner and a touch-probe scanner*. J Prosthet Dent 2006;95:194-200.
[26] Saab R.C, Leonardo Cunha L.F, Gonzaga C.C, Mushashe A.M, Correr G.M. *Micro-CT analysis of Y-TZP copings made by different CAD/CAM systems: marginal and internal Fit*. International Journal of Dentistry 2018, Article ID 5189767, 4 strane.
[27] Ender A, Mehl A. *Accuracy of complete-arch dental impressions: A new method of measuring trueness and precision*. J Prosthet Dent 2013;109:121-128
[28] Rodrigueza J.M, Bartlett D.W. *The dimensional stability of impression materials and its effect on in vitro tooth wear studie*s. Dental materials 2011;27:253–258.
[29] McCabe J.F, Walls A. *Applied dental materials 2008*. Blackwell Publishing Ltd, 9600 Garsington Road, Oxford OX4 2DQ, UK. p163-177.
[30] Teraoka F, Takahashi J. *Dimensional changes and pressure of dental stones set in silicone rubber impressions*. Dental Materials 2000;16:145–149.
[31] Michalakis K, Stratos A, Hirayama H, Pissiotis A.L, Touloumi F. *Delayed setting and hygroscopic linear expansion of three gypsum products used for cast articulation*. J Prosthet Dent 2009;102:313-318.
[32] Doshi B, Gangadhar S.A. *Efficacy of slurry water*. The Journal of Indian Prosthodontic Society 2005;5[4]:200-202.
[33] Butta R, Tredwin C.J, Nesbit M, Moles D.R. *Type IV gypsum compatibility with five addition-reaction silicone impression materials*.J Prosthet Dent 2005;93:540-4.
[34] Potran M, Strbac B, Puskar T, Hadzistevic M, Hodolic J, Trifkovic B. *Measurement of accuracy of dental working casts using a coordinate measuring machin*e. Vojnosanitetski pregled 2016;73[10]:895-903.
[35] Tomita Y, Uechi J, Konno M, Sasamoto S, Iljima M, Mizoguch I. *Accuracy of digital models generated by conventional impression/plaster-model methods and intraoral scanning*. Dent Mater J. 2018;37[4]:628-633.
[36] Rudolph H, Salmen H, Moldan M, Kuhn K, Sichwardt V, Wöstmann B, Luthard R.G. *Accuracy of intraoral and extraoral digital data acquisition for dental restorations*. J Appl Oral Sci. 2016;24[1]:85–94.
[37] Mangano F, Gandolfi A, Luongo G, Logozzo S. *Intraoral scanners in dentistry: a review of the current literature*. BMC Oral Health 2017;17:149.
[38] Kim J, Park J.M, Kim M, Heo S.J, Shin I.H, Kim M. *Comparison of experience curves between two 3-dimensional intraoral scanners.* J Prosthet Dent. 2016;116[2]:221–30.
[39] Lim J.H, Park J.M, Kim M, Heo S.J, Myung J.Y. *Comparison of digital intraoral scanner reproducibility and image trueness considering repetitive experience*. J Prosthet Dent 2017;[17]30350–5.
[40] Zimmermann M, Mehl A, Mörmann WH, Reich S. *Intraoral scanning systems - a current overview*. Int J Comput Dent. 2015;18[2]:101–29.
[41] Bosch G, Ender A, Mehl A. *A 3-dimensional accuracy analysis of chairside CAD/CAM milling processes.* J Prosthet Dent 2014;112:1425-31.
[42] Abduo J. *Accuracy of casts produced from conventionaland digital workflows: A qualitative and quantitative analyses*. J Adv Prosthodont 2019;11:138-46.
[43] Wesemann C, Muallah J, Mah J, Bumann A. *Accuracy and efficiency of full-arch digitalization and 3D printing: A comparison between desktop model scanners, an intraoral scanner, a CBCT model scan, and stereolithographic 3D printing*. Quintessence Int 2017;48:41-50.
[44] Sason G.K, Mistry G, Tabassum R, Shetty O. *A comparative evaluation of intraoral and extraoral digital impressions: An in vivo study.* The Journal of Indian Prosthodontic Society 2018;18[2]:108-116.
[45] Ender A. *In vivo precision of conventional and*

digital methods of obtaining complete-arch dental impressions. J Prosthet Dent 2016;115:313-320.
[46] Chochlidakis k.m, Papaspyridakos P, Geminiani A, Chen Ch.J, Feng J, Ercoli C. *Digital versus conventional impressions for fixed prosthodontics: A systematic review and meta-analysis*. J Prosthet Dent 2016;116:184-190
[47] Flügge TV, Schlager S, Nelson K, Nahles S, Metzger MC. *Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model scanner*. Am J Orthod Dentofac Orthop. 2013;144[3]:471–8.
[48] Ahlholm P, Sipilä K, Vallittu P, Jakonen M, Kotiranta U. *Digital Versus Conventional Impressions in Fixed Prosthodontics: A Review*. J Prosthodont. 2018;27[1]:35-41.
[49] Kenneth J. Anusavice. *Phillips' Science Of Dental Materials 2003*. 11th Ed.. Saunders Elsevier 11830 Westline Industrial Drive St. Louis, Missouri 63146. p283-293.
[50] Campagni W.V, Reisbick M.H, Jugan M. *A comparison of an accelerated technique for casting post and core restorations with conventional techniques*. J Prosthodont 1933;4:159-66.
[51] Zeltser C, Lewinstein I, Grajower R. *Fit of crown wax patterns after removal from the die*. J Prosthet Dent 1985;53:344-346.
[52] Fathi H.M, Al-Masoody A.H, El-Ghezawi N, Johnson A. *The accuracy of fit of crowns made from wax patterns produced conventionally [hand formed] and via CAD/CAM techology*. Eur J Prosthodont Restor Dent. 2016;24[1]:10-7.
[53] Örtorp A, Jönsson D, Mouhsen A, Von Steyern P.V. *The fit of cobalt–chromium three-unit fixed dental prostheses fabricated with four different techniques: A comparative in vitro study*. Dental materials 2011;27:356–363.
[54] Bhaskaran E, Azhagarasan N.S, Miglani S, Ilango T, Krishna GP, Gajapathi B. *Comparative evaluation of marginal and internal gap of Co- Cr copings fabricated from conventional wax pattern, 3D printed resin pattern and DMLS Tech: an in vitro study*. J Indian Prosthodont Soc 2013;13:189-95.
[55] Hoang L.N, Thompson G.A, Cho S.H, Berzins D.W, BS, Ahn K.W. *Die spacer thickness reproduction for central incisor crown fabrication with combined computer-aided design and 3D printing technology: An in vitro study*. J Prosthet Dent 2015;113:398-404.
[56] Ito M, Kuroiwa A, Nagasawa S, Yoshida T, Yagasaki H, Oshida Y. *Effect of wax melting range and investment liquid concentration on the accuracy of a three-quarter crown casting*. J Prosthet Dent 2002;87:57-61.
[57] Bruce R.W. *Evaluation of multiple unit castings for fixed partial dentures*. J Prosthet Dent 1964;14:828–43
[58] De Oliveira Correa G, Henriques G.E, Mesquita M.F, Sobrinho L.C. *Over-refractory casting technique as an alternative to one-piece multi-unit fixed partial denture frameworks*. J Prosthet Dent 2006;95:243–8.
[59] Venkatesh K.V, Nandini V.V. *Direct metal laser sintering: A digitised metal casting technology*. J Indian Prosthodont Soc 2013;13[4]:389–392.
[60] Kim K.B, Kim W.C, Kim H.Y, Kim J.H. *An evaluation of marginal fit of three-unit fixed dental prostheses fabricated by direct metal laser sintering system.* Dental materials 2013;29: e91–e96.
[61] Kim K.B, Kim J.H, Kim W.C, Kim J.H. *Three-dimensional evaluation of gaps associated with fixed dental prostheses fabricated with new technologies*. J Prosthet Dent 2014;112:1432-1436.
[62] Ucar Y, Akova T, Akyil M, Brantley W.A. *Internal fit evaluation of crowns prepared using a new dental crown fabrication technique: laser-sintered Co–Cr crowns*. Journal of Prosthetic Dentistry 2009;102:253–9.
[63] Kim M.J, Choi Y.J, Kim S.K, Heo S.J, Koak J.Y. *Marginal accuracy and internal fit of 3-D printing laser-sintered Co-Cr alloy copings*. Materials 2017;10:93.
[64] Strub J.R, Rekow E.D, Witkowski S. *Computer aided design and fabrication of dental restorations: current systems and future possibilities*. J Am Dent Assoc 2006;137:1289-96.
[65] Woo H.W, Cho S.A, Lee C.H, Lee K.B, Cho J.H, Lee D.H. *Precision of the milled full-arch framework fabricated using pre-sintered soft alloy: A pilot study*. J Adv Prosthodont 2018;10:128-31.
[66] Han H.S, Yang H.S, Lim H.P, Park Y.J. *Marginal accuracy and internal fit of machine-milled and cast titanium crowns*. J Prosthet Dent 2011;106:191-197.

Autori: **Potran Michal,** Univerzitet Privredna akademija, Stomatološki fakultet Pančevo, Žarka Zrenjanina 179, 26000 Pančevo, Srbija.
E-mail: michalpotran@gmail.com

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Stanojević, K., Kalamković, J., Milić, L., Stavrakis, A., Kojić, S., Plavac, N., Stojanović, G.

APPLICATION OF SEM AND CONVENTIONAL MICROSCOPY IN THE ANALYSIS OF DENTAL FLOSS WEAR AND BREAK

Abstract: *Dental floss is a floss-wrapped oral hygiene product used to remove food and plaque in places where toothbrushes cannot reach. Thread cracking and wear can compromise efficiency. The aim of this study was to examine the morphological properties of 5 different commercially available dental floss before and after use. Scanning electron microscope (SEM) and conventional microscopy at magnifications of 40, 100, and 500 were used. The analyzed dental floss showed the variability of the manner of wear and morphology of flossing, which speaks in favor of the need to know the properties of the floss before recommending it to patients for daily use in all clinical indications.*
Key words: *dentral floss, plaque, oral hygiene, SEM*

1. INTRODUCTION

According to ISO 28158:2010 dental flosses are defined as the multiple filaments gathered into thread, spun yarn, single filament or tape, commonly synthetic fibre, with or without coating material(s), designed for the removal of plaque or debris, or both, from the proximal surfaces of natural or artificial teeth and the gingival surfaces of bridges of fixed prostheses [1]. Regarding the shape, the integrated dental floss and handle shall not have any sharp surfaces or parts when examined according to visual inspection with x10 magnification. The use of dental floss as an adjunct to tooth brushing provides plaque-removal benefits above that of tooth brushing alone [2,3]. There are various types of dental floss available in the market, such as silk, nylon, or PTFE (polytetrafluoroethylene floss), with or without wax. Yet, the experimental research regarding physical properties, tensile strength and structural and morphological features of dental floss remains largely unknown. Most of the data is provided by manufacturer and is usually used for commercially claim purpose. Pooling data of various types of dental flosses about structural properties, morphology of breakdown and wear can provide the information as a database in future development of dental floss product with satisfied properties.

Dental flosses have long been used for cleaning the interdental gaps or as an under fixed bridge dental cleaner. Normally, a dental floss consists of a yarn of numerous fine filaments (individual fiber diameter is around 20–30 μm) made of nylon or polyester, unified by a binder which holds the filaments together in the yarn [4]. Nylon or polyamide (PA) is known as the second most important synthetic polymer for textiles after polyester. Properties such as its excellent strength, high Young's modulus, stiffness, toughness, lubricity, and resistance to temperature, fatigue and abrasion, make nylon one of the most versatile thermoplastics used nowadays [5,6]

Dental floss did not achieve superior outcomes in comparison to other devices for interdental cleaning and was found to be less effective than interproximal brushes when both were combined with manual toothbrushing with toothpaste. [7]

Although interdental brushes can obviously only be used in larger interproximal spaces, there are reports in the literature that there is no significant difference between interproximal toothbrushes and dental flosses. According to some national population surveys, dental floss is used by one-third of the general population (34%) while interdental brushes are used by only 18% of the population, down from 42 percent in 2010. The development of a dental floss with ellipsoidal floss knots at regular distances has been proposed to facilitate plaque removal in wider interproximal spaces, given the popularity of dental floss but the drawback of its low efficacy in these spaces. [8-10]

However, traditional dental floss has been associated with causing infections such as peri-implantitis, which can then cause dental implant failure. This is because dental floss is susceptible to shredding, especially when used around a dental implant. When dental floss shreds, it leaves behind particles or pieces that can become trapped between the implants and gum tissue, causing an infection
The aim of this study was to compare structural and morphological properties of 5 different models of dental floss using Scanning electron microscope and conventional microcopy in order to inspect the differences in size and filament appearances before and after use.

2. MATERIALS AND METHODOLOGY

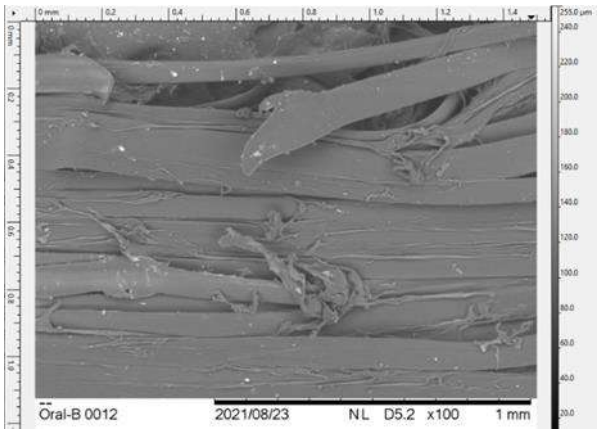


Fig. 1. SEM image of dental floss after use

The following dental flosses: Oral B (Essentials), Oral B (Satin), Lacalut, Sensodyne and TePe were included in the study. 50 samples of each product, 30 cm long, were prepared (Fig.2). 10 volunteers with all healthy teeth were included in the research and they used dental floss as instructed by their dentist. Volunteers did not have any fixed prosthodontic restorations, implants or proximal restorations. Initially, SEM and conventional microscope were used to characterize all dental floss, and then these floss were analyzed after use.

Fig. 2. Dental flosses used in the experiment.

The size of the filaments was measured in micron (μm) under 40, 100 and 500 magnification using SEM (Fig. 1, Fig.3), and the conventional microscopy. The mean fiber diameter was determined from SEM images as an average of a number of individual fibers. Moreover, fibers were analyzed under conventional optical microscopy. The breakdown of flosses has been classified as sharp, serrated and irregular. The analysis of SEM images and microscopic images was then performed using Gwyddion software (Fig 4) to quantify the changes in fiber diameter and to determine the floss breakdown pattern. Thread thinning was calculated as the ratio of the initial width measured before use and the individual measurements of the used dental floss (Figure 5).

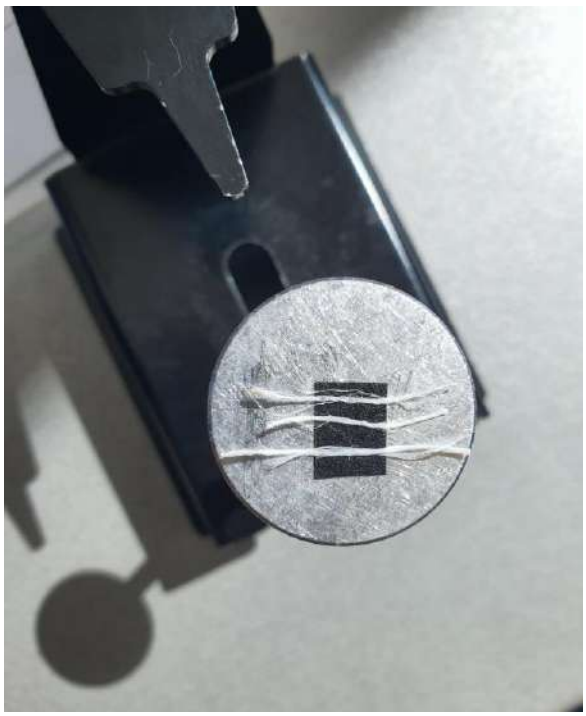


Fig. 3. Dental flosses prepared for SEM evaluation

3. RESULTS

Fiber morphology before and after use has been determined by SEM and conventional microscopy and representative images of flosses are shown in Fig. 2, 4, 6 and 7. The images allowed to observe that the dental floss is composed of a number of long solid cylindrical filaments

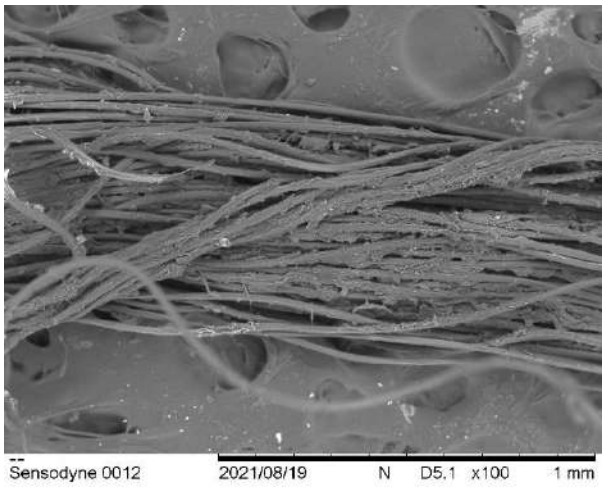


Fig. 4. Pattern of thinning and breakdown of dental floss cylindrical filaments

SEM was used to determine the morphology of the fibers. Figure 2 shows representative images of original flosses. The images revealed that dental flosses are predominately made up of a number of long, solid cylindrical filaments. Image-based measurements were used to determine the mean diameter of individual fibers from SEM images,

yielding an average value of around 30 micrometers before use (based on 20 measurements per floss). Furthermore, it was confirmed that the mean fiber diameter varied significantly between the samples.

Furthermore, when comparing Fig. 2(a–c), it can be seen that the use of some flosses causes filament separation, resulting in a more open fiber structure. When considering the size of filament, TePe had the largest fiber diameter among 5 types, which. been due to its larger diameter. On the other hand Lacalut dental floss had the smallest size of filament and disintegrated characteristics, and the difference in composition of materials resulted in the highest breakdown rate. All 5 types of dental flosses showed observable and nonuniform pattern of wear and breakdown.

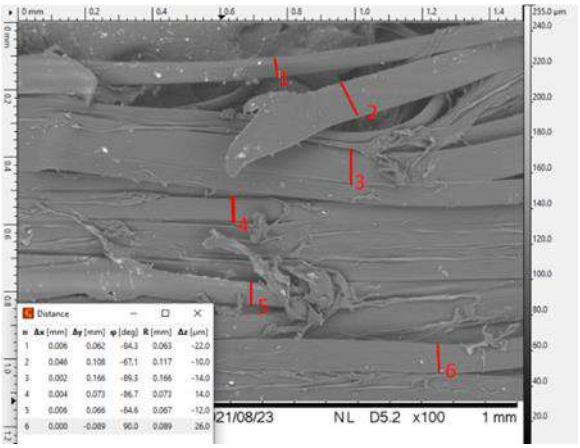


Fig. 5. Thinning and breakdown quantification using Gwiddion

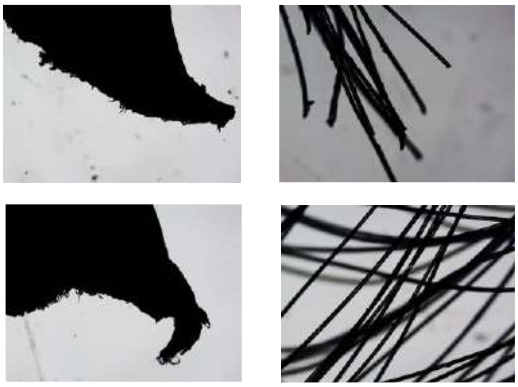


Fig. 6. The pattern of dental floss breakdown (tape form-left images; monofilament- right images)

4. DISCUSSION AND CONCLUSION

In the present investigation, from SEM and conventional microscopic images it was possible to determine the mean diameter of the individual fibers by image-based measurements, obtaining a value of 30µm (based on 20 measurements) which is in complete agreement with the reports in the literature [11] (Mosqueira). In addition, it was also confirmed that the mean fiber diameter has significant variation in the different samples.

Fig. 7. Non uniform thinning and breakdown pattern in cylindrical dental floss

Additionally, comparing Fig. 6 (left/right), and Fig 7 it can be observed that the use process induces a separation among filaments, leaving a more open fiber structure.

Despite substantial evidence indicating that flossing is ineffective at removing plaque, flossing may still provide benefits. In addition to the occasional short-term soft-tissue trauma, flossing is not harmful and has no major health risks [12]. Professional flossing has been shown to reduce the risk of interproximal caries; however, when flossing is done at home, the benefit is lost [13]. Interproximal plaque and gingivitis reductions from pre-treatment levels are reasonable expectations, and the results may not have differed when compared to a brushing-only group. As a result, the majority of studies do not recommend flossing on a regular basis. Plaque or gingivitis reductions can only be expected if patients floss properly on a regular basis.

The application of floss to exposed rough surfaces of an implant may also lead to fraying and, ultimately, the development of peri-implant conditions; hence, using interproximal brushes or toothpicks may be preferable [14]. With an increase in the number of implants placed and the occurrence of peri-mucositis and implantitis, effective oral hygiene to remove biofilm is likely to play an important role in future clinical practice.

As indicated in ten patients in the above mentioned observational study, there was strong evidence that peri-implant bone loss had occurred due to a beginning exposure of the moderately rough surface and the subsequent trapping of dental floss remnants initiating a progression of peri-implant infections. Remnants of dental floss certainly promoted plaque retention and may have acted as ligatures. As a conclusion, Van Velyen and

his coworkers provided evidence that the application of dental floss in daily oral hygiene practices in patients with dental implants may represent a risk for peri-implant disease progression owing to the fact that dental floss may be torn and trapped in the peri-implant sulcus.

Finally, it should be noted that the volunteers in this study were people with completely healthy teeth, without fixed prosthetic works, implants or proximally placed fillings. The results obtained by this research can certainly not be projected on groups of patients in whom the indications for daily use of dental floss are expanded, and the risks of cracking and wear are higher. However, it is assumed that the wear of dental floss and the way of their rupture in these groups would certainly be higher, which requires additional clinical research on more valid and carefully selected groups of subjects.

5. REFERECES

[1] ISO Standards catalogue of oral care product, ISO/TC 106/SC 7, for Integrated dental floss and handles ISO28158:2010.

[2] A. Biesbrock, P. M. Corby, R. Bartizek, et al. *Assessment of treatment responses to dental flossing in twins*, J. Periodontol. 77(8) (2006) 1386-1391.

[3] H. C. Hill, P. A. Levi, I. Glickman, *The effects of waxed and unwaxed dental floss on interdental plaque accumulation*, J. Periodontol. 44(7) (1973) 411-413.

[4] J.M. Blass, United States Patent 19, 4,996,056, 1991.

[5] M. Najafi, L. Nasri, R. Kotek, *High-Performance Nylon Fibers*, (2016), https://doi.org/10.1016/B978-0-08-100550-7.00009-7.

[6] F. Cardarelli, Mater. Handb (Ed.), *Polymers and Elastomers*, Springer, London, London, 2008,pp.691–750, https://doi.org/10.1007/978-1-84628-669-8.

[7] Roa López A, Moreu Burgos G, Aguilar Salvatierra A, Fernández Delgado J, Bravo M, González Jaranay M. *Efficacy of dental floss with ellipsoidal knots vs conventional dental floss for plaque removal: A split-mouth randomized* trial. Int J Dent Hyg. 2021 May;19(2):209-214. doi: 10.1111/idh.12473. Epub 2020 Nov 18. PMID: 33001564.

[8] Yankell SL, Shi X, Emling RC. *Efficacy and safety of BrushPicks, a new cleaning aid, compared to the use of Glide floss*. J Clin Dent. 2002; 13: 125-129.

[9] Worthington HV, MacDonald L, Poklepovic Pericic T, Sambunjak D, Johnson TM, Imai P, Clarkson JE. *Home use of interdental cleaning devices, in addition to toothbrushing, for preventing and controlling periodontal diseases and dental caries*. Cochrane Database Syst Rev. 2019; 4: CD012018.

[10] Slot DE, Dörfer CE, Van der Weijden GA. *The efficacy of interdental brushes on plaque and parameters of periodontal inflammation: a systematic review*. Int J Dent Hyg. 2008; 6: 253-264.

[11] Mosquera JE, Goñi ML, Martini RE, Gañán NA. *Supercritical carbon dioxide assisted impregnation of eugenol into polyamide fibers for application as a dental floss*. Journal of CO2 Utilization. 2019 Jul 1;32:259-68.

[12] Matthews, D.Weak, *Unreliable evidence suggests flossing plus toothbrushing may be associated with a small reduction in plaque*. Evid. Based Dent. 2012, 13, 5–6.

[13] Hujoel, P.P.; Cunha-Cruz, J.; Banting, D.W.; Loesche, W.J. *Dental flossing and interproximal caries: A systematic review*. J. Dent. Res. 2006, 85, 298–305.

[14] Van Velzen, F.J.; Lang, N.P.; Schulten, E.A.; Ten Bruggenkate, C.M. *Dental floss as a possible risk for the development of peri-implant disease: An observational study of 10 cases.* Clin. Oral Implants Res. 2016, 27, 618–621

ACKNOWLEDGMENT

This research has been conducted with help of Prof. Dr. Bojan Petrović from Faculty of Medicine, Novi Sad.

FUNDING

This research has received funding from the European Union's Horizon 2020 research and innovation programme under the grant agreement No. 854194.

Authors: **Ksenija Stanojević, Jovana Kalamković, Lazar Milić , Adrian Stavrakis, Sanja Kojić, Nikola Plavac , Goran Stojanović**

[1]University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2350, Fax: +381 21 454-495.

E-mail: ksenijastanojevic@uns.ac.rs
jovanakalamkovic@uns.ac.rs
lmilic@uns.ac.rs
astavrakis@uns.ac.rs
sanjakojic@uns.ac.rs
plavacnikola@uns.ac.rs
sgoran@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Šokac, M., Đurović Koprivica, D., Kuzmanović, M., Santoši, Ž., Vukelić, Đ., Radumilo, D., Budak, I.

PRELIMINARNA STUDIJA ODREĐIVANJA POZICIJE BAZE IMPLANTATA SA CILJEM NJIHOVE ANALIZE I MERENJA

Rezime: *Uzimajući u obzir da se danas veliki broj medicinskih modela digitalizuje primenom neke od metoda 3D digitalizacije, omogućena je jednostavna rekonstrukcija njihovih 3D modela. Međutim, uzimajući u obzir takođe kompleksnost geometrije, kao i poravnavanje iste prilikom dimenzionalnih merenja ili analiza, može da se javi problem poravnavanja njihovih koordinatnih sistema. U ovom radu će biti prikazana preliminarna studija gde je korišćen master model za merenje odstupanja digitalizovanih 3D modela dentalnih otisaka. Pošto je površinski 3D model master modela dobijen 3D digitalizacijom utvrđena je njegova tačna pozicija, kao i pozicija baze implanata primenom metode best-fit. Na ovaj način je omogućena tačna komparacija i merenje odstupanja pozicije 3D modela.*
Ključne reči: *3D digitalizacija, koordinatni sistem, implanti, best-fit metoda*

1. UVOD

3D digitalizacija fizičkih objekata je danas postala globalni fenomen, sa sve većom primenom u oblasti industrije. Razlog tome su svakako sve napredniji komercijalni sistemi za 3D digitalizaciju koji omogućavaju generisanje digitalne 3D geometrije visoke tačnosti i rezolucije. Integracija ovih sistema za 3D digitalizaciju se takođe sprovodi i u oblasti medicine [1]. Uzimajući u obzir kompleksnost ljudske anatomije, sprovođenje adekvatnog poravnavanja geometrije je od krucijalne važnosti za sprovođenje različitih analiza, dimenzionalnih merenja kao i dizajna [2-5].

U okviru ovog rada biće prikazana preliminarna studija slučaja analize preklapanja master modela dentalnih otisaka i merenje odstupanja njegovih digitalizovanih 3D modela. Pošto je površinski 3D model master modela dobijen 3D digitalizacijom utvrđena je njegova tačna pozicija, kao i pozicija baze implantata primenom metode *best-fit*. Na ovaj način je omogućena adekvatna komparacija i merenje odstupanja 3D modela.

2. MATERIJALI I METODE

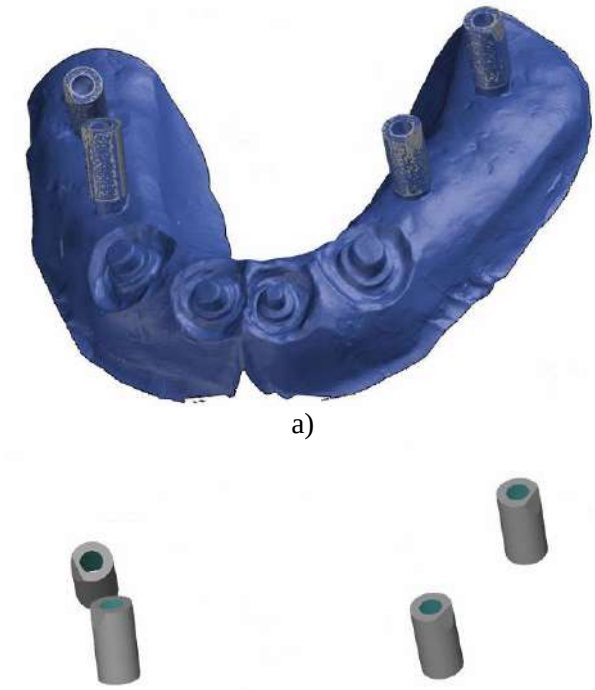
Uzimajući u obzir sve veću kompleksnost digitalizovane geometrije medicinskih modela i implantata postavlja se pitanje adekvatnog poravnavanja digitalizovane geometrije. Cilj poravnavanja rezultuje u sprovođenju daljih analiza i dizajna zamenske anatomske strukture čoveka, te kao takav predstavlja veoma važan korak.

Danas su razvijene različite metode koje se fokusiranju na poravnavanje geometrije 3D modela. Metoda za poravnavanje predstavljena u [6] je zasnovana na dve vrste simetrija modela: reflektivnoj simetriji i lokalnoj translacionoj simetriji. Autori u [7] su se bavili poravnavanjem geometrije na bazi simetrije 3D modela. Adekvatno poravnavanje 3D modela i 2D slika je takođe prikazano u [8]. Uzimajući sve ovo u obzir, može se zaključiti kako se danas mogu naći različite primene metoda za poravnavanje geometrije, i to za potrebe dizajna i izrade kastomizovanih implanata u oblasti maksilofacijalne hirurgije [9], kranijalne hirurgije [10] i dentalne hirurgije [11].

3. MERENJE ODSTUPANJA DIGITALIZOVANOG MASTER MODELA I OTISKA

Kako bi se sprovela studija slučaja, prikupljeni su digitalizovani 3D modeli otisaka donje vilice. Kako bi se mogla izvršiti komparacija digitalizovane geometrije, generisani su master model otiska primenom dentalnog 3D skenera *Identica Blue* (Medit). Master model je u ovom slučaju predstavljao nominalnu geometriju i kao takav je korišćen za merenje odstupanja digitalizovanog 3D modela otiska. Uzimajući u obzir da je sprovedena 3D digitalizacija master modela postavlja se pitanje određivanja tačne pozicije baze angularnih i paralelnih implanta na 3D modelu. Za ovu svrhu primenjen je softver *GOM Inspect* v2021 (GOM GMbH, Nemačka). Kako bi se utvrdila tačna pozicija baze implanta i omogućila tačna komparacija i merenje odstupanja

sa 3D modelom skeniranog otiska izvršen je uvoz 3D modela implanata iz Štraumanove biblioteke i njihovo poravnavanje sa master 3D modelom dentalnog otiska. Kao metoda za poravnavanje je primenjena metoda *best-fit*. Ovaj postupak je ponovljen i za preostale implante. Na slici 1a je prikazano preklapanje implanata sa master modelom, dok je na slici 1b prikazana pozicija poravnatih 3D modela implanata u 3D prostoru.



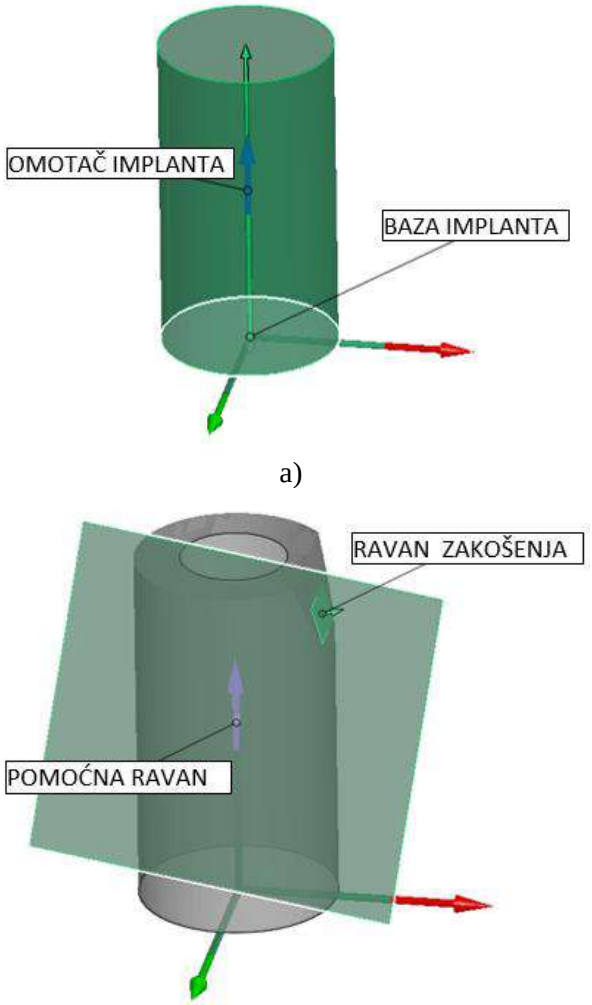
a)

b)

Sl. 1. Prikaz a) pozicioniranja implanata uveženih iz biblioteke sa master 3D modelom i b) prikaz pozicioniranih implanata u 3D prostoru

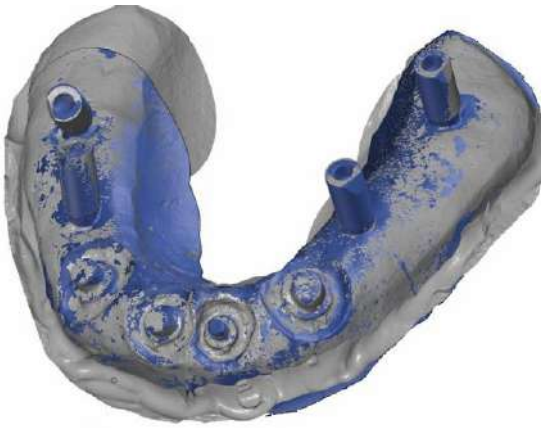
Kako bi se izvršilo njihovo poravnavanje, bilo je potrebno na svakom uvezenom implantu kreirati lokalni koordinatni sistem. Koordinatni početak svih lokalnih koordinatnih sistema je postavljen u centre kružnica koje čine bazu implanta sa sledećom orijentacijom koordinatnih osa (Slika 2a).

Na osnovu slike 2a se može videti da X i Y osa leže u baznoj ravni implanta dok se Z osa poklapa sa osom implanta. Kako bi se u potpunosti moga odrediti pravac ose Y bilo je neophodno kreirati pomoćnu ravan koja sadrži osu implanta i koja je normalna na ravan zakošenja implanta (Slika 2b).



Sl. 2. Prikaz a) orijentacije lokalnog koordinatnog sistema (X,Y,Z) i b) kreiranje pomoćne ravni

Nakon ovog koraka pristupljeno je učitavanju digitalizovanog 3D modela otisaka (siva boja) i njegovo poravnavanje sa master 3D modelom otiska (plava boja) primenom metode *best-fit* (Slika 3).

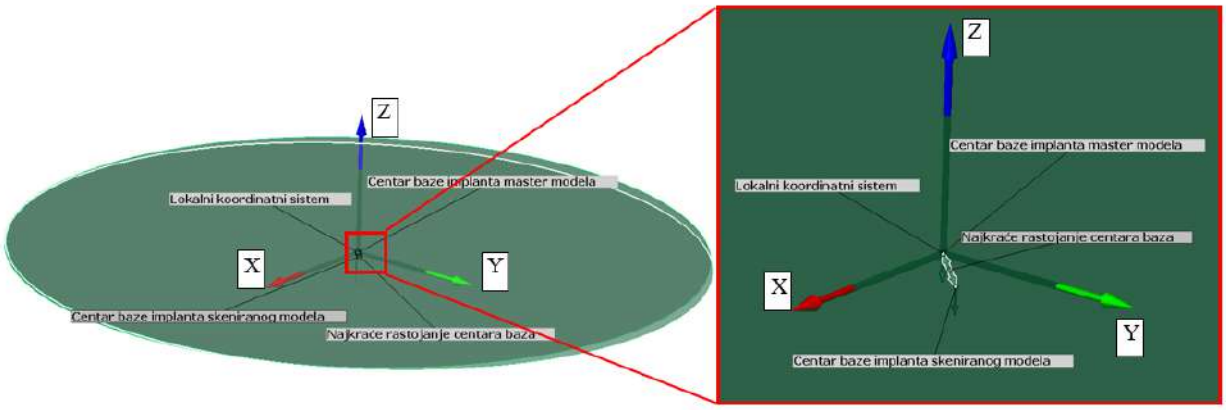


Sl. 3. Primer poravnavanja 3D geometrije digitalizovanog (siva boja) i master 3D modela (plava boja)

Nakon poravnavanja 3D geometrije, pozicionirani 3D model otiska (siva boja) je sačuvan kao novi fajl, a zatim ponovo učitan u novi projekat kao nominalna geometrija. Nakon toga su se učitali i pozicionirali površinski 3D modeli implanta iz Štraumanove biblioteke. Na ovim pozicioniranim implantima su takođe kreirane baze i omotači implanata.

3.1 Analiza odstupanja baze digitalizovanog implanta u odnosu na master model

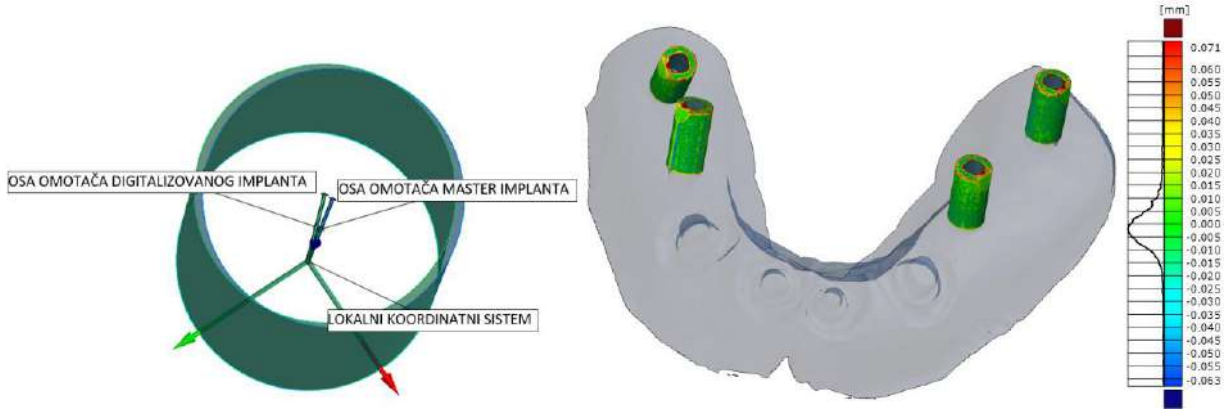
Poravnavanjem 3D geometrije implanata sa master modelom je omogućeno sprovođenje analize gde je izvršeno merenje odstupanja centra baze digitalizovanog 3D modela u odnosu na koordinatni početak odgovarajućeg lokalnog koordinatnog sistema master modela. Ovde su izvršena merenja odstupanja u sve tri ose (X,Y,Z), kao i najkraće rastojanje između centra baze i lokalnog koordinatnog početka (XYZ) (Slika 4).



Sl. 4. Odstupanje baze implanta skeniranog otiska i master modela

3.2 Analiza odstupanja ose omotača digitalizovanog implanta u odnosu na master model

Drugi vid analize je sproveden sa ciljem merenja ose omotača digitalizovanog implanta u odnosu na osu omotača implanta master modela. Ovo je izvršeno proračunom apsolutnog ugla između osa (Slika 5a). Ovom analizom je omogućen detaljniji uvid u poziciju i odstupanje osa omotača oba 3D modela. Slika 5b prikazuje postupak CAD Inspekcije za sva četiri poravnata implanta iz biblioteke, u odnosu na nominalni master model.



Sl. 5. Prikaz a) odstupanja osa omotača digitalizovanog implanta u odnosu na osu omotača implanta master modela i b) CAD Inspekcija implanata

4. ZAKLJUČAK

U radu je prikazana preliminarna studija slučaja određivanja pozicije baze implantata sa ciljem njihove analize i merenja, a na osnovu prethodno pozicionirane geometrije 3D modela iz oblasti stomatologije. Uzimajući u obzir kompleksnost geometrije, poravnavanje iste omogućava sprovođenje naknadnih analiza i merenja dentalnih modela što za rezultat daje mnogo veću sigurnost kada je u pitanju sprovođenje dimenzionalnih analiza, kao i njihove naknadne

hirurške implantacije.

5. REFERENCE

[1] A. Haleem and M. Javaid: *3D scanning applications in medical field: A literature-based review*, Clinical Epidemiology and Global Health, Vol. 7, No. 2, pp. 199–210, 2019.

[2] Q. Xing, R. Han, Y. Li, W. Yang, and J. X. Chen: *Automatically assessing limb alignment and hip fracture using 3D models*, Computing in Science and Engineering, Vol. 15, No. 2, pp. 10–20, 2013.

[3] S. M. Roser, S. Ramachandra, H. Blair, W. Grist, G. W. Carlson, A. M. Christensen, K. A. Weimer, and M. B. Steed: *The accuracy of virtual surgical planning in free fibula mandibular reconstruction: Comparison of planned and final results*, Journal of Oral and Maxillofacial Surgery, Vol. 68, No. 11, pp. 2824–2832, 2010.

[4] W. Sun, B. Starly, J. Nam, and a. Darling: *Bio-CAD modeling and its applications in computer-aided tissue engineering*, Computer-Aided Design, Vol. 37, No. 11, pp. 1097–1114, 2005.

[5] J. Parthasarathy: *3D modeling, custom implants and its future perspectives in craniofacial surgery*, Annals of Maxillofacial Surgery, Vol. 4, No. 1, pp. 9–18, 2014.

[6] M. Chaouch and A. Verroust-Blondet: *Alignment of 3D models*, Graphical Models, Vol. 71, No. 2, pp. 63–76, 2009.

[7] Q. V. Dang, S. Mouysset, and G. Morin: *Symmetry-based alignment for 3D model retrieval*, Proceedings - International Workshop on Content-Based Multimedia Indexing, Vol. 14, pp. 28-34, 2014.

[8] Y. Iwashita, R. Kurazume, T. Hasegawa, and K. Hara: *Fast alignment of 3D geometrical models and 2D color images using 2D distance maps*, Proceedings of International Conference on 3-D Digital Imaging and Modeling - 3DIM, pp. 164–171, 2005.

[9] I. Budak, A. Kiralj, M. Sokac, Z. Santosi, D. Eggbeer, and S. Peel: *Computer-aided methods for single-stage fibrous dysplasia excision and reconstruction in the zygomatico-orbital complex*, Rapid Prototyping Journal, Vol. 25, No. 4, pp. 728–737, 2019.

[10] A. L. Jardini, M. A. Larosa, R. M. Filho, C. A. D. C. Zavaglia, L. F. Bernardes, C. S. Lambert, D. R. Calderoni, and P. Kharmandayan: *Cranial reconstruction: 3D biomodel and custom-built implant created using additive manufacturing*., Journal of cranio-maxillo-facial surgery : official publication of the European Association for Cranio-Maxillo-Facial Surgery, Vol. 42, No. 8, pp. 1877–84, 2014.

[11] I. Budak, S. Mirkovic, M. Sokac, Z. Santosi, T. Puskar, and D. Vukelic: *An approach to modelling of personalized bone grafts based on advanced technologies*, International Journal of Simulation Modelling, Vol. 15, No. 4, pp. 637–648, 2016.

ZAHVALNICA

Rezultati prezentovani u ovom radu su realizovani u okviru projekta "Inovativna naučna i umetnička ispitivanja iz domena delatnosti Fakulteta tehničkih nauka" (broj 451-03-68/2021-14/200156) finansiranog od strane Ministarstva prosvete, nauke i tehnološkog razvoja Republike Srbije.

Rezultati prezentovani u ovom radu su takođe realizovani u okviru projekta „Tačnost otisnih materijala u dentalnoj medicini“ (br. 142-451-3233/2020-02) finansiranog od strane Pokrajinskog sekretarijata za visoko obrazovanje i naučnoistraživačku delatnost.

Autori: **Doc. dr Mario Šokac, Asist. dr Željko Santoši, Prof. dr Đorđe Vukelić, Prof. dr Igor Budak,** Univerzitet Novi Sad, Fakultet Tehničkih Nauka, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2332.
E-mail: marios@uns.ac.rs
zeljkos@uns.ac.rs
vukelic@uns.ac.rs
budaki@uns.ac.rs

Doc. dr Daniela Đurović Koprivica, Miloš Kuzmanović, Danijela Radumilo, Univerzitet Novi Sad, Medicinski fakultet, Hajduk Veljkova 3, 21000 Novi Sad, Serbia, Tel: +381 21 661 2222.
E-mail: daniela.djurovic-koprivica@mf.uns.ac.rs
milos.kuzmanovic021@gmail.com
radumilod@gmail.com

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Kuzmanović, M., Đurović Koprivica, D., Puškar, T,. Jeremić-Knežević, M, Ilić Mićunović, M.

CAD/CAM TEHNOLOGIJA - INOVATIVAN METOD U RESTORATIVNOJ STOMATOLOGIJI

Rezime: *CAD/CAM tehnologija se intenzivno koristi u inženjerstvu zbog svoje visoke preciznosti i tačnosti. Ova tehnologija je uvedena u stomatologiju kasnih 1980-ih i počela je da se koristi u različitim granama stomatologije. U ovom članku pokušavamo da sumiramo neke važne i osnovne informacije o primeni i prednostima CAD/CAM tehnologije u različitim oblastima stomatologije.*
Ključne reči: *CAD/CAM- tehnologija, restaurativna stomatologija, protetika.*

1. UVOD

Pre desetak godina u stomatologiji i stomatološkoj protetici počelo je novo razdoblje. Skoro da se može zaboraviti na plombe ispod kojih karijes buja, ili krunice koje ne traju ni par meseci. Revolucionarna novost zove se CAD/CAM.

CAD/CAM je skraćenica od Computer-Aided Design/Computer-Aided Manufacturing ili u prevodu računarski potpomognuti dizajn (CAD) i računarski potpomognuta izrada (CAM). To su su relativno novi pojmovi u stomatologiji i oni se zapravo odnose na softver koji stomatolozima omogućava brže, lakše i tačnije obavljanje složenih procedura [1, 2].

Temelji se na kompjuterskim 3D programima pomoću kojih se izrađuju savršene zubne nadoknade, krunice, mostovi, fasete, inleji, onleji, overleji, endokrune, viniri, kao i krune na implantu. Pri tradicionalnim načinima izrade protetskih nadoknada bilo je nemoguće izbeći greške zbog tesnog i oku teško dostupnog radnog polja. Pomoću ove tehnologije sve se radi izvan zubne šupljine pri čemu složeni kompjuterski softver ispravlja eventualne ljudske greške.

2. ISTORIJA CAD/CAM SISTEMA

Iako je CAD/CAM sistem u stomatologiji korišćen još sredinom 1980-ih, rani napori su smatrani prevelikom novinom, zahtevajući prekomernu količinu vremena da bi se napravio isplativ proizvod. Ova neisplativost je sprečila korišćenje CAD/CAM sistema u ordinacijama i ograničila ove sisteme na stomatološke laboratorije. Kao pomoć u tehničkim laboratorijama, sa poboljšanim softverom i materijalima koji su to pratili, upotreba CAD/CAM tehnologije u ordinacijama se povećala.

CAD/CAM tehnologija je inovativan metod u restaurativnoj stomatologiji i protetici. Ova tehnologija je u stomatologiji zauzela veoma važno mesto u izradi visoko preciznih bezmetalnih keramičkih krunica, ali i drugih keramičkih nadoknada. Takođe, CAD/CAM tehnologija se koristi i u izradi odgovarajućih ortodontskih aparata i hirurških vođica u implantologiji [3, 4].

Kompjuterski potpomognuto projektovanje i proizvodnja razvijeni su 1960-ih za upotrebu u avionskoj i automobilskoj industriji [3]. U stomatologiju, CAD/CAM tehnologija je uvedena 1989. godine od strane kompanije Mormann & Brandestinni u Nemačkoj i danas se široko koristi u svim granama protetike [5, 6]. Tokom proteklih godina, CAD/CAM tehnologija je postala izuzetno popularna [2]. Uvođenje i evolucija CAD/CAM tehnologije u stomatologiji je u velikoj meri promenila koncepte lečenja i izradu proteza.

Uz pomoć CAD/CAM sistema, izrada krunice je jednostavnija i brža, dok je procedura izrade krunica skraćena, uz mnogo veći komfor za pacijenta.

3. PROCES IZRADE CAD/CAM ZUBNIH NADOKNADA

CAD je sistem softverskog dela, to jest planiranje računarskim upravljanjem. Na monitoru kompjutera pojavljuje se senzorima opipan gipsani model, po kojem se izrađuje digitalni model, nakon čega se planira nadoknada, što može da bude krunica ili most. Time se osigurava savršeno i tačno prijanjanje restaurirane tvorevine.

CAM - ovaj sistem je deo “realizacije”, takođe, pomoću upravljanja računarom.
Jedna frez mašina, predhodno isplanirani skelet krunice ili mosta, izrađuje od odgovarajućeg materijala.

Obično se CAD/CAM zubne nadoknade prave od čvrstih blokova keramike ili kompozita koji

najviše odgovaraju osnovnoj boji zuba koji se rekonstruiše. Nakon preparacije i pripreme delova zuba od strane stomatologa, u zavisnosti od primenjenog sistema, uzima se otisak. Naime, slika se (skenira se) ili gipsani model ili, kao što je slučaj sa CEREC sistemom, skeniraju se preparisani i okolni zubi u ustima pacijenta. Ova slika, pod nazivom digitalni otisak, šalje podatke u računar. Nakon toga, originalni 3D softver stvara zamenu za deo nedostajućih delova zuba, stvarajući virtuelnu restauraciju. Softver šalje ove virtuelne podatke ka glodalici tj. mašini koja svojim sistemom rada podseća na tzv. CNC glodalicu koja se koristi u mašinskoj industriji. U okviru glodalice nedostajući deo zuba biva isklesan iz čvrstog bloka od keramike ili kompozita. U peći za glaziranje pomoću različitih pigmenata se postiže individualizacija restauracije. Naime, mrlje i glazura na povr¬šinama izrađenih keramičkih nadoknada mogu ispraviti inače monohromatski izgled restauracije. Restauracija se zatim prilagođava u ustima pacijenta i cementira.

Nakon kliničkog pregleda i pripreme zuba, za samo nekoliko minuta, vrši se skeniranje pripremljenog zuba i njegovog odnosa sa susednim zubima. Ovako dobijena slika naziva se digitalni otisak i ona zamenjuje fazu otiskivanja otisnim masama prilikom standardne izrade krunice. Softver koristi digitalni otisak zuba i predlaže dizajn nadoknade za deo zuba koji je potrebno rekonstruisati. Predloženi dizajn se dodatno može kompjuterski individualizovati i napraviti savršenim u funkcionalnom i estetskom smislu.

Kada je dizajn završen, vrši se odabir vrste keramike za odgovarajuću nadoknadu i softver prosleđuje informacije mašini za rezanje u kojoj će keramički blok biti izrezan u obliku prethodno dizajnirane keramičke nadoknade. Sledi proba nadoknade od nekoliko minuta, tačno definisanje boje i ponovna pauza za pacijenta za vreme faze karakterizacije boje nadoknade. Nakon toga, nadoknada je spremna za fiksiranje.

Ovakva procedura smanjuje mogućnost grešaka, omogućava da se dobiju nadoknade visoke preciznosti i odličnih estetskih karakteristika. Za izradu jedne ovakve nadokndade CAD/CAM sistemom potrebno je samo par sati. Nešto više vremena je potrebno u situacijama kada se rade veće protetske rekonstrukcije [7].

Kompjuterski potpomognut dizajn i kompjuterski potpomognuta izrada pojavili su se kao novi pristup projektovanju i u izradi totalnih proteza [8]. Iako je upotreba CAD/CAM tehnologije do nedavno bila ograničena u proizvodnji totalnih proteza zbog nedostatka odgovarajućeg CAD softvera [9], CAD/CAM totalnih proteza je uveden nakon postignutih uspeha ove tehnologije u implantološkoj i fiksnoj protetici [10].

4. PREDNOSTI CAD/CAM RESTAURACIJA U ODNOSU NA KONVENCIONALNE RESTAURACIJE

Ordinacijska CAD/CAM restauracija razlikuje se od konvencionalnog načina izrade nadoknada u stomatologiji po tome što nadoknada u slučaju primene CAD/CAM sistema bude gotova istog dana.

Pacijenti kojima se izrađuju konvencionalne nadoknade, kao što su krunice, imaju privremene krunice postavljene od jedne do nekoliko nedelja na zbrušene zube, sve dok se u zubotehničkoj laboratoriji ne izradi definitivna krunica. Nakon što je krunica izrađena, pacijentu se uklanjaju privremene krunice, a laboratorijski izrađene krunice se cementiraju.

U ordinaciji, CAD/CAM sistem omogućuje stomatologu da inlej ili bilo koja druga nadoknada bude gotova za samo sat vremena u nekim slučajevima. CAD/ CAM restauracije su konzervativnije u pogledu pripreme zuba. Pošto je vezivanje nadoknade kvalitetnije za gleđ nego za dentin zuba, treba voditi računa da se ne ukloni sloj gleđi tokom brušenja

5. CAD/CAM TEHNOLOGIJA U FIKSNOJ PROTETICI

Matrica za preparaciju zuba je osigurana u platformi za skeniranje i podaci se snimaju beskontaktnim laserom. U komoru za mlevenje postavlja se keramički blok (ingot). Dva dijamanta za glodanje stvaraju preciznu restauraciju. Vrši se nadogradnja porcelana što rezultira estetski pogodnom restauracijom. Zatim se potvrđuje prijanjanje u ustima pacijenta i vrše se potrebna podešavanja.

6. CAD/CAM TEHNOLOGIJA U MAKSILOFACIJALNOJ PROTETICI

CAD/CAM se veoma često koristi za izradu maksilofacijalnih proteza, uređaja za ekstraoralno zračenje, individualnih respiratornih maski i uređaja za zaštitu lica.

Snimanje trodimenzionalnih površina se vrši korišćenjem CAD softvera. Ova 3-D slika površine pomaže u izradi modela od smole litografskom tehnikom.

Od završenog voštanog uzorka, ponovo se izvodi kompjuterski potpomognuto

trodimenzionalno snimanje. Podaci se unose kompjuterski i proteza se gloda kompjuterski podržanom glodalicom. Tako se silikonska maksilofacijalna proteza proizvodi korišćenjem CAD/CAM tehnologije.

7. CAD/CAM TEHNOLOGIJA U IZRADI PARCIJALNIH PROTEZA

Izrada livenih parcijalnih proteza može se obaviti korišćenjem kobalt-hrom legura ili komercijalno čistog titanijuma i legure Ti-6Al-4V korišćenjem CAD/CAM tehnologija.

Williams i saradnici su demonstrirali metodu izrade konstrukcije okvira parcijalne zubne proteze korišćenjem CAD/CAM tehnologija. Koristeći CAD/CAM softver, dizajn okvira za ovaj tip proteza zasnovan je na trodimenzionalnom skeniranju [11, 12].

8. CAD/CAM TEHNOLOGIJA U IMPLANTOLOŠKOJ PROTETICI

Upotreba računara pri postavljanju implantata (navigaciona tehnika) se povećala u poslednjoj deceniji. Nedavno, uz upotrebu CAD/CAM tehnologije, mogu se proizvesti krunice specifične za pacijenta. Ove CAD/CAM napravljene i prilagođene krunice su dizajnirane računarom i proizvedene na računarskim mašinama za postizanje nenadmašne tačnosti i preciznosti. Pošto su izrađene od mlevenog medicinskog titanijuma, imaju superiornu biokompatibilnost i najbolju moguću integraciju sa implantatima.

CAD/CAM napravljene i prilagođene krunice imaju prednosti kao što su: preciznost, brušene su od titanijuma, idealna krunska priprema, ispravan put umetanja, savršen profil izbijanja, osovina implantata pod uglom od 6° oblikovana kao prirodni zub i smanjeno vreme koje pacijent provede „u stolici“ [13].

9. ZNAČAJ PRIMENE CAD/CAM SISTEMA

U tradicionalnim restauracijama, porcelan se u slojevima postavljao na metalnu osnovu, zbog čega se često videla mlečno bela boja veštačkih zuba zbog sloja opakera koji se koristio da zamaskira sivu boju metala, i „čuvenu” tamnu liniju oksida, u blizini linije desni. Kako ove tamne metalne konstrukcije nisu doprinosile prirod¬nom izgledu, bezmetalna restauracija se obično preporučivala kao više estetska za pacijenta.

Samo feldspat, litijum disilikat i neki kompozitni materi¬jali su “radio-prozirni”, tj. ne blokiraju x zrake, što stomatolozima omogućava praćenje potencijalnog propadanja nadoknade. Cirkonijum, konvencionalni metali, zlato i tradicionalne metal-keramičke krune blokiraju rentgensko zračenje, onemogućavajući evaluaciju nadoknade i zuba nosača tokom vremena.

Konačno, preciznost nadoknada koje koriste CAD/CAM tehnologiju je mnogo veća u odnosu na druge stomatološke nadoknade koje se proizvode klasičnim metodama. Krunice i mostovi zahtevaju izuzetno precizno uklapanje u odnosu na potporne zidove zbrušenog zuba. Preciznost skeniranja i matematički proračun površine zbrušenog zubnog patrljka je izuzetna. Trenutni standardi zahtevaju preciznost manju od 10 mikrona, što znači da je odstupanje od savršenog manje od deset hiljaditih delova milimetra. Trenutno, nema ručno izrađenog proizvoda koji može postići ovakvu preciznost bez pomoći CAD/CAM sistema u procesu izrade.

Od CAD/CAM sistema koji su najzastupljeniji na tržištu mogu se izdvojiti CEREC sistem, koji je proizvela nemačka firma Sirona. Uz poboljšani, najnoviji softver i veliki izbor različitih blokova keramike mogućnosti ove mašine su izuzetne. Naime, moguće je u jednom danu rekonstruisati velika ošte¬ćenja na zubima, velike amalgamske plombe zameniti gotovo neuništivim keramičkim inlejima i onlejima, koji u potpunosti rekonstruišu morfologiju zuba. O preciznosti svega ovoga suviš¬no je raspravljati jer međuzubne kontakte kao i tzv. naleganje nadoknade određuje računar. S druge strane, preskaču se neke faze, kao što su klasično otiskivanje pomoću testastih otisnih masa, koje predstavljaju neprijatnost za pacijente sa izraženim nagonom za povraćanjem, kao i čuvene „probe metala”.

Naravno, mašina deluje savršeno, ali neophodno je da stomatolog sa velikim iskust¬vom iz stomatološke protetike pripremi zub na odgovarajući način, jer i najmanju grešku u brušenju i pripremi sistem će registrovati i buduća nadoknada neće biti tako savršena.

10. REFERENCE

[1] Tamrakar, A., Rathee, I., Mallick, R., Dabas, S.: *CAD/CAM in Prosthodontics - A Futuristic Overview*. Annals of Dental Specialty. Volume 2, pp. 14-20, 2014..

[2] Al Essa, H.A.: *CAD/CAM in prosthodontics: A gate to the future*, International Journal of Applied Dental Sciences , Volume 5, pp. 394-397, 2019.

[3] Davidowitz, G., Kotick, P.G.: *The use of CAD/CAM in dentistry*. Dent Clin North Am, pp. 559-570, 2011.

[4] Rekow, D.: *Computer-aided design and*

manufacturing in dentistry: a review of the state of the art, J Prosthetic Dent., Volume 58, pp. 512-516, 1987.
[5] Goodacre, C., Garbacea, A., Naylor, W., Daher, T., Marchack, C., Lowry, J.: *CAD/CAM fabricated complete dentures: concepts and clinical methods of obtaining required morphological data*, J Prosthetic Dent., Volume 107, pp. 34-46, 2012.
[6] Mormann, W.: *The evolution of the CEREC system*, J Am Dent Assoc. Volume 137, pp. 7-13, 2006.
[7] Srinivasan, M., Cantin, Y., Mehl, A., Gjengedal, H., Muller, F., Schimmel, M.: *CAD/CAM milled removable complete dentures: an in vitro evaluation of trueness*, Clin Oral Investig, Volume 21, pp. 2007-2019, 2017.
[8] Infante, L., Yilmaz, B., McGlumphy, E., Finger, I.: *Fabricating complete dentures with CAD/CAM technology*, J Prosthet Dentistry, Volume 111, pp. 351-355, 2014.
[9] Pascu, N., Dobrescu, T., Opran, C., Enciu, G.: *Realistic scenes in CAD application*, Proc Eng, Volume 69, pp. 304-309, 2014.
[10] Ettinger, R., Beck, J., Jakobsen, J.: *Removable prosthodontic treatment needs: a survey*. Prosthet Dent. Volume 51, pp. 419-427, 1984.
[11] Bibb, R., Eggbeer, D., Williams, R.J.:. *Rapid manufacture of removable partial denture frameworks*, Rapid Prototyping Journal, Volume 12, pp. 95-99, 2006.
[12] Williams, R.J., Bibb, R., Eggbeer, D., Collis, J., et al. *Use of CAD/CAM technology to fabricate a removable partial denture framework.* J Prosthet Dent, Volume 96, pp. 96-99, 2006.
[13] Marchack, C.B., *An immediately loaded CAD/CAMguided definitive prosthesis: A clinical report.* J Prosthet Dent, Volume 93, pp. 8-12, 2005.
[14] Bibb, R., Eggbeer, D., Evans, P., Bocca, A., Sugar, A.: *Rapid manufacture of custom-fitting surgical guides*, Rapid Prototyping Journal, Volume 15, pp. 346-354, 2019.

Autori: **Dr Miloš Kuzmanović[1], Doc. dr Daniela Đurović Koprivica[1], Prof. dr Tatjana Puškar[1], Dr Milica Jeremić Knežević[1], Doc. dr Milana Ilić-Mićunović[2]**

[1] Univerzitet u Novom Sadu, Medicinski fakultet, Hajduk Veljkova 3, 21000 Novi Sad, Serbia, Tel: +381 21 6420 677.
E-mail: milos.kuzmanovic021@uns.ac.rs
daniela.djurovic-koprivica@mf.uns.ac.rs
tatjana.puskar@mf.uns.ac.rs
milica.jeremic-knezevic@mf.uns.ac.rs

[2] Univerzitet u Novom Sadu, Fakultet tehničkih nauka, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia, Tel: +381 21 450 810.
E-mail: milanai@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Đurović Koprivica, D., Puškar. T., Jeremić Knežević. M., Milekić, B., Maletin, A, Kuzmanović, M.

PRIMENA OPTIČKIH LUPA U STOMATOLOGIJI

Rezime: *Ograničena vidljivost, male dimenzije oralnih struktura i vremenska ograničenja kojima su stomatolozi izloženi u svakodnevnoj kliničkoj praksi uzrokuju zanemarivanje pravilnog položaja tela pri radu. To dovodi do problema sa kojim se bori većina stomatologa u nekom trenutku svoje karijere kao što su hronični bolovi u ledjima sa manjim ili većim posledicama po njihovo opšte zdravlje. Optičke lupe pružaju kliničaru jasno i pregledno radno polje, uz istovremeno ergonomski pravilno držanje. Kako bi ova optička pomagala doprinela poboljšanju kvaliteta stomatološke prakse, neophodno ih je pravilno odabrati i adekvatno koristiti. Najvažnije su tehničke karakteristike optičke opreme i njihov odgovor zahtevima svakodnevne upotrebe.*

Ključne reči: *optičke lupe, optička pomagala, optička oprema, stomatologija*

1. UVOD

Napretkom moderne stomatologije u svetu i kod nas, dolaze do sve većeg izražaja nove sfere mikrostomatologije. Mikrostomatologija, kao relativno nova disciplina u ovoj oblasti, podrazumeva izvođenje stomatoloških terapeutskih procedura uz korišćenje specijalno dizajniranih optičkih pomagala. Lupe, kao najčešće korišćena optička pomagala, postaju deo svakodnevnice u stomatološkoj praksi, posebno u Zapadnoj Evropi i Severnoj Americi. Velika prednost je ta što uvećavaju radno polje, odnosno strukturu radnog polja, a u direktnoj su korelaciji sa ergonomijom. Naime, prilikom rada sa lupama kliničar ima jasnije i preciznije vidno polje bez potrebe da se približava pacijentu pri čemu zadržava neutralan, ergonomski položaj. Istraživanja su pokazala da stomatolozi koji koriste lupe u svom svakodnevnom radu znatno manje pate od zamora u leđima i kičmi [1, 2]. Optička pomagala takođe povećavaju i nivo kvaliteta stomatološke usluge, stepen produktivnosti i sigurnosti stomatologa u efikasnost i preciznost sprovedenog stomatološkog tretmana. U optička pomagala ubrajamo optičke lupe, mikroskope i LCD-ekrane. Tokom poslednje dekade razvoj optičkih pomagala je pokazao izuzetan napredak. Međutim, veoma važna je i edukacija kliničara o njihovoj pravilnoj primeni, kao i određeno vreme prilagođavanja da bi se ispoljio njihov potpun pozitivan efekat [3].

2. ISTORIJAT I OPŠTE KARAKTERISTIKE OPTIČKIH LUPA

2.1 Istorijat

Lupa je optički instrument kojim se uvećava slika predmeta, onoliko puta koliko je puta uvećan ugao pod kojim vidimo predmet prostim okom u daljini jasnog vida. Upotrebljava se za uvećavanje i posmatranje predmeta malih dimenzija radi njihovog proučavanja, da bi se lakše obrađivali, da bi se po njima pisalo i sl. Upotrebljava se u nauci, umetnosti, proizvodnji, instustriji. Aristofanov objektiv- lupa iz 424 godine p. n. e. je staklena kugla ispunjena vodom koja je, kao alternacija bikonveksnom sočivu mogla da uveličava. Bejkon je opisao osobine lupe u 13. veku u Engleskoj, a naočare su razvijene takođe u 13. veku u Italiji.
Prve hirurške lupe datiraju iz davne 1876. godine kada je nemački oftalmolog koristio par konveksnih sočiva sa izvorom svetlosti postavljenim na traku za glavu. Uvećanje je u hirurgiji je među prvima upotrebio u otologiji američki hirurg Najlen 1920-ih godina, a 1960-ih godina su Suarez i Jacobsen doveli mikrohirurgiju do velikog napretka dokazavši vrednost operativnog mikroskopa u mikroanastomozama [3, 4].

2.2 Opšte karakteristike

Zakon optike- refrakcije omogućava da predmet određenih dimenzija koji se postavi na odgovarajuću udaljenost između sočiva tj. lupe, i njene žiže, odnosno fokusa, u oku posmatrača pruži prividnu (virtuelnu), uvećanu sliku posmatranog predmeta. Kako je daljina jasnog vida konstanta, povećanje lupom zavisi jedino od žižne daljine sočiva. Žižna daljina sočiva je direktno proporcionalna zakrivljenosti površine sočiva. Zakrivljenost površine sočiva se iscrpljuje tehničko-tehnološkim mogućnostima izrade takvih sočiva. Sa jedne strane, nemoguće bi bilo napraviti lupu sa tako malim žižnim daljinama i tako

velikim povećanjima, jer bi trebalo napraviti sočiva vrlo malih prečnika zakrivljenosti, a sa druge strane, i kada bismo ih i uspeli napraviti, tako velika zakrivljenost bi proizvodila ogromne greške sočiva koje ni složeni sistemi sočiva ne bi mogli da kompenzuju. Jednostavnije rečeno, slike predmeta dobijene takvim lupama bile bi potpuno neupotrebljive. Lupe imaju najmanju žižnu daljinu od 2 centimetra. Znači maksimalno uvećanje lupom je oko 12 puta [5, 6, 7].

3. OPTIČKE LUPE U STOMATOLOGIJI

Lupe u stomatologiji su od izuzetne pomoći jer omogućavaju pre svega bolju vidljivost radnog polja i sitnih detalja što umnogome olakšava rad terapeutu, postavljanje dijagnoze i precizniju upotrebu instrumenata. Takođe, nošenje ove vrste pomagala lekaru obezbeđuje bolje držanje tela i komforniji rad. Dakle, glavne funkcije optičkih lupa za operativnu stomatologiju su poboljšavanje vizuelizacije sitnih detalja, nadoknađivanje gubitka vida na blizu i osiguravanje ispravnog držanja. Nošenje lupa polako postaje prihvaćena norma među kvalifikovanim praktičarima [1, 2, 3].

Mnogi stomatolozi svakodnevno koriste optičke lupe za klinički rad. Međutim, kliničari se moraju pozabaviti problemima vezanim za potencijalne rizike za oko, kada se lupe nose kratkoročno i kada se nose tokom čitavog radnog veka lekara. Ukoliko se lupe ne koriste u praksi to predstavlja vidni nedostatak terapeutu, a može doprineti hroničnim mišićno-koštanim problemima zbog lošeg držanja [1, 2, 6, 8].

Komponente lupa koje su bitne za korisnike su:

1. Vidno polje;
2. Dubina polja;
3. Deklinacija ili ugao gledanja;
4. Individualni dizajn lupe

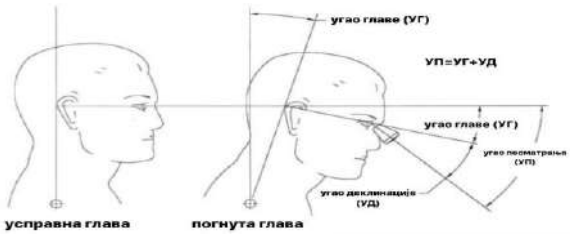
Vidno polje, poznato i kao širina polja, je veličina slike ili prečnik polja ciljanog područja pri korišćenju lupa. Zubne lupe sa širim vidnim poljem imaju veću dubinu polja i duži radni razmak. Dok one lupe sa užim vidnim poljem imaju veći faktor uvećanja. Drugim rečima, povećanjem uvećanja, smanjuje se polje koje posmatramo. Postoje lupe koje vidno polje povećavaju do 8 puta. Međutim, u praktičnom smislu, uvećanje od 2 – 2.5 puta omogućava stomatolologu da može da vidi više kvadrantnih područja (slika 1). Ovo je uvećanje koje se obično koristi u opštoj stomatološkoj praksi i ono je optimalno. Pri uvećanjima od 3.5 puta polje postaje ograničeno na jedan kvadrant, sa većim uvećanjem vidno polje je sve ograničenije dok u fokusu ne ostane samo jedan zub. To ga čini prevelikim i neprikladnim za rutinsku operativnu stomatologiju, ali je korisno kada se preduzimaju posebni postupci poput endodoncije.

Sl. 1. Vidno polje

Dubina polja ili dubina pogleda (slika 2) je raspon fokusa ili dubina područja koja je vidljiva pri radu sa lupom. To je merenje koliko blizu se može prići, ali da se i dalje jasno vidi ciljno područje. Dubina polja odnosi se na sposobnost sistema sočiva da se fokusira i na bliže i na daleke predmete, a da ne mora da menja položaj. Za normalan vid, to se kreće od radne daljine do beskonačnosti. Veličina dubine prikaza ili dubine polja direktno je povezana sa radnom rastojanjem i faktorom uvećanja. Drugim rečima, što je dubina polja veća, to će biti duži radni razmak i obrnuto. Isto tako, što je veća dubina polja, manji je faktor uvećanja i obrnuto.

Sl. 2. Dubina polja

Ugao deklinacije (slika 3) tj. posmatranja je ugao pod kojim se sočivo postavlja na vodoravnu referentnu ravan povučenu od gornje ivice spoljašnjeg otvora ušnog kanala do mosta nosa i određuje liniju vida. Prilikom rada, što je veći ugao u odnosu na ovu liniju, to je veći nagib vrata potreban za pregled predmeta. Ergonomski je važno odrediti da li je ovaj ugao pravilan za terapeuta, kako bi se smanjilo naprezanje na vratu, leđima i ramenima. Preferira se 20 stepeni ili manji ugao nagiba jer omogućava minimalno držanje glave napred [4, 6, 7].



Sl. 3. Ugao deklinacije

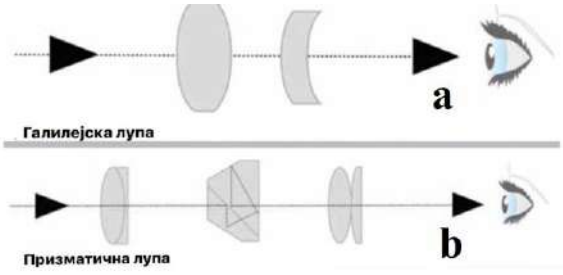
4. VRSTE OPTIČKIH LUPA

Postoje dva osnovna sistema optičkih lupa, Galilejske i Keplerske - prizmatične lupe.

Galilejski sistem nudi opseg uvećanja od 2 x do 4,5 x i mali je, lagan i veoma kompaktan sistem. Lupe sa prizmom (Keplerian sistem) koristi vatrostalne prizme koje su zapravo teleskopi sa složenim putanjama svetlosti koje pružaju, a uvećanje je do 6 puta. Oba sistema proizvode gornje uvećanje, ispravno sferično i hromatske aberacije, imaju odličnu dubinsku oštrinu i imaju sposobnost povećanja žižne daljine (30-45 cm), koja smanjuje naprezanje očiju, umor i bol u vratu [4, 5, 6, 7].

Kod Galilejskog sistema praktični opseg uvećanja je ograničen na 3.5 puta ili manje, jer je sistem ograničen sfernom aberacijom i ravnanje polja odozgo na dole i sa leva na desno narušava kvalitet slike kako se uvećanje povećava. Svi sistemi Galilejskih sočiva (slika 4a) proizvode halo efekat na periferiji vidnog polja, koji u nekim slučajevima može smetati. Oni su, međutim, relativno lagani, jeftini i češće se koriste.

Prizmatične lupe pružaju najviši optički kvalitet koji je dostupan danas. Ove lupe (slika 4b) omogućavaju poboljšani kvalitet uvećanja, šire vidno polje i povećavaju dubinu polja. Njihov princip rada jeste da se sastoje on mnoštva sitnih prizmi koje prelamaju svetlost. Mogu se koristiti za sve nivoe uvećanja. Nedostaci su što su teže, imaju duge cevi i skuplje su [6, 7].

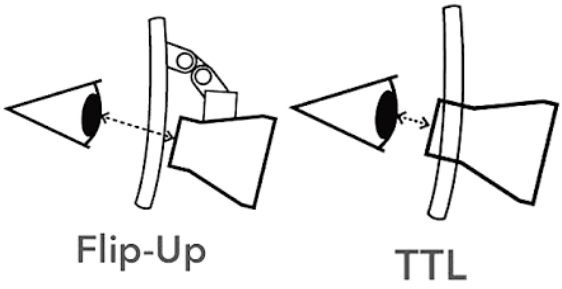


Sl

Sl. 4. a) Galilejske lupe; b) Prizmatične lupe

Dve najčešće konfiguracije optičkih lupa koje se koriste u stomatološkoj praksi su tzv. *flip-up* oprema (slika 5a), za koju je karakteristično da se okulari montiraju na okvir i po potrebi dižu i spuštaju i TTL (*Through the Lens*) oprema (slika 5b) kod koje su okulari fiksirani za okvir [7, 8, 9, 10].

Fiksirani okulari kod TTL opreme kompletiraju se individualno prema specifičnim potrebama lekara i učvršćuju se permanentnim lepkom za čeoni nosač ili okvir. Prednosti TTL opreme u odnosu na flip-up opremu su sledeće: - optika je trajno podešena i neće tokom upotrebe izaći iz fokusa; - oprema je bolje balansirana i pogodnija za nošenje; - oprema je lagana i - oprema omogućuje šire vidno polje jer se sočivo nalazi bliže oku. TTL oprema je slična bifokalnim naočarima za čitanje tako da se na daljinu gleda preko sočiva, bez uvećanja, dok se kroz ugrađena sočiva gleda u usnu duplju pacijenta iz blizine. Danas postoji i hibridni model koji podrazumeva TTL opremu koja se kači na okvir pomoću žabice sa oprugom, nalik na specijalno dizajnirane naočare za sunce kod kojih se samo jednim dodirom stakla podižu u horizontalan položaj [9, 10].



a) **b)**

Sl. 5. a) flip-up lupe; b) TTL lupe

Kod flip-up opreme, okulari koji se kače na okvir mogu se podešavati prema potrebi. Lekari koji inače koriste oftamološka pomagala sa velikom dioptrijom ili bifokalne naočare radije se odlučuju za korišćenje flip-up opreme, jer ih, kada nemaju potrebu za korišćenjem okulara, jednostavno podignu da im ne smetaju. Flip-up oprema zbog težine okulara blago preteže unapred, što može biti i uzrok povremenog ispadanja iz fokusa. Važna napomena za korisnike flip-up opreme jeste da obavezno zategnu sigurnosnu traku oko glave tokom nošenja okulara. Ako traka nije dobro zategnuta, okulari će se činiti težim, neprikladnim za nošenje, a mogu i da klize niz nos. Ovaj tip opreme može se montirati na različite ramove. Ukoliko dođe do pogoršanja vida lekara, potrebna promena dioptrije u flip-up okularima biće jednostavna. Danas je poseban hibridni model TTL opreme koji se može podizati na dodir, a koji ima i dodatni uložak za sočivo sa dioptrijom koji se koristi po potrebi, postao popularan zbog dodatne fleksibilnosti [8, 9, 10].

5. DISKUSIJA

U prednosti lupa ubrajamo ergonomske, optičke, poboljšanje nege pacijenta kao i izdržljivost terapeuta.

Ergonomske prednosti obuhvataju sve karakteristike pomagala koje se prilagođavaju čovekovim bio-psiho-socijalnim zahtevima kako

bi upotreba pomagala bila efikasnija, bezbednija i pouzdanija. Kod mnogih stomatologa se razvija hronični bol u leđima i vratu. Ispravno operativno držanje postaje dvostruko važno za stomatologa koji koristi lupe, jer je održavanje poprečne ose oka u vodoravnoj ravni od suštinskog značaja. Operater to postiže pomeranjem pacijenta u vertikalnoj ravni [1, 2, 6].

Nema sumnje da je upotreba optičkih pomagala sve popularnija kako kliničke tehnike postaju sve zahtevnije. Neke studije su pokazale da se broj, obim i smer linija loma zuba mogu lako utvrditi pomoću uvećanja, a druge studije da uvećanje može značajno poboljšati tačnost dijagnoze karijesa u izvađenim zubima in vitro [8, 9].

Upotreba lupa omogućava kliničaru da izvodi procedure sa većom preciznošću i lakoćom. Klinička istraživanja potvrđuju da uvećanje dovodi do manje invazivne, a konzervativnije nege što rezultuje većim poverenjem pacijenta [6, 7, 8].

Primena lupa u svakodnevnom kliničkom radu omogućava kliničaru manje naprezanje očiju, kao i smanjenje stresa u mišićima oka čime se smanjuje pojava inače čestih migrenskih glavobolja kod stomatologa i utiče na poboljšanje opšteg zdravlja [7].

6. ZAKLJUČAK

Zahtevi koji stoje iza moderne minimalno invazivne stomatologije utiču na sve učestaliju primenu optičkih pomagala u svakodnevnom stomatološkom radu. Sistemi za uvećanje posmatranih objekata osim što omogućavaju kliničaru jasno i pregledno radno polje, takođe utiču i na veoma bitnu štednju zdravog zubnog tkiva, obezbeđujući bolju vizuelizaciju promenjenog tkiva. Ergonomske prednosti optičkih sistema su neprikosnovene i razlog zbog kojeg se kliničari sve intenzivnije odlučuju na ovaj vid praktičnih pomagala pri izvođenju određenih terapijskih procedura.

7. REFERENCE

[1] Alshouibi EN, Almansour LA, Alqurashi AM, Alaqil FE. *The Effect of Number of Patients Treated, Dental Loupes Usage, Stress, and Exercise on Musculoskeletal Pain among Dentists in Jeddah*. J Int Soc Prev Community Dent. 2020 Apr 30;10(3):336-340.

[2] Valachi B. *Magnification in dentistry: how ergonomic features impact your health*. Dent Today. 2009 Apr;28(4):132, 134, 136-7.

[3] van As G. *Magnification and the alternatives for microdentistry*. Compend Contin Educ Dent. 2001 Nov;22(11A):1008-12, 1014-6.

[4] McClelland E, Marzouk S, Coyle P, Tatla T. *Optical Loupes: A Useful Tool for the Oncall Otorhinolaryngologist-Our Experience*. Indian J Otolaryngol Head Neck Surg. 2019 Oct;71(Suppl 1):137-141.

[5] Urlic I, Pavan J, Verzak Z, Karlovic Z, Negovetic Vranic D. *The Best Dentistry Professional Visual Acuity Measured under Simulated Clinical Conditions Provides Keplerian Magnification Loupe: A Cross-Sectional Study*. Dentistry Journal. 2021; 9(6):69.

[6] Ludwig EA, McCombs GB, Tolle SL, Russell DM. *The Effect of Magnification Loupes on Dental Hygienists' Posture while Exploring*. J Dent Hyg. 2017 Aug;91(4):46-52.

[7] James T, Gilmour AS. *Magnifying loupes in modern dental practice: an update.* Dent Update. 2010 Nov;37(9):633-6..

[8] Braga T, Robb N, Love RM, Amaral RR, Rodrigues VP, de Camargo JMP, Duarte MAH. *The impact of the use of magnifying dental loupes on the performance of undergraduate dental students undertaking simulated dental procedures*. J Dent Educ. 2021 Mar;85(3):418-426.

[9] Low JF, Dom TNM, Baharin SA. *Magnification in endodontics: A review of its application and acceptance among dental practitioners*. Eur J Dent. 2018 Oct-Dec;12(4):610-616.

[10] Farook SA, Stokes RJ, Davis AK, Sneddon K, Collyer J. *Use of dental loupes among dental trainers and trainees in the UK*. J Investig Clin Dent. 2013 May;4(2):120-3.

Autori: **Doc. dr Daniela Đurović Koprivica[1], Prof. dr Tatjana Puškar[1], Doc. dr Milica Jeremić Knežević[1], Prof. dr Bojana Milekić[1], Doc. dr Aleksandra Maletin[1], Dr Miloš Kuzmanović[1]**

[1] Univerzitet u Novom Sadu, Medicinski fakultet, Hajduk Veljkova 3, 21000 Novi Sad, Serbia, Tel: +381 21 6420 677.

E-mail: daniela.djurovic-koprivica@mf.uns.ac.rs; tatjana.puskar@mf.uns.ac.rs milica.jeremic-knezevic@mf.uns.ac.rs bojana.milekic@mf.uns.ac.rs aleksandra.maletin@mf.uns.ac.rs milos.kuzmanovic021@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Jeremic Knezevic M, Knezevic A, Djurovic Koprivica D, Milekic B, Maletin A, Puskar T

CAD SYSTEMS IN DENTAL MEDICINE

Abstract: *CAD/CAM systems in dentistry are a part of dentistry and prosthodontics that uses computer-aided design (CAD) and computer aided manufacturing (CAM) to improve the design and manufacturing of dental restorations. With the advancements intechnology, digital systems and CAD/CAM have the potential to replace traditional technologies. This allows faster fabrication of restorations with better properties and esthetic demands of the patient. CAD technology has become an essential component of dentistry, with an increasing number of restorations being created.*
Key words: *CAD/ CAM system, 3D design restoration, CAD design;*

1. INTRODUCTION

CAD/CAM dentistry is a branch of dentistry and prosthodontics that uses computer-aided design (CAD) and computer aided manufacturing (CAM) to improve the design and manufacturing of dental restorations, particularly crowns, inlays, onlays, veneers, bridges, dental implant supported restorations, dentures (removable or fixed) and orthodontic appliances. Parts and components can be precisely designed and machined with CAD/CAM using a computer with integrated software linked to a milling device. Dental computer-aided design (CAD) and computer-assisted manufacturing (CAM) technology is a combination of three processes: data or image acquisition; image or information analysis and manipulation, or computer-aided design; and fabrication, or computer-assisted manufacturing.

Fig. 1. CAD/CAM system

Data is collected using a variety of image-capture techniques, such as digital scanning or digital photography. The images are then rendered, analyzed, and manipulated using software. The CAD-created restorations or treatment components are then fabricated using milling units or three-dimensional (3D) printers.

CAD (+CAM) technologies were introduced to dentistry in 1970s, when François Duret first envisioned how these technologies could be applied to the profession. His original reasoning was that by using computer-controlled machine tools, he could fabricate a dental restoration with less effort, less variability, and lower production costs.

2. CAD SYSTEM IN DENTAL MEDICINE

Three functional components are involved in the fabrication of a restoration using a CAD (and CAM) system: data capture, restoration design and restoration fabrication (CAM).

Making an optical impression of the preparation is required for data collection. It is possible to accomplish this with the aid of various intraoral scanning devices such as intraoral cameras, mechanical or optical digitizers, and so on. Following cavity preparation, this procedure entails creating an optical impression via surface digitizing or scanning. Methods for digitizing or scanning 3D surfaces are classified as follows: direct (at the tooth) and indirect methods (via impression making and model fabrication). Various surface digitization techniques which have been explored are: laser scanning, computed tomography, magnetic resonance imaging (MRI), ultrasound, contact profilometry. The term scanner in dentistry means data collection tools that measure three-dimensional jaw and tooth structures and transform them into digital data sets. There are two different types of scanners: optical and mechanical scanners.

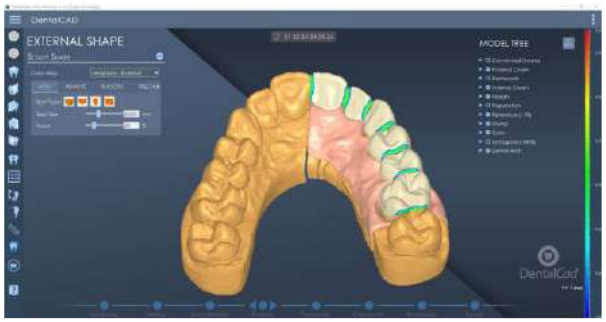


Fig. 2. Design of restoration on computer using CAD software

The restorations are designed on computers using CAD software, which is provided by the manufacturers for the design of various 3D dental restorations (Figure 1.) . Several commercially available CAD programs are available for designing virtual 3D dental restorations on a computer screen. Some of these programs can create restorations that are nearly as good as those created by master dental technicians. The amount of interaction required from the CAD/CAM system operator to design a restoration varies, ranging from significant to none.

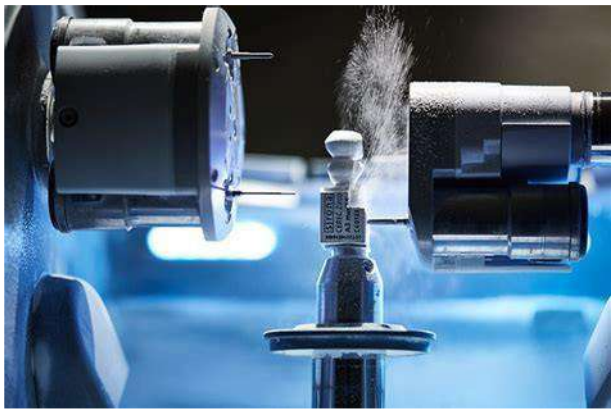


Fig. 3. Milling prefabricated ceramic block

The operator enters the data obtained from the scanning process and confirms the preparations features. These data are saved in a format known as standard transformation language (STL) data. When the software has finished designing the restoration, it is transformed into a virtual model using a specific set of commands. Even in the most automated system, the operator has the option to modify the automatically designed restoration to meet their specific needs. The CAM unit fabricates the final restoration after the restoration has been designed in CAD.

There are several CAD softwares used today: CEREC, the E4D dental system, TRIOS design studio, Planmeca PlanCAD software, Exocad, 3 shape dental system.

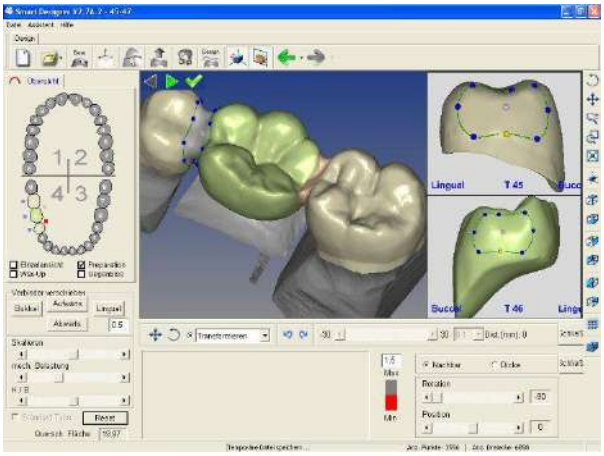


Fig. 4. CAD system

2.1 CAD in general

Computer-aided design is one of many tools used by engineers and designers, and it can be used in a variety of ways depending on the users profession and the type of software in question. CAD is also used to accurately create photo simulations, which are frequently required in the preparation of environmental impact reports, in which computer-aided designs of proposed buildings are superimposed onto photographs of existing environments to represent what that locale will be like if the proposed facilities are built. Potential view corridor blockage and shadow studies are also frequently analyzed using CAD.

3. ADVANTAGES OF CAD SYSTEMS

3.1 Time efficient

Because CAD (and CAM) technology captures and displays your client's tooth or teeth and gums in a 3D image system on a computer screen before sending it to the lab, work can be done faster to get the perfect design of the digital dental restoration. It allows us to produce restorations in 2 to 5 days instead of the 2 to 3 weeks required by the traditional procedure. In some cases, patients can have their restorations completed on the same day as their initial visit.

3.2 Final restoration can be predicted

Outcome of the restoration can be predicted and how it will appear on a patient using CAD (and CAM) technology in dentistry. It provides patients with an exceptional experience in determining the type of restoration that best suits their desired appearance. And, because there is no need for the traditional impression, patients will have a more convenient visit to have a dental restoration done in your office.

3.3 Improved restoration quality

There is complete control over the design of a suitable restoration for each patient. Computer-aided design and manufacturing enables dental lab technician to design and create a precise and accurate dental restoration, as well as increases confidence in producing a restoration that fits well and lasts longer. Quality is also consistent because prefabricated ceramic blocks are free from internal defects and the computer program is designed to produce shapes that will stand up to wear.

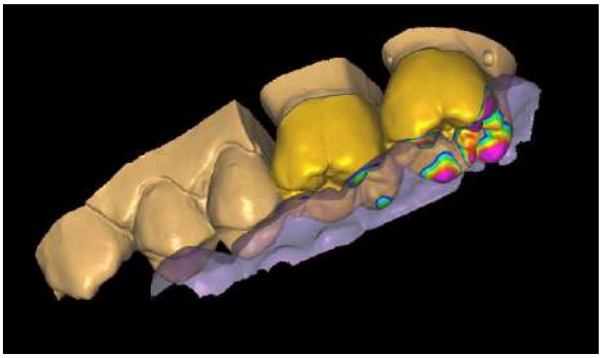


Fig. 5. Physiological and premature occlusal contacts on the both first and second upper molars

3.4 Natural appearance

Because the ceramic block is not transparent but clear enough to allow light to pass through, CAD/CAM restoration is preferred because it creates a natural appearance. This has a close resemblance to enamel and can be worn as posterior teeth. This technology allows for the creation of dental restorations in a wide range of shades, sizes, and colors.

4. DISADVANTAGES OF CAD SYSTEMS

4.1 Costs

The equipment and software are expensive at first, and the practitioner must invest time and money in training. Dentists who do not perform a large enough volume of restorations will struggle to make their investment pay off.

4.2 Software complexity

As CAD software advances, it becomes more flexible and adaptable. However, this comes at the cost of making software more complex. This complexity makes it more difficult for first time users to learn the software. Computers can also be affected by software problems, viruses and corrupted files, meaning work could be lost.

5. STEPS IN CAD/CAM PROCEDURE

1. Anesthesia
2. Tooth preparation
3. Intraoral scanning
4. Restoration design
5. Milling
6. Sintering and polishing
7. Cementation

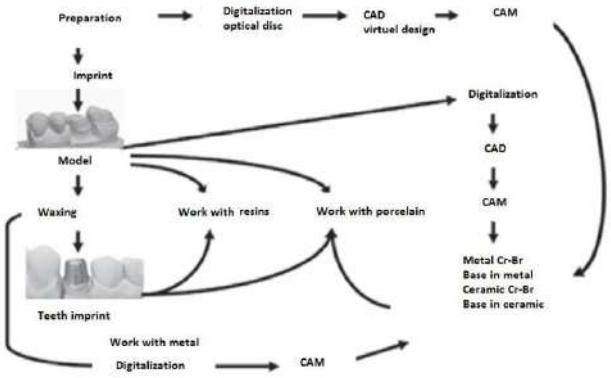


Fig. 6. Schematic view- steps in CAD/CAM dentistry

6. CONCLUSION

To sum up, CAD technology has become an essential component of dentistry, with an increasing number of restorations being created. By providing high-quality restorations, CAD systems have improved dentistry. The evolution of existing systems and the introduction of new systems demonstrate increased user friendliness, expanded capabilities, and improved quality, as well as a wide range in complexity and application. With the advancements in technology, digital systems and CAD/CAM have the potential to replace traditional technologies. This allows for faster fabrication of restorations with better properties and esthetic demands of the patient.

7. REFERENCES

[1] G. Uzun (2008) *An Overview of Dental CAD/CAM Systems*, Biotechnology & Biotechnological Equipment, 22:1, 530-535, 2008.DOI: 10.1080/13102818.2008.10817506

[2] Todorovic, A., Lazic, V. *Computer aided design and manufacturing of dental restorations - "computerized impression" technology*. Serbian Dental Journal Stomatoloski Glasnik Srbije,53(1), 42-53 2006. doi:10.2298/sgs0601042

[3] I Susic et al. 2017 IOP Conf. Ser.: Mater. Sci. Eng. 200 012020

Authors: **doc. dr Milica Jeremic Knezevic, Prof.dr Aleksandar Knezevic, doc.dr Daniela Djurovic Koprivica, prof.dr Bojana Milekic, doc.dr Aleksandra Maletin, prof.dr Tatjana**

Puskar;
University of Novi Sad, Faculty of Medicine Novi Sad, Department of dental medicine, Hajduk Veljkova 12, 21000 Novi Sad, Serbia, Phone.: +381 21 6612222.
E-mail: milica.jeremic-knezevic@mf.uns.ac.rs
aleksandar.knezevic@mf.uns.ac.rs
daniela.djurovic-koprivica@mf.uns.ac.rs
bojana.milekic@mf.uns.ac.rs
aleksandra.maletin@mf.uns.ac.rs
tatjana.puskar@mf.uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Maletin, A., Ristić, I., Puškar, T., Jeremić-Knežević, M., Đurović-Koprivica, D., Veljović, T., Ramić, B., Milekić, B.

PRIMENA PUSH-OUT TESTA U DENTALNIM ADHEZIVNIM ISTRAŽIVANJIMA

Rezime: *Za klinički uspeh restaurativne procedure od značaja je postojanost i dugotrajnost adhezivne veze zuba i odgovarajućeg restaurativnog i cementnog materijala. Brojne su metode koje se primenjuju u svrhu istražvanja jačine adhezivne veze dentalnih materijala. U oblasti ispitivanja i procene jačine adhezivne veze cementnih materijala na bazi smola i kompozitnih kanalnih kočića neprikosnovena je push-out metoda. Primenom push-out testa sila se usmerava direktno na kompozitni kanalni kočić koji je fiksiran odgovarajućim cementnim materijalom u uzorku zuba. U poređenju sa drugim dostupnim metodama za ispitivanje jačine adhezivne veze push-out test pokazuje manji broj prevremenih neuspeha i manju varijabilnost podataka a približnije simulira kliničke uslove.*
Ključne reči: *adhezivna veza; push out test; fiber kočići; dentalni cementi;*

1. UVOD

U savremenoj stomatološkoj praksi postojanost i jačina uspostavljene veze između zuba i nekog od restaurativnih materijala predstavlja značajan činioc kliničkog uspeha. Idealno bi bilo da uspostavljanje adhezivne veze između zuba i materijala za restauraciju (kompozitne smole, dentalni cementni materijali, keramički materijali, legure) nije tehnički komplikovana i zahtevna procedura i da se relativno brzo uspostavi [1]. Iz tog razloga se tehnologija dentalnih materijala konstantno unapređuje i usavršava te su brojna istraživanja na temu kvaliteta adhezije dentalnih materijala.

U dentalnim adhezivnim istraživanjima u cilju ispitivanja jačine veze (eng. bond strength) primenjuju se testovi bazirani na ispitivanju otpornosti na istezanje (eng. tensile) ili otpornosti na smicanje (eng. shear) koji u određenom stepenu simuliraju kliničke uslove [2-5]. Specifičnost „tensile“ testova je perpendikularno usmerenje primenjene sile na površinu uzorka te su uzorci zuba ili materijala podvrgnuti vučnim silama [6]. Primena sile paralelno sa površinom uzorka je karakteristična za grupu „shear“ testova te je uzorak podvrgnut silama smicanja [7]. Takođe, značajno mesto u oblasti adhezije dentalnih materijala zauzima test ispitivanja jačine veze primenom opterećenja u tri tačke (eng. three-point bending) [2].

Modaliteti tensile testova su „microtensile“ [8,9], „pull-off“ [10] i „push-out“ test [11].

2. PUSH-OUT TEST

Početak primene push-out testa vezuje se za istraživanja koje je prvi sproveo Roydhouse tako što je merio otpornost na smicanje uzoraka oblika poprečnog preseka [12]. Danas i godinama unazad push-out test se smatra neprikosnovenim za potrebe ispitivanja jačine veze (eng. bond strength) za dentalne adhezivne materijale. Ukoliko se za potrebe izvođenja push-out testa pripreme uzorci debljine jednake i manje od 1mm onda je u pitanju micro push-out test [13].

U oblasti istraživanja adhezivne veze dentalnih materijala, push-out test se smatra metodom prvog izbora za grupu cementnih materijala i kompozitnih kanalnih kočića (fiber kočića) [14]. Naime, primenom push-out testa se sila usmerava direktno na fiber kočić koji je fiksiran odgovarajućim cementnim materijalom u uzorku zuba i meri se sila koja je neophodna za izbacivanje kočića iz uzorka zuba [15].

Jačina adhezivne veze se vrlo jednostavno izračunava primenom sledeće matematičke formule [16]:

$$\text{BOND STRENGTH (MPa)} = F / 2\, r\, \pi\, h \qquad (1)$$

F=sila u N

r= poluprečnik kočića

(cervikalna trećina 2r=2 mm, srednja trećina 2r=1,5 mm, apikalna trećina 2r=1 mm)

π=3,14

h=debljina segmenta zuba

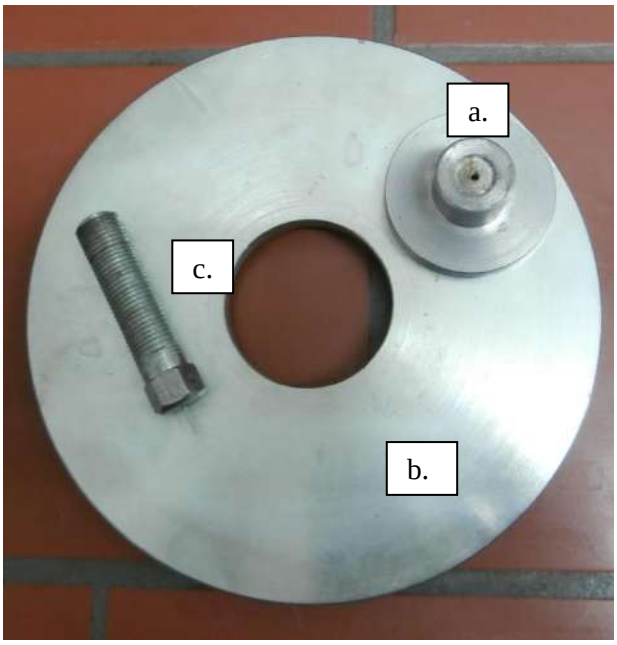
2.1. Priprema i izvođenje push-out testa

U cilju izvođenja push-out testa neophodno je pripremiti alat koji se fiksira u univerzalnoj kidalici. Alat neophodan za izvođenje push-out testa mora da poseduje nekoliko strukturnih komponenti koje treba da omoguće precizno i stabilno postavljanje i fiksaciju uzorka dentalnog cementnog materijala i zuba i delovanje sile usmerene ka odvajanju delova uzoraka ispitivanog materijala. Priprema uzoraka za potrebe ispitivanja jačine adhezivne veze primenom push out testa smatra se vrlo zahtevnom procedurom koja uključuje niz faza u smislu sledećeg:

1. Prikupljanje humanog materijala (humani materijal su ekstrahovani zubi).
2. Čuvanje humanog materijala pod standardizovanim uslovima (precizno definisan medijum, temperatura i period čuvanja).
3. Priprema restaurativnog ili cementnog materijala i aplikacija istog u zub pod strogo kontrolisanim uslovima koji simuliraju situaciju u usnoj duplji.
4. Čuvanje uzoraka zuba sa dentalnim materijalom pod standardizovanim uslovima (precizno definisan medijum, temperatura i period čuvanja).
5. Priprema zuba sa aplikovanim dentalnim materijalom za sečenje (individualno osmišljavanje načina na koji će zubi biti pripremljeni za sečenje).
6. Sečenje zuba na delove (eng. slice) debljine 1mm. Tokom postupka sečenja korena zuba na segmente moguće je oštećenje uzoraka što se kasnije manifestuje izbacivanjem kočića cementiranog materijalom na bazi smola iz segmenta korena zuba praktično bez upotrebe sile.
7. Provera dimenzija dobijenih uzoraka.
8. Čuvanje uzoraka pod standardizovanim uslovima (precizno definisan medijum, temperatura i period čuvanja).
9. Dizajn i izrada alata za sprovođenje push out testa (pregledom dostupnih literaturnih podataka utvrđeno je da ne postoje jasne smernice kako bi alat trebao da izgleda po pitanju dimenzija i oblika, što se posebno odnosi na deo alata-tzv. pin odnosno promer i dužinu pina koji treba da omogući izbacivanje dela fiber kočića fiksiranog cementnim materijalom na bazi smola i prekid adhezivne veze uzorka zuba i ispitivanog cementnog materijala na bazi smola).
10. Postavljanje i fiksiranje uzoraka u alat.
11. Montiranje alata u kidalicu [18].

2.2. Alat neophodan za push-out test

Pregledom dostupnih literaturnih podataka utvrđeno je da ne postoje usaglašeni stavovi kako treba da izgleda alat neophodan za izvođenje push-out testa, odnosno nisu definisani standardi koji bi se mogli primeniti u svrhu dizajna alata [1]. Nedostataka definisanih standarda u tom smislu može predstavljati i jednu vrstu ograničenja kod tumačenja rezultata primenjenog push-out testa [3,9,11]. Alat neophodan za izvođenje push-out testa u cilju određivanja bond strength između komopzitnog kanalnog kočića i kompozitnog cementnog materijala poseduje nekoliko strukturnih komponenti (slika 1):

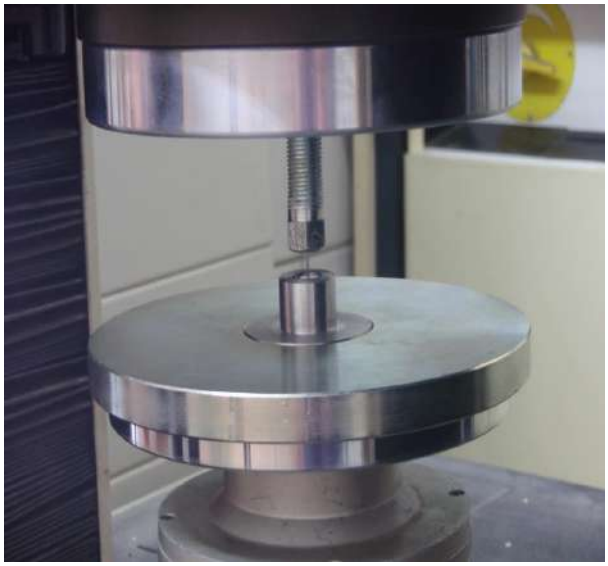


Sl. 1. Strukturne komponente alata za push out test.

a. Postolje za prihvatanje i fiksaciju uzorka zuba i isipitivanog materijala.
b. Platforma za fiksaciju postolja za prihvatanje uzorka zuba i ispitivanog materijala.
c. Pin za razdvajanje adhezivne veze zuba i dentalnog cementnog materijala.

Slika 2 prikazuje uzorak korena zuba (debljina uzorka je 1mm) i ispitivanog dentalnog cementnog materijala koji je postavljen na postolje alata.

Sl. 2. Postavljen uzorak zuba u alat za push-out test.



Sl. 3. Alat za push out test montiran u univerzalnoj kidalici.

Slika 3 prikazuje alat za izvođenje push out testa koji je montiran u univerzalnoj kidalici kako bi primenom sile došlo do izbacivanja kompozitnog kanalnog kočića iz uzorka zuba odnosno prekida njihove adhezivne veze [19].

3. ZAKLJUČAK

U istraživanjima koja se bave retencijom kompozitnih kanalnih kočića push-out test je test izbora [4,20,21] jer se smatra da je u poređenju sa microtensile testom pouzdanija metoda koja pokazuje manji broj prevremenih neuspeha i manju varijabilnost podataka [21]. U odnosu na ostale dostupne metode, push-out test približnije simulira kliničke uslove [22]. Takođe, primenom metode konačnih elemenata (eng. Finite Element Analysis) pokazano je da je push-out test apsolutno primenjiva i pogodna metodologija za evaluaciju retencije kompozitnih kanalnih kočića [22]. Postoji potreba da se utvrde jasno definisani standardi dizajna alata potrebnog za izvođenje push-out testa.

4. REFERENCE

[1] Marshall S., Bayne S., Baier R., Tomsia A., Marshall G.: *A review of adhesion science*, Dental Materials, 26, p.p. e11-e16, 2010.

[2] Jongsma LA., Kleverlaan C., Feilzer A.: *Influence of surface pretreatment of fiber posts on cement delamination*, Dental Materials, 26, p.p. 901-907, 2010.

[3] Scherrer SS., Cesar PF., Swain MV.: *Direct comparison of the bond strength results of the different test methods: A critical literature review*, Dental Materials, 26, p.p.78-93, 2010.

[4] Tagami J., Nikaido T., Nakajima M., Shimada Y.: *Relationship between bond strength tests and other in vitro phenomena*, Dental Materials, 26, p.p.94-99, 2010.

[5] Braga RR., Meira JBC., Boaro LCC., Xavier TA.: *Adhesion to tooth structure: A critical review of „macro“ test methods,* Dental Materials, 26, p.p.38-49, 2010.

[6] Bouillaguet S., Troesch S., Wataha J., Krejci I., Meyer JM., Pashley D.: *Microtensile bond strength between adhesive cements and root canal dentin*, Dental Materials, 19, p.p. 199-205, 2003.

[7] Placido E., Meira J., Lima RG., Muench A., de Souza RM., Ballester RY.: *Shear versus micro-shear bond strength test: A finite element stress analysis*, Dental Materials, 23, p.p. 1086-1092, 2007.

[8] Aksornmuang J., Nakajima M., Senawongse P., Tagami J.: *Effects of C-factor and resin volume on the bonding to root canal with and without fibre post insertion,* Journal of Dentstry, 39, p.p. 422-429, 2011.

[9] Hidehiko S., Almas Chowdhury M., Saikaew P., Matsumoto M., Hoshika S., Yamauti M.: *The microtensile bond strength test: Its historical background and application to bond testing*, Japanese Dental Science Review, 56, p.p.24-31,2020.

[10] Ebert J., Leyer A., Günther O., Lohbauer U., Petschelt A., Frankenberger R., Roggendorf MJ.: *Bond Strength of Adhesive Cements to Root Canal Dentin Tested with a Novel Pull-out Approach*, Journal of Endodontics, 37, p.p. 1558-1561, 2011.

[11] Chen WP., Chen YY., Huang SH., Lin CP.: *Limitations of Push-out Test in Bond Strength*

Measurement, Journal of Endodontics, 39, p.p. 283-287, 2013.
[12] Wng VJJ., Chen YM., Yip KHK., Smales RJ., Meng QF., Chen L.: *Effect of two fiber post types and two luting cement systems on regional post retention using the push-out test*, Dental Materials, 24, p.p. 372-377, 2008.
[13] Pawar AM., Pawar S., Kfir A., Kokate MP.: *Push-out bond strength of root fillings made with C-Point and BC sealer versus gutta-percha and AH Plus after the instrumentation of oval canals with the Self-Adjusting File versus WaveOne*, International Endodontic Journal, 49, p.p. 374-381, 2016.
[14] Guneser MB., Akbulut MB., Ayce Unverdi Eldeniz.: *Effect of Various Endodontic Irrigants on the Push-out Bond Strength of Biodentine and Conventional Root Perforation Repair Materials*, Journal of Endodontics, 39, p.p. 380-384, 2013.
[15] Monticelli F., Mazzitelli C., Casucci A., Osorio R., Toledano M., Ferrari M.: *Bond strengths of self-adhesive cements to fiber-reinforced posts*, Dental Materials, 25, p.p. 35, 2009.
[16] Ivanovic C., Magni E., Cantoro A., Goracci C., Ferrari M.: *Push-out bond strength of circular and oval-shaped fiber posts*, Clinical Oral Investigations, 15, p. p. 667–672, 2011.
[17] Maletin A., Markovic D., Neskovic I., Ramic B., Veljovic T.,, Ristic I.: *Application of a Novel Modification of the Microbond Test for Evaluation of Adhesive Bond Strength Between Fiber Posts and Dual-Cure Dental Resin Cement*, Medical Science Monitor, 25, p.p. 3397-3405, 2019.
[18] Anđelković A.: *Uticaj efikasnosti polimerizacije cemenata na bazi smola na retenciju kompozitnih kanalnih kočića*, Medicinski fakultet, Novi Sad, 2014.
[19] Pane E., Palamara J., Messer H.: *Critical Evaluation of the Push-out Test for Root Canal Filling Materials*, Journal of Endodontics, 39, p.p. 669-673, 2013.
[20] Lindblad RM., Lassila LVJ., Salo V., Vallittu PK., Tjaderhane L.: *One year effect of chlorhexidine on bonding of fibre-reinforced composite root canal post to dentine*, Journal of Dentistry, 40, p.p. 718-722, 2012.
[21] Sirisha K., Rambabu T., Ravishankar Y., Ravikumar P.: *Validity of bond strength tests: A critical review-Part II*, Journal of Conservative Dentistry, 17, p.p. 420–426, 2014.
[22] Soares CJ., Santana FR., Castro CG., Santos-Filho CF:, Soares PV., Qian F., Armstrong SR.: *Finite element analysis and bond strength of a glass post to intraradicular dentin: Comparison between microtensile and push-out tests*, Dental Materials 24, p.p. 1405-1411, 2008.

Autori: **Doc.dr Aleksandra Maletin, Doc. dr Ivan Ristić, Prof. dr Tatjana Puskar, Doc. dr Milica Jeremic Knezevic, Doc. dr Daniela Djurovic Koprivica, Doc. dr Tanja Veljović, Doc. dr Bojana Ramić, Prof. dr Bojana Milekic.**
Univerzitet u Novom Sadu, Medicinski fakultet, Hajduk Veljkova 3, 21000 Novi Sad, Serbia, Tel:+381 21 6420 677.
E-mail: aleksandra.maletin@mf.uns.ac.rs
ivan.ristic@uns.ac.rs
tatjana.puskar@mf.uns.ac.rs
milica.jeremic-knezevic@mf.uns.ac.rs
daniela.djurovic-koprivica@mf.uns.ac.rs
tanja.veljovic@mf.uns.ac.rs
bojana.ramic@mf.uns.ac.rs
bojana.milekic@mf.uns.ac.rs

INTERNATIONAL SCIENTIFIC CONFERENCE ETIKUM 2021

PROCEEDINGS

Session 3:

METROLOGY AND QUALITY IN THE FIELD OF ENVIRONMENTAL PROTECTION AND OCCUPATIONAL SAFETY

Novi Sad, 02 – 04 December 2021

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Benčina, A., Udir, T., Karpe, B., Kosec, B.

CALORIFIC VALUE OF WOOD AND WOOD PELLETS

Abstract: *In Slovenia (the forest covers almost 60% of the area) in the field of heating of individual residential buildings, the share of wood and wood fuels exceeds 50%.*
The use of wood for energy purposes, both in terms of energy independence and ecological acceptability, is therefore certainly welcome, but it is necessary to be aware that wood heating is not environmentally friendly and only efficient use of quality wood fuels provides environmentally friendly heating.
Wood pellets are wood fuels used in modern heating stoves. They have a relatively high density and low water content, which allows high combustion efficiencies. They are mostly made of spruce and beech wood.
As part of the research, we analyzed air-dried beech or spruce wood and wood pellets from various manufacturers, which are available on the market today.
For each individual type of pellets and air-dried beech or spruce wood, we measured or determined the proportion of moisture, ash, volatile and the most important energy parameter, calorific value, with the C200 IKA calorimeter.
Key words: *calorific value, wood, wood pellets, energy, ecology*

1. INTRODUCTION

Each of us is faced with heating on a daily basis. Energy is needed for heating as well as for other processes in life (for example, transport, food production, car production). We cannot create energy from nothing, nor can we annihilate it, we can only transfer it from one system to another or store it. In Slovenia, households use more than 80% of total energy, 62% of this energy is used for heating, 19.5% for hot water preparation, and the remaining 20% is used for the operation of electrical appliances, household appliances, lighting and cooking. It should be noted that a lot of energy is also used for transport. Cars consume the most energy, followed by trucks, and a small share of energy is used for public passenger transport. We know several types of renewable energy sources (solar, wind, wood), in addition to these we also know the chemical energy stored in food and beverages, moving energy (sea waves, wind) and finally the energy coming from the heated Earth's interior [1].

There is no shortage of wood biomass in Slovenia, as the country is covered by as much as 60 % of the forest. The availability of wood is limited by the slope of the surface in Slovenia, more than half of the country has a 20 % slope, and a good fifth even over 35 %. In addition to the slope, accessibility is also limited by altitude. The forest boundary ranges from 1600 to 1900 meters above sea level [2].

Burning wood biomass is also a major source of pollution with dust particles in the air. It is important for each individual to be aware of what proper heating looks like and how to recognize poor combustion of wood fuels in a stove boiler. The biggest indicators of proper heating are the color of the flame and smoke. As a rule, the color of the flame should be light in color, and the color of the smoke almost invisible.

Fig. 1. Beech wood in different shapes.

2. WOOD AND WOOD PELLETS

Wood biomass or wood fuels are divided into:

- firewood,
- wood chips,
- pellets and
- briquettes.

Pellets are made from dry wood dust and sawdust. Production takes place at high pressure (up to 1000 bar) and the presence of water vapor. As a rule, it should not contain chemicals, only the addition of starch is allowed. The length of the

pellets is 5 to 50 mm and the diameter is 6 to 12 mm. Briquettes are larger pieces of various shapes, most often cylindrical in shape. They are similar to firewood in shape, size and method of use. They are used in fireplaces with manual filling. The length of the briquettes is from 60 to 150 mm and the diameter from 50 to 100 mm. They are made by pressing bark, dry wood dust, shavings and other uncontaminated wood residues. The moisture content should not exceed 10 % and the ash content of combustion should not exceed 0.5 % [2].

Wood pellets are a modern form of wood fuels that are ground into dry wood powder. For better mechanical resistance, they are allowed to add up to 3% starch during the manufacturing process. They have a cylindrical shape with a diameter of 6 to 8 mm and are up to 40 mm long. In 2017, 19 active pellet producers were registered in Slovenia. However, this number has been maintained to this day [2].

Wood pellets are made from all types of wood or other raw materials such as straw, grain and energy grass. Energy grass was developed in Hungary and is used as a stand-alone raw material or as an additive to wood for pelleting. Depending on the choice of wood, the resulting pellets differ in color. In principle, there is no measure of whether lighter pellets are better than darker ones, as has sometimes been claimed. However, it has been proven that pellets are of the highest quality from spruce or fir wood, so these two types are most often used to make pellets. Beech wood pellets can also be found on the market. Such wood contains a predominantly small proportion of ash below 0.5% and is relatively light. However, the types of wood can be mixed with each other as desired, resulting in quality pellets. Some manufacturers also add bark to the wood mixture, which reduces the quality of the pellets due to the higher amount of ash. During the transport of the bark, soil, sand or even small stones accumulate in it, a small percentage of which also enters the pellets, which negatively affects the calorific value of the pellets, causes slag formation during burner operation and increases the amount of ash.

The pellet production process begins with the felling of trees in forests. Various mechanization is used to facilitate work in the forest. The trees they cut down are taken out of the forest and cut to the appropriate length and taken by truck to the central center. This is followed by wood treatment, which can leave up to 30% of sawdust, roundwood and wood dust, which is used to make pellets.

Pellet production is divided into five stages. The first stage of pellet preparation is grinding. During the process, different pieces of untreated wood acquire an even structure. The mixture becomes homogeneous, which is very important in the manufacture of pellets. Grinding is most often carried out with hammer mills and usually takes place in several stages from coarse to final fine grinding.

Drying of finely ground material is the second stage of the pellet production process. Fresh wood can contain up to 50% moisture. Drying takes place in electrically operated drum dryers. Drum dryers use hot air and steam. Hot air is used for drying wood and water vapor for controlled humidification as the pellet must not be too dry when it enters the pelleting process. After drying, the humidity is reduced to 8%. The drying phase is crucial, as humidity also affects the calorific value of the pellets - the drier the wood, the higher the calorific value.

The next technological operation is compression or pelleting. The process takes place in special presses called pellets. These contain circular matrices through which pellets are formed. In presses, the raw material is exposed to high pressure and temperature. The compressive force ensures that pellets are obtained from the die, which are cut to the prescribed length by knives. The heat released during the process has a positive property as it allows the lignin to be released, which is a binder. Due to this phenomenon, it is not necessary to add additional binder to the pellets, as they will retain their structure even when cooled.

The cooling phase follows, as the pellet reaches high temperatures when pressed, up to 95 °C. In the cooling phase, the final shape of the pellets is formed, and they are also stabilized.

The last stage is sowing, in which small fractions, dust and debris are removed.

Finally, the cooled and sieved pellets are packed in 15 kg bags, BIG BAG bags, with a capacity of 1000 kg, or left in bulk.

3. QUALITY OF WOOD PELLETS

The quality of pellets is described by a number of factors, the most typical of which are:

- raw material used (origin and origin),
- dimensions (diameter and length),
- water content,
- mechanical resistance,
- bulk density,
- ash content,
- proportion of fine particles,
- calorific value and
- presence of chemical elements.

According to the quality according to the SIST EN ISO 17225 - 2 standard, pellets are classified into three quality classes, namely A1, A2 and B [3].

Individual classes allow different proportions of ash in pellets. They also differ in the value of mechanical resistance. The highest quality pellets include pellets of the highest quality. Class A2 already allows a higher proportion of ash than class A1, while class B allows the highest ash content and slightly lower mechanical stability. Class B allows the use of wood residues and used wood for the production of pellets, which is not suitable for use in the vast majority of domestic stoves. The quality of the pellets is also important for the long-term, economical and reliable operation of the device. Higher quality and proper use extend its lifespan.

3. EXPERIMENTAL

The analysis of pellet quality was performed in the thermotechnical laboratory. We focused on the analysis of ash content, water, calorific value, bulk density, and in addition, we analyzed the ash samples using a scanning electron microscope.

The analysis was performed for five different types of pellets, which are shown in Figure 2.

Fig. 2. Testing samples.

The composition of all five samples is as follows:

- Sample 1: Pine
- Sample 2: Fir
- Sample 3: Conifers
- Sample 4: Fir (darker pellets than in sample 2)
- Sample 5: Mixed.

The percentage (content) of ash is small in all five samples (Table 1). This is a positive feature for the user as the intervals between emptying the ash tank are longer.

Table 1. Results of ash content

Sample	Ash content (%)
1	0.3570
2	0.4626
3	0.3252
4	0.9055
5	0.9052

The results of the water content are given in Table 2.

Table 2. Results of the water content

Sample	Ash content (%)
1	7.2197
2	7.7351
3	6.9814
4	8.0414
5	7.4627

The calorific value of the samples was determined by a calorimeter system IKA C200 (Figure 3), which was previously set and calibrated [4]. We chose the isoperibolic program, which is one of the four programs the device offers. The calorific value was measured for air-dried samples as well as dried at 105 °C.

Fig. 3. Calorimeter system IKA C200.

Results of measurements of the calorific values of all five air - dry samples and dried samples at 105 °C are collected in Table 3.

Table 3. Calorific values

Sample	Calorific value of air - dry sample (kJ/kg)	Calorific value dried sample at 105 °C (kJ/kg)
1	18536	19958
2	18544	19967
3	18841	20273
4	18364	19887
5	18368	19829

The ash analysis was performed on a field electron microscope on a field emission Thermo Scientific Quattro S. All five ash samples were prepared accordingly. We applied a small amount of ash to the carbon strip, smoothed it and shook off the excess particles. The samples were then placed under a microscope and waited for a vacuum to form. This took about seven minutes. We started to change the resolution, sharpness and magnification in order to get a sharp image. Once we had a sharp

image, we performed energy dispersion spectroscopy (EDS) from this area on the image, which gave us a thorough analysis of the chemical composition of the sample (Figure 4).

We analyzed each sample separately, but found that they changed minimally in composition. All samples contain a lot of carbon and oxygen, on average a good 20 % of carbon, and oxygen just under 40 %. In addition to these two elements, sodium, magnesium, aluminum, silicon, potassium, calcium, manganese and, in small quantities, phosphorus and sulfur are also present in the sample.

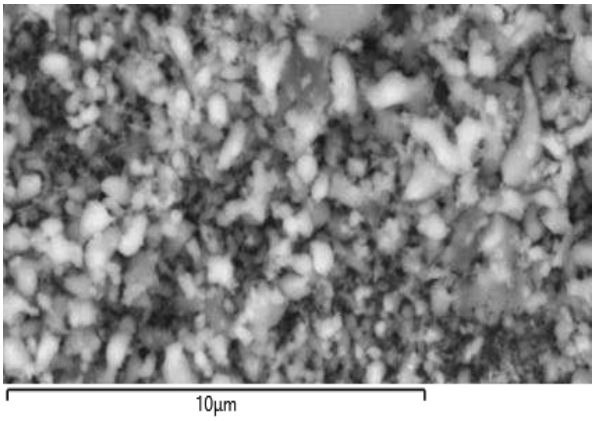


Fig. 4. The microstructure of sample 1.

4. CONCLUSIONS

Wood pellets are wood fuels used in modern heating stoves. They have a relatively high density and low water content, which allows high combustion efficiencies. They are mostly made of spruce and beech wood.

In our case the analyzes of water content and calorific value, all types of pellets achieved classification in the quality class. In other analyzes, however, there were only a few pellets that were classified in quality class A1. The others met standard A2, B, or none at all.

From the results of the presented analyzes, we found that conifers have a higher calorific value than deciduous trees.

REFERENCES

[1] Obernberger, I., Thek, G., *The pellet handbook: the production and thermal utilisation of pellets*. London; Washington; Earthscan, 2010.

[2] Protić, M., Mitić, D., Stefanović, V., *Wood pellets production technology*. Safety engineering, 1 (2011), pp. 23–26.

[3] Zielkiewicz, W., Margas, E., *Theory of calorimetry. Dordrecht;* Boston; London: Kluwer Academic Publishers, 2002.

[4] Solid biofuels – *Method for calorific value determination*. SIST EN14918, 2010.

Authors: **Alja Benčina, Prof. Dr. Borut Kosec, Ass. Prof. Dr. Blaž Karpe,** University of Ljubljana, Faculty of Natural Sciences and Engineering, Aškerčeva 12, 1000 Ljubljana, Slovenia, Phone: +386 1 2000410, Fax: +386 1 4704560.
E-mail: alja.bencina@gmail.com
borut.kosec@ntf.uni-lj.si
blaz.karpe@ntf.uni-lj.si
Tinkara Udir, LOTRIČ Metrology, d.o.o., Selca 163, 4227 Selca, Slovenia, Phone: ++386 4 5170700.
E-mail: tinkara.udir@lotric.si

*Corresponding author **Prof. Dr. Borut Kosec**, e-mail: borut.kosec@ntf.uni-lj.si

ETIKUM 2021

INTERNATIONAL SCIENTIFIC CONFERENCE
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Lemeš, S. Prcanović, H., Duraković, M.

VERIFIKACIJA REZULTATA MJERENJA EMISIJA U ZRAK IZ INDUSTRIJSKIH POSTROJENJA

Rezime: *Industrijska postrojenja podliježu obavezi instaliranja sistema za kontinuirani monitoring emisija u zrak, u skladu sa zahtjevima standarda BS EN 14181:2004 i BS EN 15259:2007. Rezultati mjerenja koriste se za izvještavanje o ukupnoj količini emisija u zrak na osnovu kojih se obračunava naknada po principu "zagađivač plaća", ali i za praćenje tehnoloških parametara i detekciju problema u proizvodnji. Prikupljeni podaci mogu se koristiti i za identifikaciju i kvantifikaciju različitih izvora zagađenosti zraka. U ovom radu izvršena je verifikacija podataka o emisijama u zrak iz metalurških postrojenja u gradu Zenici poređenjem s detaljnim podacima o kvalitetu zraka tokom 2020. godine.*
Ključne reči: *emisije, zrak, verifikacija, kvalitet zraka*

1. UVOD

Integralna metalurška proizvodnja u Zenici, u Bosni i Hercegovini postoji skoro 130 godina. Značajno povećanje proizvodnje u drugoj polovini XX vijeka pratile su i povećane emisije štetnih materija, prvenstveno u zrak. Nakon prekida proizvodnje 1992-2008 i privatizacije, očekivalo se da će novi vlasnik izvršiti neophodna ulaganja u postrojenja za smanjenje emisija, ali su te investicije bile ograničenog obima i efekata. Obnovljena integralna proizvodnja u pogonima sinterovanja, koksare, visoke peći, konvertorske čeličane, te termoelektrane na ugalj dovela je do pogoršanja kvaliteta zraka u gradu, ali je do danas ostalo otvoreno pitanje koliki je doprinos emisija iz metalurških postrojenja na ukupni kvalitet zraka, a koliko doprinose ostali izvori, kao što su kućna ložišta, male kotlovnice, saobraćaj i deponije otpada.

Sl. 1. Fugitivne emisije iz metalurških postrojenja

U procesu obnove okolinske dozvole [1] za ova postrojenja 2017. godine, utvrđena su odstupanja od standarda za kontinuirani monitoring, i kompaniji je naređeno da taj sistem uskladi s odredbama standarda EN 14181 i EN 15259. Usklađivanje je izvršeno 2019. godine. Izvještaji o kontinuiranom mjerenju emisija iz industrijskih postrojenja po prvi put su postali javno dostupni 2021. godine, tako da se mogla izvršiti analiza i verifikacija podataka o emisijama poređenjem trendova koncentracija zagađujućih materija u zraku i satnih podataka o emisijama iz ovih industrijskih postrojenja.

2. EMISIJE I KVALITET ZRAKA

Kvantifikacija izvora emisija bila je predmet mnogih istraživanja koja su koristila različite metode i pristupe.

Lewandowska i Falkowska u [2] istraživale su koji faktori povećane koncentracije PM10 u atmosferi u Poljskoj prevladavaju u različitim sinoptičkim uvjetima i u različito vrijeme. U rezultatima su se pokazala tri različita slučaja: prirodno aerosolno zagađenje morskom soli, transport aerosola iz udaljenih izvora, te emisije iz lokalnih izvora, uglavnom iz komunalnog sektora, lučkog područja i pretovarne baze. Koristili su hemijske markere kao što je elementarni ugljik da identifikuju izvore zagađenja.

Mutlu [3] koristio je aplikaciju za modeliranje kvaliteta zraka zasnovanu na AERMOD-u za analizu atmosferske disperzije PM10 ispuštenog iz industrijskog postrojenja u Turskoj. Zaključio je da su na koncentracije PM10 izvori emisija više uticali nego meteorološki uslovi.

Soggiu i dr. [4] analizirali su razlike u izmjerenim koncentracijama mikro zagađujućih materija u odnosu na smjerove vjetra, veličine frakcija PM i mjesta uzorkovanja, te na sezonske trendove koncentracija zagađujućih materija. Fokusirali su se na karakterizaciju glavnih izvora

PM10 i PM2,5 lociranih u lučko-industrijskom području u centralnoj Italiji. Prikupili su mjesečne prosjeke uzoraka PM10 i PM2,5 za jednu godinu i izvršili hemometrijsku analizu organskih i neorganskih frakcija.

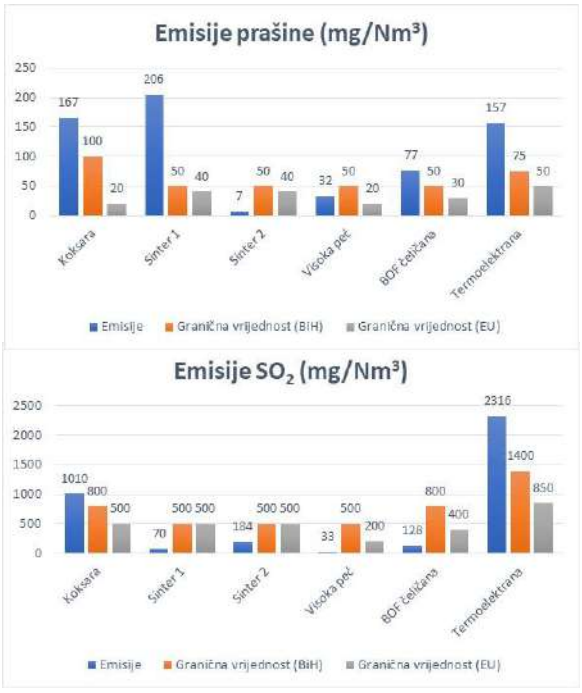
Szeląg i dr. [5] analizirali su uticaj meteoroloških uslova i antropogenih faktora (broj stanovnika u gradovima i ruralnim područjima, dužine puteva, broja vozila, emisije prašine i gasova, potrošnje uglja u industrijskim postrojenjima, broja uređaja za prečišćavanje zraka instaliranih u industrijskim postrojenjima) na koncentracije PM2,5 i PM10 u zraku u jednoj regiji u Poljskoj. Izračunati koeficijent korelacije pokazao je statistički značajne veze između kvaliteta zraka i količine instalirane opreme za pročišćavanje zraka u industrijskim postrojenjima.

Tang i dr. [6] istraživali su koliko je doprinos emisija iz kineske industrije željeza i čelika na kvalitet ambijentalnog zraka na nacionalnom nivou, nakon implementacije novih kineskih standarda za industrijske emisije. Koristili su 3D Eulerov numerički model kvaliteta zraka CAMx kako bi simulirali uticaje emisija iz industrije željeza i čelika na kvalitet zraka. Zaključili su da su najveće emisije lokalizirane u određenim područjima i da su emisije općenito u skladu s prostornom distribucijom metalurške proizvodnje. Također su zaključili da su značajnija ulaganja u zaštitu životne sredine dovela do smanjenja emisija. Utvrđeno je da proces sinterovanja ima najveći doprinos. Preko 50% emisija u prosjeku potiče iz postrojenja za sinterovanje. Nasuprot tome, doprinosi električnih peći i valjaonica čelika bili su u prosjeku manji od 4% za sve zagađujuće materije. Koksovanje je drugi po redu najveći zagađivač emisijama VOC (42%), a konvertorske čeličane najviše doprinose emisijama CO (38%) i fluorida (59%).

3. PODACI O EMISIJAMA

Rezultati kontinuiranog monitoringa emisija u zrak iz postrojenja ArcelorMittal Zenica za 2020. godinu sa 6 mjernih mjesta [7] pokazuju da su granične vrijednosti emisija prašine prekoračene na tri mjerna mjesta, SO_2 na dva i NO_x samo na jednom mjernom mjestu (slika 2).

Treba napomenuti da su granične vrijednosti u Bosni i Hercegovini veće nego u Evropskoj uniji, i veće u odnosu na vrijednosti koje propisuju BAT [8] referentni dokumenti za industriju gvožđa i čelika. Emisije prašine za koksare u [8] su ograničene na 20 mg/Nm^3, prema propisima u BiH ograničene su na 50 mg/Nm^3, a okolinskom dozvolom [1] granična vrijednost je povećana na 100 mg/Nm^3.



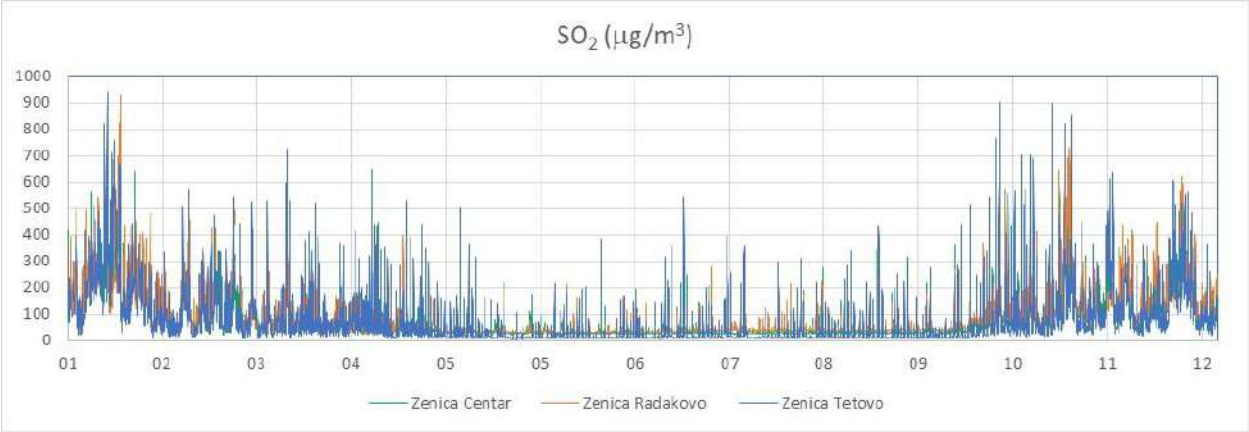
Sl. 2. Emisije i granične vrijednosti za 2020

4. PODACI O KVALITETU ZRAKA

Koncentracije zagađujućih materija u zraku na području Zenice tokom 2020. godine praćene su pomoću 5 mjernih stanica, od kojih su tri u vlasništvu grada Zenice, jedna (pozadinska) u vlasništvu kantonalnog Centra za monitoring okoliša i jedna u vlasništvu Hidrometeorološkog zavoda.

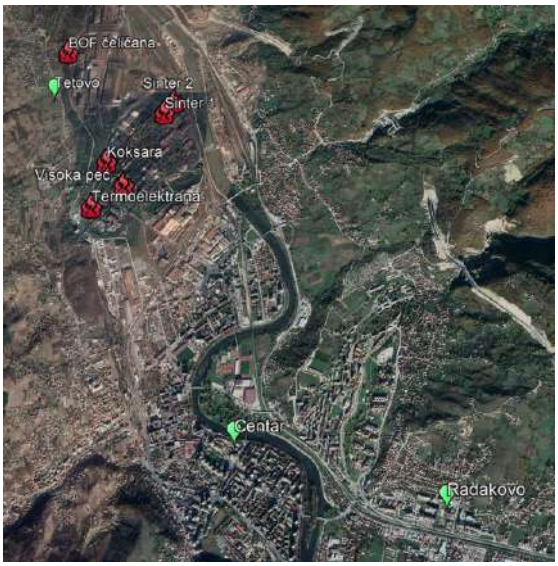
Prema podacima sa gradskih mjernih stanica, godišnji prosjek koncentracija SO_2 tokom 2020. kretao se od 78 do 93 μg/m^3, (propisana tolerantna vrijednost je 50 μg/m^3), maksimalna izmjerena vrijednost bila je 945 μg/m^3, a satni prosjek graničnu vrijednost od 350 μg/m^3 prekoračio je 287 puta. Prema propisima BiH ta granica ne smije biti prekoračena više od 24 puta tokom jedne kalendarske godine [9].

Godišnji prosjek koncentracija PM10 tokom 2020. godine kretao se od 53 do 71 μg/m^3 (tolerantna vrijednost je 40 μg/m^3), a maksimalna izmjerena vrijednost bila je 698 μg/m^3. Na slici 3 prikazane su koncentracije SO_2 tokom 2020. godine. Može se uočiti da su koncentracije i prašine i sumpor dioksida povećane tokom cijele godine, ali su izraženije tokom zimskog perioda. Za zimsko period karakteristična je pojava temperaturne inverzije i povećanog korištenja uglja i drugih čvrstih goriva za zagrijavanje prostora. Treba napomenuti i da grad koristi centralno grijanje, koje za izvor toplote koristi energiju proizvedenu u termoelektrani ArcelorMittal Zenica, koja se koristi i za tehnološke potrebe i za grijanje grada.



Sl. 3. Izmjerene koncentracije SO_2 u zraku u Zenici tokom 2020. godine (satni prosjeci)

Na slici 4 prikazan je prostorni raspored izvora emisija i tri gradske mjerne stanice. Mjerna stanica Tetovo najizloženija je emisijama kad je smjer vjetra od 60° do 150°. Mjerne stanice Centar i Radakovo najizloženije su emisijama kad je smjer vjetra od 300°do 360°.

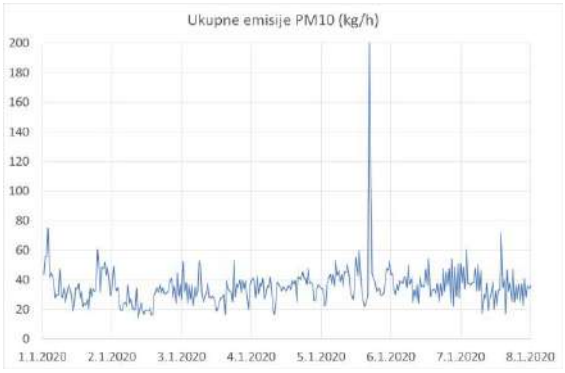


Sl. 4. Prostorni raspored izvora i mjernih stanica

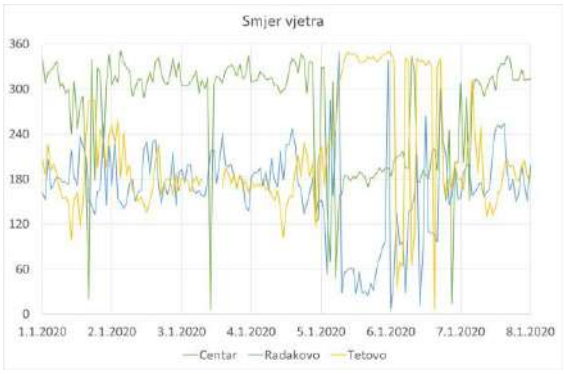
5. VERIFIKACIJA PODATAKA

Nacionalni propis BiH OD 07-07 [10], definiše metode za ispitivanje i kalibraciju koje se tretiraju kao nestandardne i koje podliježu validaciji. Tim propisom definisani su pojmovi validacije i verifikacije, koji su preuzeti iz Međunarodnog rječnika metrologije (VIM) [8]. Validacija je proces "potvrđivanja ispitivanjem i prikupljanjem objektivnih dokaza da su posebni zahtjevi za predviđenu specifičnu upotrebu zadovoljeni". S druge strane, verifikacija je postupak "prikupljanja objektivnih dokaza o ispunjavanju specificiranih zahtjeva".

Prema tim definicijama, verifikacija emisija mogla bi se provesti tako da se uporede trendovi emisija izmjerenih na mjernim mjestima s trendovima promjene koncentracija zagađujućih materija na mjernim mjestima, uzimajući u obzir smjer vjetra, u intervalima reprezentativnim za zimsku i ljetnu sezonu. Na slikama 5 do 7 prikazani su primjeri dijagrama za verifikaciju posmatrani u periodu od 7 dana. Slika 5 pokazuje ukupne emisije sa svih 6 izvora, gdje se može uočiti nagli skok emisija 5.1.2020 u 16:00 sati. Za verifikaciju bi trebalo uočiti sličnu anomaliju i na mjernim mjestima za praćenje kvaliteta zraka.



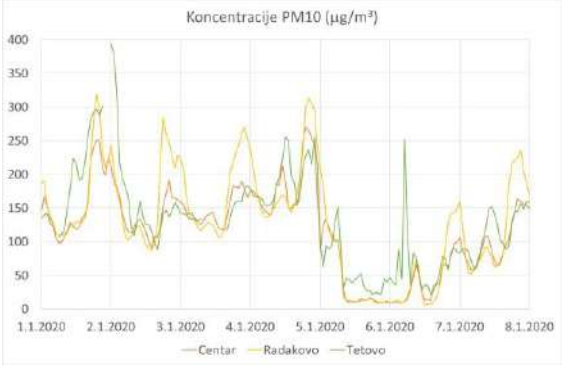
Sl. 5. Ukupne emisije PM10 iz 6 izvora



Sl. 6. Smjer vjetra izmjeren na 3 mjerne stanice

Na slici 6 prikazan je smjer vjetra. U periodu nakon uočene anomalije (5.1.2020 nakon 16:00

sati, smjer vjetra na lokaciji Tetovo je oko 340°, što znači da vjetar puše ka izvorima emisija, odnosno koncentracije ne bi trebale biti značajno veće. U istom periodu, na lokaciji Centar smjer vjetra je oko 180°, a na lokaciji Radakovo između 0°i 60°. To znači da na koncentracije u tom periodu ne utječu značajno emisije iz metalurških postrojenja. Na slici 7 vidi se da su u periodu uočene anomalije koncentracije PM10 veoma niske, što je u skladu s podacima o smjeru vjetra.



Sl. 7. Koncentracije PM10 na 3 mjerne stanice

S druge strane, ako se posmatra period od prvih 5 dana u januaru 2020, smjer vjetra na lokaciji Centar je između 300° i 360°, a u istom periodu su koncentracije PM10 na tom mjernom mjestu značajno povećane.

6. ZAKLJUČCI

Verifikacija provedena na ovaj način može se u ograničenom obimu koristiti kao brza metoda provjere podataka o emisijama i alokaciji izvora zagađenja zraka. Međutim, za pouzdaniju analizu i uspostavljanje direktnih relacija između emisija i izmjerenih koncentracija potrebno je izvršiti modeliranje disperzije zagađujućih materija, ali uzimajući u obzir ograničenja koja te simulacije imaju, kao što je to opisano u [12].

Za primjenu ove metode neophodno je imati podatke o emisijama i o kvalitetu zraka u realnom vremenu, što je rijetko slučaj u praksi. Dobar primjer bila je praksa željezare Ilva u Tarantu, Italija, koja je jedno vrijeme javno objavljivala podatke s automatskih sistema za monitoring.

7. REFERENCE

[1] Ministarstvo okoliša i turizma FBiH *Integralna okolinska dozvola za pogone i postrojenja* ArcelorMittal Zenica, 2017.

[2] Lewandowska, AU., Falkowska, LM.: *High concentration episodes of PM10 in the air over the urbanized coastal zone of the Baltic Sea* (Gdynia — Poland). Atmospheric Research, 120-121, 55–67, 2013.

[3] Mutlu, A.: *Air quality impact of particulate matter (PM 10) releases from an industrial source*. Environmental Monitoring and Assessment, 192(8), 1-17, 2020.

[4] Soggiu, ME., Inglessis, M., Gagliardi, RV., Settimo, G., Marsili, G., Notardonato, I.: Avino P *PM10 and PM2.5 qualitative source apportionment using selective wind direction sampling in a port-industrial area in Civitavecchia*,. Atmosphere, 11(1), 94. Italy, 2020.

[5] Szeląg, B., Studziński, J., Majewska, M.: *Effect of Meteorological Conditions and Anthropogenic Factors on Air Concentrations of PM2. 5 and PM10 Particulates on the Examples of the City of Kielce*, J. of Modeling and Optimization, 13(1), 1-11., Poland, 2021.

[6] Tang, L., Xue, X., Jia, M., Jing, H., Wang, T., Zhen, R., … Wang, S.: *Iron and steel industry emissions and contribution to the air quality in China*. Atmospheric Environment, 117668, 2020.

[7] BH PRTR (2021) Izvještaj o rezultatima kontinuiranog monitoringa emisija u zrak iz pogona i postrojenja ArcelorMittal Zenica, ENV-19-03-21, 2020.

[8] Remus, R., Aguado Monsonet, M., Roudier, S., Delgado Sancho, L.: *Best Available Techniques (BAT) Reference Document:for: Iron and Steel Production: Industrial Emissions Directive 2010/75/EU*. EUR 25521 EN. Luxembourg; EU JRC69967, 2012.

[9] Hidrometeorološki zavod FBiH (2021) Godišnji izvještaj o kvalitetu zraka u Federaciji BiH za 2020.

[10] BATA (2014) Uputstvo za validaciju metoda za ispitivanje i kalibraciju (opći zahtjevi), Institut za akreditiranje Bosne i Hercegovine.

[11] ISO/IEC Guide 99:2007 International vocabulary of metrology — Basic and general concepts and associated terms (VIM)

[12] Lemeš, S.: *Influence of input data on the quality of air pollution distribution computer simulations, Regional symposium on air quality in cities*, Association of Consulting Engineers B&H, Sarajevo, 2020 .

Autori: **Prof. dr Samir Lemeš, mr Halim Prcanović, mr Mirnes Duraković,** Univerzitet u Zenici, Fakultetska 3, 72000 Zenica, Bosna i Hercegovina, Tel: +387 32 449 147, Fax: +387 32 449 126.

E-mail: samir.lemes@unze.ba
halim.prcanovic@unze.ba
mirnes.durakovic@unze.ba

ETIKUM 2021

INTERNATIONAL SCIENTIFIC CONFERENCE
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Imamović, N., Birdahić, V., Kadušić, E.

IZRADA MODELA KARTE BUKE NA PRIMERU INDUSTRIJSKE ZONE

Rezime: *U radu su prezentirani rezultati monitoringa buke u okoliš i dat grafički prikaz modela karte buke kao postojećeg stanja nivoa buke za industrijsku zonu „Bukva-Vila“ u općini Tešanj, prema izmerenim podacima na bukomeru Brüel&Kjær uz primenu softverskih paketa iNoise i QGIS. Na osnovu izmerenih i obrađenih podataka utvrđen je uticaj industrijske buke na ukupnu buku u okolišu, te definisani delovi industrijske zone koji su najviše izloženi buci. Na osnovu izrađenog modela karte, konstatovano je da prosečni udio koji industrijska buka ima na ukupnu buku u okolišu iznosi cca 67,7%, da u periodu dana (06-22 h) na pet mernih mesta dolazi do prekoračenja graničnih vrednosti u proseku za 1,5 dB, a najveće odstupanje je 2,2 dB. Za period noći na jednom mernom mestu nivo buke za 0,7 dB prelazi graničnu vrednost od 70 dB. Predložene su mere i preporuke za smanjenje uticaja buke, te prema analizi rešenja prikazan je model karte buke kao dobra osnova za izradu prostornih i akcionih planova u perspektivi.*
Ključne reči**:** *buka, karta buke, iNoise, QGIS*

1. UVOD

Urbanizacijom i porastom broja stanovništva neminovno se javljaju problemi koji utiču na okoliš i čoveka. Jedan od tih problema je i buka. Najčešći izvori buke na otvorenom prostoru u urbanim sredinama uglavnom su promet i industrijska postrojenja koja mogu prouzročiti niz kratkoročnih i dugoročnih zdravstvenih problema, kao što su poremećaji spavanja, hipertenzija, povećanje nivoa stresa, oštećenja sluha i drugo.

Neadekvatno prostorno planiranje može povećati nivo buke, odnosno građenje industrijskih postrojenja u blizini stambenih objekata može rezultirati povećanjem nivoa buke u stambenim delovima. Monitoring buke je jedan od važnih alata upravljanja bukom u okolišu, jer predstavlja osnovu nacionalne politike i strategije upravljanja bukom, kao i planiranje mera za kontrolu buke i sprovođenje i unapređenje mera zaštite od buke. Uticaj buke na zdravlje ljudi i kvalitetu života potakle su Europsku komisiju na donošenje Direktive o procenjivanju i upravljanju bukom u okolišu – END (Environmental Noice Directive 2002/49/EC) koja je stupila na snagu u aprilu 2002. godini, a prema kojoj su države članice EU, kao i države koje to nameravaju postati obavezne izraditi jedan od najvažnijih alata upravljanja bukom i zaštitom od buke životnih prostora, tj. izraditi karte buke. Karta buke se definiše kao prikaz postojećeg i/ili predviđenog nivoa buke na promatranom području, izražena zakonskim unapred definisanim indikatorima buke. Najčešći podaci koje karta buke može sadržavati su prekoračenje propisanih dopuštenih vrednosti, procenjeni broj ljudi i objekata izloženih pojedinim nivoima buke na posmatranom području [1]. U Federaciji Bosne i Hercegovine koja svojim Zakonom o zaštiti okoliša („Službene novine Federacije BiH“ br. 15/21-Član 20.) propisuje zaštitu od buke - problemu buke u okolišu i alatima zaštite se ne posvećuje dovoljno pažnje. Proučavajući prostorno plansku dokumentaciju jasno se vidi da nema sistemskog praćenja buke u okolišu kao ni istraživanja ili statističkih podataka kojima bi se procenila izloženost stanovništva buci u smislu merenja, monitoringa i izrade karata buke uopće, a posebno partikularnih područja [2]. Bez mapiranja buke nije moguće rešavanje negativnog uticaja buke, kao ni smanjenje rizika na zdravlje stanovništva. Prema iskustvima država članica EU, najveće se poteškoće javljaju na početku procesu izrade karte buke jer je sam proces prikupljanja i obrade podataka dugotrajan i skup. U ovom radu, analiziran je i ocenjen uticaj i izrađena karta buke za područje industrijske zone „Bukva-Vila“ u Tešnju površine 59,5 ha, sa 38 privrednih subjekata koji zapošljavaju 3.800 radnika, izvršeno je merenje nivoa buke i komparacija sa graničnim vrednostima, te predložene mere za zaštitu od uticaja buke.

2. PRIKUPLJANJE I OBRADA PODATAKA PRIMENOM SOFTVERA *iNoise i QGIS*

Svrha merenja buke je postizanje tačnih i pouzdanih podataka koji će na pravi način prikazati situaciju u vezi s bukom i koja će biti osnova za buduća istraživanja. Merenje buke je provedeno u skladu sa BAS ISO 17025:2005 uz prethodno odobrenje i obuku pravnog lica ovlaštenog za obavljanje te delatnosti. Karakertistične veličine

koje su merene i na osnovu kojih se vršila ocena buke je ekvivaletni nivo buke u dB (A) (LAeq), nivo buke koji se pojavljuje 1% vremena merenja u dB(A) kao i Lmax, Lmin, L10 i L90. Prilikom merenja potrebno je opisati i meteorološke uslove (temperatura, relativna vlaga, brzina i smer vetra, opisati količinu i vrstu padavina, zasneženost i druga opažanja značajna za merenje buke). [3]

Danas je u upotrebi veoma širok dijapazon instrumenata namenjenih za merenje buke. Ističući primat merenja a ujedno zadovoljavajući ciljeve rada, tj. analizu i obradu dobijenih rezultata merenja pomoću bukomera, primenu softverskih paketa i izradu karte buke, praktični dio merenja je izvršen korištenjem bukomera Brüel & Kjær Tip 2250.

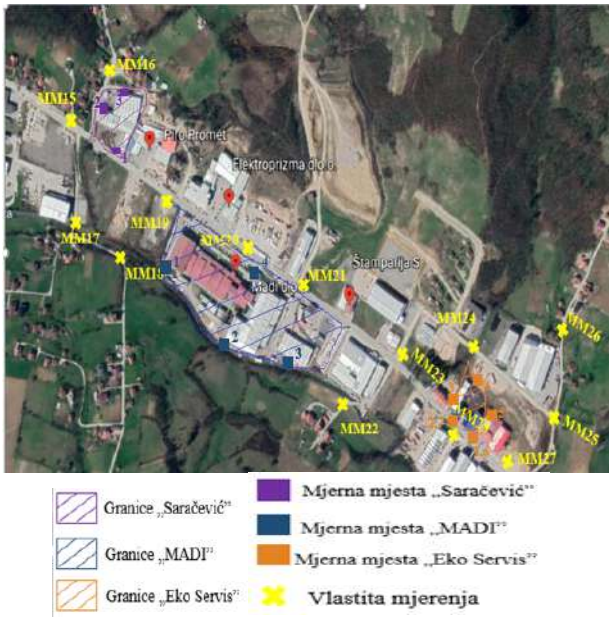
2.1 Primena softverskog paketa iNoise

Za potrebe izrade karte buke prema dosadašnjem monitoringu buke na području poslovne zone korišten je softver iNoise, a za kreiranje karte ukupne buke u okolišu duž čitave zone koja je izrađena na bazi praktičnih merenja korišten je softver QGIS. Softverski paket iNoise verzije V2021.1 predstavlja besplatan softver za akustično modeliranje industrijske buke u okolišu prema metodi ISO 9613 i preporukama standarda. Međutim, omogućuje unos velikog broja parametara pomoću kojih se opisuju sve stavke, koji na kraju rezultiraju realnim rezultatima. Jedna od tipičnih upotreba softvera iNoise, a i razlog zbog čega je izabran ovaj softver, je određivanje nivoa buke ako nije poznata zvučna snaga izvora industrijske buke. Program izračunava nivo buke na određenim lokacijama iz određenih izvora na temelju međunarodnih standarda.

2.2 Primena softverskog paketa QGIS

Za potrebe izrade karte ukupne buke u okolišu izabran je program Quantum GIS (QGIS) verzija 3.20.11. QGIS je računarska GIS aplikacija otvorenog koda koja omogućuje vizualizaciju, upravljanje, uređivanje i analiziranje geopodataka na Windows, Mac OS, Linux and Android (korištenjem Qfield aplikacije). [4] Kao i većina GIS aplikacija, QGIS omogućava izradu karata s većim brojem slojeva koji koriste različite projekcije karata. Obrađujući uvjete merenja i aparaturu, neizostavno je utvrditi broj i položaj mernih mesta u cilju dobijanja što reprezentativnijih podataka o stvarnom stanju nivoa buke na merenim područjima. Uz brojna ograničenja, odabrano je 28 mernh mesta prema Slikama 1. i 2., u blizini industrijskih postrojenja i na onim delovima koja predstavljaju granicu između dela industrijske zone „Bukva-Vila“ i naseljenih mesta Bukva, Logobare i Novo Selo.

Sl. 1. Karta 1- lokacije merenja nivoa buke



Sl. 2. Karta 2- lokacije merenja nivoa buke

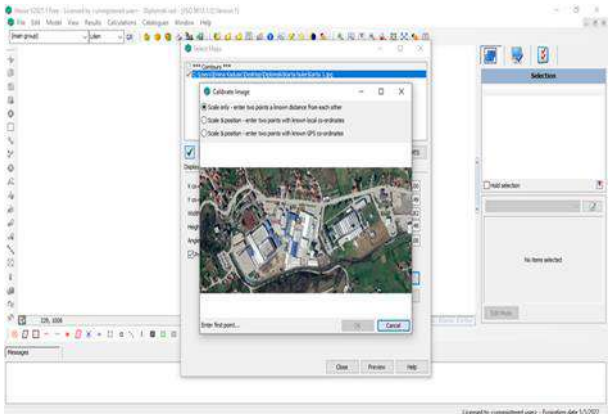
3. ANALIZA REZULTATA I IZRADA INDUSTRIJSKE KARTE BUKE

U cilju verodostojnosti merenja definisani su meteorološki uslovi koji su očitani sa aplikacije AccuWeather. Rezultati dobivenih vrednosti nivoa buke za navedene lokacije merenja merenih pomoću bukomera Bjuel&Kjaer samo za prekoračene vrednosti su prikazani u Tabeli 1., posebno za periode dnevnog i noćnog merenja.
U iNoise softveru jednostavno se slika sa Google Earth može georeferencirati u model korištenjem opcije View→Background Map→Calibrate.

Za kalibraciju karte kao što je prikazano na Slici 3. korištena je opcija Scale only za koju je potrebno poznavati udaljenost između dve odabrane tačke koja je već izmerena u programu Google Earth Pro.

Tabela 1. Rezultati merenja bukomerom (prekoračene vrednosti) za dnevni i noćni period

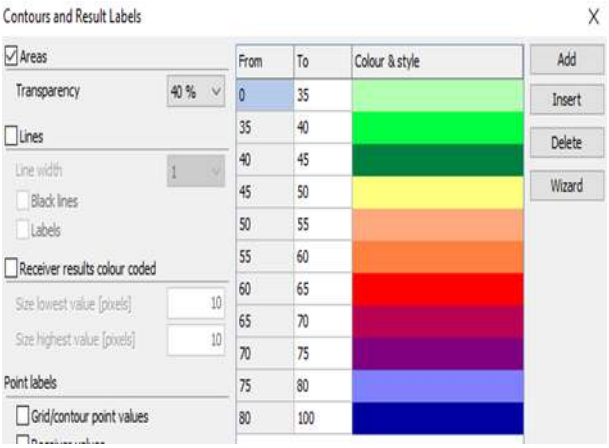
Merno mjesto	Broj vozila	Izmjerene vrijednosti [dB]					
	Put.+Ter. vozila	LA eq	L_1	LAF max	LAF min	LAF 90	LAF 10
	Dnevni period						
MM10	201+12	**71,9**	82,2	88,4	44,1	50,1	75,9
MM11	183+7	**71,1**	80,7	87,7	46,4	55,8	75,0
MM14	239+16	**71,8**	81,4	92,9	52,3	59,6	75,2
MM15	177+8	**72,2**	82,0	88,2	53,2	59,5	76,2
MM27	82+2	**70,7**	79,8	96,2	44,2	51,7	72,6
	Noćni period						
MM27	74+2	**70,7**	83,0	96,2	44,2	51,7	72,6



Sl. 3. Georeferenciranje karte u model

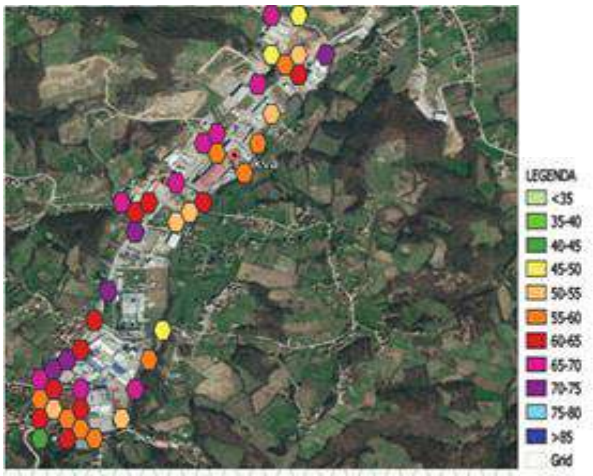
Nakon georeferenciranja karte, potrebno je postaviti mrežu za proračun samog modela. Mreža je nacrtana tako da pokriva čitavu površinu karte sa razmakom između mrežnih tačaka 10 m po x i y osi. Pored mreže modela, potrebno je postaviti i druge slojeve modela, kao što su objekti, vegetacijski sloj te stambena naselja. Svaki od slojeva kako bi bio potpun i da bi se mogao izvršiti proračun modela, potrebno je da ima visinu i da se ne presecaju jedan sa drugim. Pokretanje proračuna modela vrši se klikom na Calculations→Start Calcultation. Prije nego proračun se pokrene potrebno je izvršiti pregled modela korištenjem opcije Check Model, u slučaju da neki od parametara slojeva nedostaje ili se objekti presecaju. Nakon završetka proračuna potrebno je urediti kartu kreiranjem legende karte buke kao što je prikazano na Slici 4., tj. klasifikacijom nivoa buke u 11 klasa i postavljanjem transparetnosti karte buke na 40% kako bi bila vidljivija i georeferetna karta.

Prije početka rada u QGIS potrebno je odabrati koji koordinatni sistem će finalna karta imati, te koji je potreban za unos ostalih vektorskih i rasterskih podataka. U ovom slučaju to je WGS84 referetni koordinatni sistem. Unos kontrolnih tačaka vrši se otvaranjem padajućeg menija Layer→Add Layer→Add Vector Layer.



Sl. 4. Uređivanje karte buke izrađene u softveru *iNoise*

Na osnovu dnevnog i noćnog merenja na prostoru industrijske zone „Bukva-Vila“ izrađene su dve karte buke za period dana i noći za parametar Leq, zakonski propisanog indikatora nivoa buke u Federaciji BiH prema Zakonu o zaštiti od buke („Službene novine Federacije BiH“ br. 110/12).



Sl. 5. Karta buke za industrijsku zonu „Bukva-Vila“ za razdoblje dana (06-22 h)

Sa Slike 5. može se uočiti da izmerene vrednosti Leq na pet mernih mesta, tačnije MM10, MM11 i MM14, MM15 i MM27 prelaze zakonski dozvoljene vrednosti za industrijsku zonu koja iznosi 70 dB, i označeni su ljubičastom bojom koja predstavlja interval od 70-75dB. Međutim, interval prekoračenja granične vrednosti za ovih pet mernih mesta iznosi 0,7-2,2 dB.

Razlog povišenog nivoa buke nije rad najbližeg industrijskog subjekta, već frekvencija saobraćaja zbog povećane brzine kretanja vozila na ovoj dionici. Kao što se može uočiti na osnovu podataka sa Slike 6. u razdoblju noći na području ove zone dolazi do prekoračenja graničnih vrednosti propisanih za datu namenu prostora, samo na jednom mernom mestu. Izmerena vrednost za Leq

za period noći prekoračuje graničnu vrednost za 0,7 dB. Prema podacima postojećih merenja iz industrijskih postrojenja u ovoj zoni izrađene su karte buke za industrijska postrojenja, te uporednom analizom rezultata merenja bukomerom i korištenjem softvera na istim mernim mestima, utvrđeno je da udio industrijske buke na ukupnu buku u okolišu po mernim mestima varira od 48,1 do 92,6 %.

Sl. 6. Karta buke za industrijsku zonu „Bukva-Vila“ za razdoblje noći (22-06 h)

Zaštita od buke u poslovnoj zoni se postiže prvenstveno primenom mera kao što su:

- Edukativne mere (informisanje javnosti o uticaju buke na zdravlje, smanjenje brzine vozila pri vožnji, smanjenje korištenja sirena, savesna i vožnja vozila prema zakonskom ograničenju brzine za dato područje),
- Inženjerske mere (izgradnja barijera, oklopljavanje mašina, orentacija izvora buke dalje od naseljenih mesta, korištenje prigušivača zvuka, tiših ventilatora, izolacija zgrada, korištenje specijalno izolacionih prozora, ograničavanje izgradnje industrijskih postrojenja u blizini naseljenih područja),
- Zakonodavne mere (zona za poslovno stanovanje, konstruktivni zahtevi za zvučnu izolaciju elemenata zgrada itd.)

4. ZAKLJUČAK

Na osnovu rezultata merenja i izrade modela karte buke za predmetnu industrijsku zonu može se zaključiti sledeće:

-merenjem nivoa buke bukomerom i kompariranjem sa graničnim vrednostima za parametar Leq (70 dB), evidentno je da u periodu dana (06-22 h) na pet mernih mesta dolazi do prekoračenja graničnih vrednosti za 1,5 dB,

- najveće prekoračenje od 2,2 dB jeste na MM15 koje je prouzrokovano poslovnim aktivnostima najbližih privrednih subjekata, te zbog povećane brzine kretanja vozila na toj dionici,
- za period noći samo na jednom mernom mestu je nivo buke prelazio graničnu vrednost i to na MM27 za 0,7 dB, zbog povećane brzine vozila jer većina preduzeća ne obavlja aktivnost tokom noći,
- kompariranjem rezultata merenja bukomerom i korištenjem softvera na istim mernim mestima, utvrđeno je da prosečno 67,7% od ukupne buke u okolišu potiče od postrojenja iz industrijske zone,
- rezultati merenja buke i izrade karata buke u iNoisu i QGIS mogu biti odlična polazna osnova za izradu novog ili reprogram postojećeg prostornog plana, te za buduće istraživačke projekte koji treba da sadrže izradu modela zadanog područja, model građevina u gradu, model saobraćajnica, raspodelu stanovništa, meteorološke uslove tokom godine i sl.,
- rezultate izrade karata buke prema ovom radu je moguće iskoristiti za izradu obavezne i jedinstvene karte buke svih područja od važnosti, što se od odgovorne društvene zajednice shodno evropskim trendovima očekuje u budućnosti.

5. REFERENCE

1] Ahac M.; Ahac S; Dragčević V; Lakušić S. (2008)- *Prilog optimizaciji postupka izrade karata buke*, Građevinar, Vol. 60 No. 09., 2008., dostupno na: https:// hrcak.srce.hr /28951. (pristup: IX/ 2021.)

2] *Zagađenje bukom-često zanemaren okolišni problem*–BiH ESAP 2030+, dostupno na: https://esap.ba/bs/zagadenje-bukom-cesto-zanemaren-okolisni-problem/(pristup:IX/ 21.)

3] *Zakon o zaštiti od buke* (Službene novine Federacije BIH br. 110/12), dostupno na: http://www.fuzip.gov.ba, (pristup: IX/ 2021.)

4] Čurin P.,– *Dinamička karta buke grada Čakovca*, Međimursko veleučilište u Čakovcu -Stručni studij Održivi razvoj, 2018.

Autori: **V. prof. dr Nusret Imamović, Doc. dr Vehid Birdahić, dipl.inž. Emina Kadušić,**
Univerzitet u Zenici, Mašinski Fakultet Zenica, ul. Fakultetska 1, 72000 Zenica, BiH, Tel:+387 32 449 120, Fax: +387 32 246 612.
E-mail: nimamovic@mf.unze.ba
vehid.birdahic@unze.ba
emina.kadusic@dl.unze.ba

ETIKUM 2021

INTERNATIONAL SCIENTIFIC CONFERENCE
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Pravdić, P., Đorđević, V.

CAR FUELS CONSUMPTION OPTIONS AND THEIR IMPACT ON ENVIRONMENT

Abstract: *The fuel consumption testing scheme is intended to give potential car buyers comparative information about the relative fuel consumption of different models in standard tests. The different fuels have different merits from an environmental perspective. Compared to petrol, diesel vehicles have significantly lower CO_2 emissions per kilometre travelled because of the higher efficiency of diesel engines, and hence have a lower, though still significant, impact on climate change.*
Key words: cars, fuel options, testing, air pollution

1. INTRODUCTION

The different fuels have different merits from an environmental perspective. Compared to petrol, diesel vehicles have significantly lower CO2 emissions per kilometer travelled because of the higher efficiency of diesel engines, and hence have a lower, though still significant, impact on climate change. Diesel vehicles also emit lower levels of CO and HC than equivalent petrol vehicles. However, diesel engines emit greater levels of NOx than new petrol vehicles. As mentioned earlier, emissions of NOx are an air quality issue, particularly in urban areas. LPG and CNG cars are generally converted from petrol-fueled cars, either by the original manufacturer or by an aftermarket converter. For practicality, CNG and LPG cars tend to be bi-fuel, meaning that they can run on either petrol or the gaseous fuel. LPG vehicles tend to fall between petrol and diesel in CO2 performance. This is due to the lower carbon and higher energy content by mass of the fuel. CNG offers even lower CO2 emissions than LPG, typically comparable with that of diesels. Local pollutant (CO, HC, NOx and particulate matter) emissions performance of well-engineered LPG and CNG vehicles is similar to that of a petrol vehicle. Sustainable biofuels also offer a way to reduce the impact of vehicles on climate change. The fuels are not entirely CO2 neutral because of the energy used to grow and process crops, but they can offer substantial CO2 savings over fossil petrol and diesel. Today, most biofuels are sold in blends of up to 5% in fossil petrol and 7% in fossil diesel. These blends are suitable for use in nearly all vehicles. Some manufacturers offer 'flexi-fuel' vehicles that can run on bioethanol blends up to E85 - a blend of 85% bioethanol with 15% petrol - as well as fossil petrol. Some manufacturers also allow the use of higher blends of biodiesel in their vehicles (check with your vehicle manufacturer). It is important that only high quality biodiesel meeting the European quality standard - EN 14214 - is used. Blended fuels produced to the EN228 or EN590 standards will contain high quality biofuel as a matter of course [3].

2. THE FUEL CONSUMPTION TESTING SCHEME

The fuel consumption testing scheme is intended to give potential car buyers comparative information about the relative fuel consumption of different models in standard tests. Nearly all new car models which are type approved for sale in the European Union have to undergo the standard tests to determine their fuel consumption. Official fuel consumption test procedures have been in use since the 1970s. EU Directive 80/1268/EEC as amended or, for Euro 5 vehicles onwards, Regulation 692/2008 describe the tests which all new cars on sale after 1 January 2001 are required to take. The current test for conventional internal combustion engine vehicles has two parts. These are an urban and an extra-urban cycle. The test cycle is the same as that used to determine the official exhaust air quality pollutant emission classification for the model of vehicle in question. The cars tested have to be ‘run-in’ so they must have been driven for at least 1,800 miles (3,000

kilometers) before testing. The urban test cycle is carried out in a laboratory at an ambient temperature of 20°C to 30°C on a rolling road from a cold start where the engine has not run for several hours. The cycle consists of a series of accelerations, steady speeds, decelerations and idling. The maximum speed is 31 mph (50 km/h). The average speed 12 mph (19 km/h) and the distance covered is 2.5 miles (4 km). The cycle is shown as Part One in the diagram below. The extra-urban cycle is a cycle that is intended to represent the use of the vehicle on roads that are external to the urban environment. The cycle is conducted immediately following the urban cycle and consists of roughly half steady-speed driving with the remainder being accelerations, decelerations, and some idling. The maximum speed is 75 mph (120 km/h). The average speed is 39 mph (63 km/h) and the distance covered is 4.3 miles (7 km). A range of factors may influence actual fuel consumption - for example, driving style and behavior, as well as the environment and conditions under which the vehicle is operated. Furthermore, since several different specifications (variants or versions) of a given model may be grouped together in the list, the figures used in this guide should be treated as indicative only. Vehicles which are designed to run on LPG or CNG and Petrol are required to be tested on both fuels. In view of this, two sets of figures will be shown for a given bi-fuel vehicle. One set for the vehicle running on petrol, and another for the vehicle running on gas. Hybrid vehicles usually combine an internal combustion engine with an electric motor and battery. There are various ways in which hybrid vehicles can operate. For example, the vehicle may be able to operate solely on its engine, solely on battery power, or on a combination of the two with the battery providing additional power during acceleration and high load conditions. The battery can then be recharged by the internal combustion engine or from energy absorbed during braking or, in some cases, from an external electrical supply. Hybrid vehicles can offer reduced fuel consumption and CO2 emissions, and potentially some reduction in emissions of local pollutants, especially in stop-start motoring. Plug-In Vehicle (PIV) is the term for any vehicle that is powered, either in part or in full, by a battery that can be recharged by plugging into an external electricity supply [1,2]. This includes those that run purely on electricity (pure-electric) and plug-in hybrid electric vehicles. This guide includes those cars that use a combination of a conventional petrol or diesel engine and battery propulsion. These are known as ‘petrol-electric hybrid’, ‘diesel-electric hybrid’ [8]. Cars that run purely on electricity are also listed in the guide but, since they do not use liquid fuel or emit CO2 while being driven, there is no data given for the fuel consumption or CO2 emissions of pure electric models.

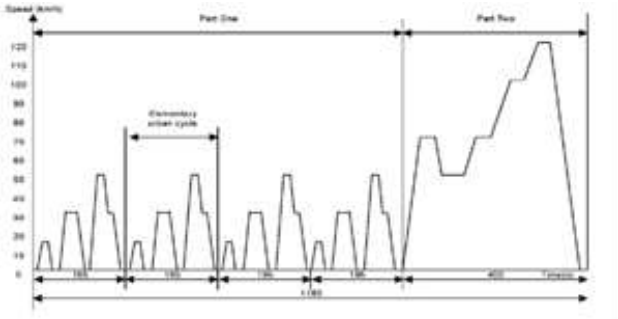


Fig. 1. Testing scheme

Cars not exceeding 2.5 tonnes laden – Euro 5 – EC Regulation EC/715/2007

Table 1 - Euro 5

Number of seats	Fuel	Limit values (mg/km)							Implementation Dates	
		CO	THC	NMHC	NOx	THC+NOX	PM	Particles (number/km)	Type Approval of new models	All Models
up to 9	P	1000	100	68	60	–	5.0/4.5	–	1/09/09	1/01/11
up to 9	D	500	–	–	180	230	5.0/4.5	6.0×10^{11}	1/09/09	1/01/11

Key: P- petrol, D - diesel, CO - carbon monoxide, HC - hydrocarbons, NOx - oxides of nitrogen, PM - particulate matter

Table 2 - Euro 6

Cars not exceeding 2.5 tonnes laden – Euro 6 – EC Regulation EC/715/2007

Table 2 - Euro 6

Number of seats	Fuel	Limit values (mg/km)							Implementation Dates	
		CO	THC	NMHC	NOx	THC+NOX	PM	Particles (number/km)	Type Approval of new models	All Models
up to 9	P	1000	100	68	60	–	5.0/4.5	–	1/09/14	1/09/15
up to 9	D	500	–	–	80	170	5.0/4.5	6.0×10^{11}	1/09/14	1/09/15

Key: P- petrol, D – diesel, CO – carbon monoxide, HC – hydrocarbons, NOx – oxides of nitrogen, PM – particulate matter

Fig. 2. Emission limits relating to vehicles

3. EXHAUST AIR QUALITY POLLUTANT EMISSIONS TESTING

Before passenger cars can be type approved for sale in the European Union, they must meet certain standards for exhaust emissions of air quality pollutants [7]. In 2007, European Regulation EC/715/2007 introduced Euro 5 and Euro 6 limits [6]. Since the 1st January 2011, all new cars have been required to be approved to the Euro 5 standard and as from 1st September 2015 tested to the more stringent Euro 6 standard [5]. As with the fuel consumption tests, a single vehicle representative of a particular version is tested. Because the testing procedures are intended to confirm whether a car meets a Euro standard or not, the type approval emission figures listed in

the tables should not be used for other purposes, such as to rank a number of vehicles [4,5]. Because of the need to maintain strict comparability of the results achieved by the standard tests, they cannot be fully representative of real-life driving conditions. Firstly, it is not practicable, nor is it viable to test each individual new car. Only one production car is tested as being representative of the model and this may produce a slightly better or worse result than another similar vehicle. Secondly, there are infinite variations in driving styles, as well as road, car and weather conditions, all of which can have a bearing on the results achieved. For these reasons the fuel consumption achieved on the road is unlikely to be the same as the official test results [9]. The purpose of the official fuel consumption test is to provide data that will permit a comparison of the fuel consumption of different cars, rather than to provide an estimate of average, on-the-road, fuel economy [10]. It is recognized that, for a variety of reasons, the fuel consumption achieved by the majority of motorists is poorer than that suggested by the standard tests, and work is going on with the intention of introducing a new test cycle which will better represent the way in which most people actually use their cars. The testing is carried out either by independent test organizations, or by the vehicle manufacturers or importers themselves, usually at their own test facilities. In the UK, and before the results are officially recognized, the DfT will:

- ✓ inspect the test laboratories and witness some tests being carried out, or;
- ✓ check that the figures have been certified by a European member state national authority under the agreed arrangements for mutual recognition of test results.

Almost all types of new passenger cars have to be tested. However, several models which do not differ significantly in certain technical characteristics important in determining fuel consumption may be grouped together into a 'class'. Only one representative car of each class needs to be tested [11]. Certain types of vehicles are excluded from the fuel consumption testing scheme. These are cars manufactured in low volume, cars adapted to carry more than eight passengers (excluding the driver), three-wheelers, invalid carriages, van-derived passenger cars and cars built specially for export. These vehicles will not, therefore, be labelled in showrooms. [11]

4. CONCLUSION

The principal air-quality pollutant emissions from petrol, diesel, and alternative-fuel engines are carbon monoxide, oxides of nitrogen, un-burnt hydrocarbons and particulate matter. It is emissions of these pollutants that are regulated by the Euro emissions standards. Modern cars, if kept in good condition, produce only quite small quantities of the air quality pollutants, but the emissions from large numbers of cars add to a significant air quality problem. Carbon monoxide, oxides of nitrogen, and un-burnt hydrocarbons are gases, and are generally invisible. Particulate matter is usually invisible although under certain operating conditions diesel engines will produce visible particles, appearing as smoke. Petrol engines will also produce visible particles if they are burning engine oil or running "rich", for example, following a cold start. Fine particles can also be produced by tyre and brake wear. Pollutant emission levels depend more on vehicle technology and the state of maintenance of the vehicle. Scientists use sophisticated instruments to measure concentrations of harmful substances in the air, but it's tough to say exactly what percentage of air pollution comes from cars. This makes sense, because many other human activities contribute to air pollution as well. In fact, the production of electricity by coal-fired power plants and other sources can cause more pollution than most cars. If that wasn't enough, we pollute the air when we heat our homes and public buildings with fuels other than electricity -- just as we do when we drive our cars. Even people who don't drive add to pollution when they buy goods and services that involve fuel when they're made or delivered.

5. REFERENCES

[1] https://waqi.info/sr/
[2] https://www.airnow.gov/aqi/aqi-basics/
[3] https://aqicn.org/
[4] https://www.amazon.com/Urban-Air-Quality-International-Hertfordshire/dp/9401061556
[5] https://www.unep.org/explore-topics/resource-efficiency/what-we-do/cities/urban-environmental-planning

[6] https://ec.europa.eu/environment/air/quality/
[7] https://www.who.int/data/gho/data/themes/topics/topic-details/GHO/ambient-air-pollution
[8] https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health
[9] https://www.iomworld.org/media/1242/iom_tm0601.pdf
[10] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/304641/COMEAP_mortality_effects_of_long_term_exposure.pdf
[11] https://www.epa.gov/ground-level-ozone-pollution

Authors: **Assis. prof. dr Predrag Pravdić, Assis. prof. dr Violeta Đorđević,** Academy of professional studies Šumadija, Department in Trstenik, Radoja Krstića 19, 37240 Trstenik, Serbia, Phone.: +381 37 714 121.
E-mail: ppravdic@asss.edu.rs
vdjordjevic@asss.edu.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Savković, M., Đapan, M., Mačužić, I., Vukićević, A., Jovičić, M.

MODEL FOR THE OCCUPATIONAL SAFETY AND HEALTH IMPROVEMENT IN SMALL AND MEDIUM ENTERPRISES IN SERBIA

Abstract:*Given the occurrence of a large number of accidents and injuries at work, occupational diseases and work-related diseases in small and medium enterprises (SMEs) in Serbia (as evidenced by statistics), improving the occupational safety and health of workers (OSH) in these companies is essential importance. Improving OSH (through the implementation of preventive measures, increasing investment in OSH programs, continuous training/education of employers and employees, etc.) reduces injuries at work and occupational diseases, detects and eliminates or reduces hazards that can endanger life, safety and worker health.*

The main goal of the paper is to emphasize the specifics of occupational safety and health management in SMEs, to point out the most common problems that occur in small and medium enterprises in Serbia, to emphasize the importance of improving OSH in these companies.

The paper proposes a complex model of OSH improvement with four basic dependent variables (level of organization safety and health, occupational injuries and occupational diseases, economic consequences of occupational injuries and occupational diseases and business results) and several variables that have a direct impact on these four variables.

Key words: *Occupational safety and health, OSH model,Small and medium enterprises, workplace safety improvement*

1. INTRODUCTION

Modern companies that perform activities in accordance with the principles of world-class production strive to achieve the highest level of safety and health at work, minimize injuries at work, occupational and work-related diseases and provide safe working conditions in which employees would be undisturbed performed work activities and had a sense of satisfaction when performing professional tasks. The application of proactive and preventive technical, organizational, health, psychological and other measures detects and eliminates or reduces hazards that may endanger the safety and health of workers and thus improves the safety and health of workers.

Small and medium enterprises (SMEs) are considered to be the main drivers of economic growth and development of the national and world economy, the greatest potential for self-employment and generators of new jobs [1]. In the countries of the European Union (EU-28), small and medium enterprises cover 99.8% of all enterprises and employ 66.8% of the total number of employees [2]. In Serbia, the SME sector comprises 99.8% of all enterprises and generates 64.8% of employees, 65.4% of turnover and 56% of gross value added [3].

Employees in small and medium enterprises in Serbia are generally more often exposed to dangers, injuries at work (in the form of burns, blows, bone fractures, internal injuries, head injuries etc.), occupational diseases and work-related diseases, unlike workers in larger companies. Also, injuries at work and occupational diseases are more common in SMEs in developing countries, where workers do not have adequate health and social protection. The reason for that can be found in the fact that in small and medium enterprises, workers are exposed more often to physical hazards, chemical and biological hazards.

Injuries at work and occupational diseases in small and medium-sized enterprises can have catastrophic consequences. Injuries at work cause a decrease or loss of working ability and a decrease in life activities. Absence from work causes an increase in costs and expenses due to sick leave, additional hiring new workers. Even small accidents can cause long-term absence from work due to occupational disease and recovery [4] and experienced and skilled workers in these companies cannot be easily and quickly replaced. Also, serious injuries can lead to a drop in productivity and interruptions in production.Personal injury at work in these companies comes due execution of the operations onunsafe manner and unsafe workingconditions.

Given the large number of accidents and injuries at work and the more frequent occurrence of occupational and work-related diseases in small and medium enterprises in Serbia and taking into account the fact that injuries at work and occupational diseases negatively affect economic indicators, improve safety and health workers in these companies is essential.

Improving safety and health at work, reducing deaths, injuries at work and occupational diseases, improving ergonomic conditions in the work environment and achieving full physical, mental and social well-being of employees is a legal obligation of all small and medium enterprises. The paper is structured as follows: after the introduction, the paper points out the specifics and basic characteristics of OSH management in SMEs and points out the basic problems of OSH management in SMEs. In the next part of the paper, a complex integrated model of OSH management in SMEs is presented and explained. In the concluding part, concluding remarks are given.

2. SPECIFICS OF OCCUPATIONAL SAFETY AND HEALTH MANAGEMENT IN SMALL AND MEDIUM ENTERPRISES IN SERBIA

According to the European Agency for Safety and Health at Work [5], the challenges in managing the safety and health of workers in small and medium-sized enterprises are increasing given that workers in those enterprises are due to unsafe and risky working conditions and non-compliance with procedures, non-application of preventive measures, inadequate use of equipment exposed to higher risks of injuries at work and occupational diseases than workers in larger companies. Also, in SMEs there is a problem related to poor work organization, inadequate assignment of workers and redeployment of workers from one job to another without professional training (especially from the practical part) and training for safe work [6]. The occurrence of injuries at work is greatly contributed by the performance of activities under the influence of alcohol or psychoactive substances.

Workers in SMEs are most often exposed to noise, vibrations, strong light, extreme temperatures, radiation, which causes the appearance of numerous occupational diseases. Also, workers in these companies are exposed to chemical hazards - gases, dust and toxic fumes. Workers in SMEs most often suffer from high blood pressure, cardiovascular disorders and diabetes and mental illness (depression and anxiety). Due to lifting and carrying heavy loads, frequent non-ergonomic and repetitive movements (for example, pushing and pulling), workers suffer from musculoskeletal diseases. Work pressure and stress to which workers in these companies are exposed cause fatigue, decreased attention and concentration, and lead to errors during activities.

The most common problems that occur in small and medium enterprises in Serbia are related to the large number of non-permanent workers (compared to larger enterprises). In SMEs, employees are hired without employment contracts, mostly on a part-time basis or work overtime (weekends or night shifts), do not have adequate expertise and experience and are not sufficiently trained to perform activities. All this contributes to the increased risk of injuries at work and occupational diseases. Also, the SMEs does not keep records on the correctness of machines and electrical installations, and that can further cause accidents and injuries at work.

In SMEs in Serbia, there are problems when keeping records of injuries at work and the occurrence of occupational diseases. Statistics on injuries at work and occupational diseases are the basis for the implementation of programs for the prevention of injuries at work and occupational diseases. The data differ because there is no single register for keeping injuries at work and occupational diseases.

In addition to the underdeveloped awareness of the importance of safety and health at work, the reason for the greater number of injuries at work and occupational diseases in SMEs in Serbia lies in the lack of time and inability to provide financial resources needed to implement laws and bylaws in this area and to respect international norms and standards. The specifics of SMEs in Serbia are reflected in: inadequate management of safety and health of workers and lack of necessary documentation. Also, small and medium enterprises in Serbia, unlike SMEs at the EU level, are characterized by unsafe conditions in which workers perform professional tasks and inadequate use of personal protective equipment, etc [7].

Unlike SMEs at the EU level, where the importance of improving safety and health at work is recognized, in SMEs in Serbia, the necessary attention was not paid to safety and protection at work, legislation was applied selectively or not applied at all. The focus of SMEs in Serbia is focused on solving the problem of financial survival and not on the implementation of preventive measures, timely elimination of the causes of injuries at work and occupational diseases and prevention of their consequences.

Unlike SMEs at the EU level, where the importance of improving safety and health at work

is recognized, in SMEs in Serbia, the necessary attention was not paid to safety and protection at work, legislation was applied selectively or not applied at all. The focus of SMEs in Serbia is focused on solving the problem of financial survival and not on the implementation of preventive measures, timely elimination of the causes of injuries at work and occupational diseases and prevention of their consequences.

3. MODEL FOR THE IMPROVEMENT OCCUPATIONAL SAFETY AND HEALTH IN SMALL AND MEDIUM ENTERPRISES IN SERBIA

Figure 1. presents an integrated model for occupational safety and health improvement in small and medium enterprises that points to a causal link between four dependent variables: the level of occupational safety and health, occupational injuries, the economic consequences of occupational injuries and work-related illness, and business results. The level of safety and health of workers in SMEs is affected by: leadership and commitment of management, OSH awareness, value system in the organization, OSH policy and compliance with regulations and procedures in this area, training/education of employees and management, workorganisation, workplace characteristics and workers characteristics.

Increasing safety levels contributes to reducing the number of injuries at work, occupational diseases and work-related illnesses.The greatest responsibility for improving OSH in SMEs is taken by the employer and management, although to a large extent workers take responsibility for the safe implementation of activities and the implementation of OSH interventions [8]. Employers are obliged to provide employees with safe conditions in the work environment and the necessary equipment and means for personal protection in accordance with the requirements of the workplace and regular conduct of systematic examinations.

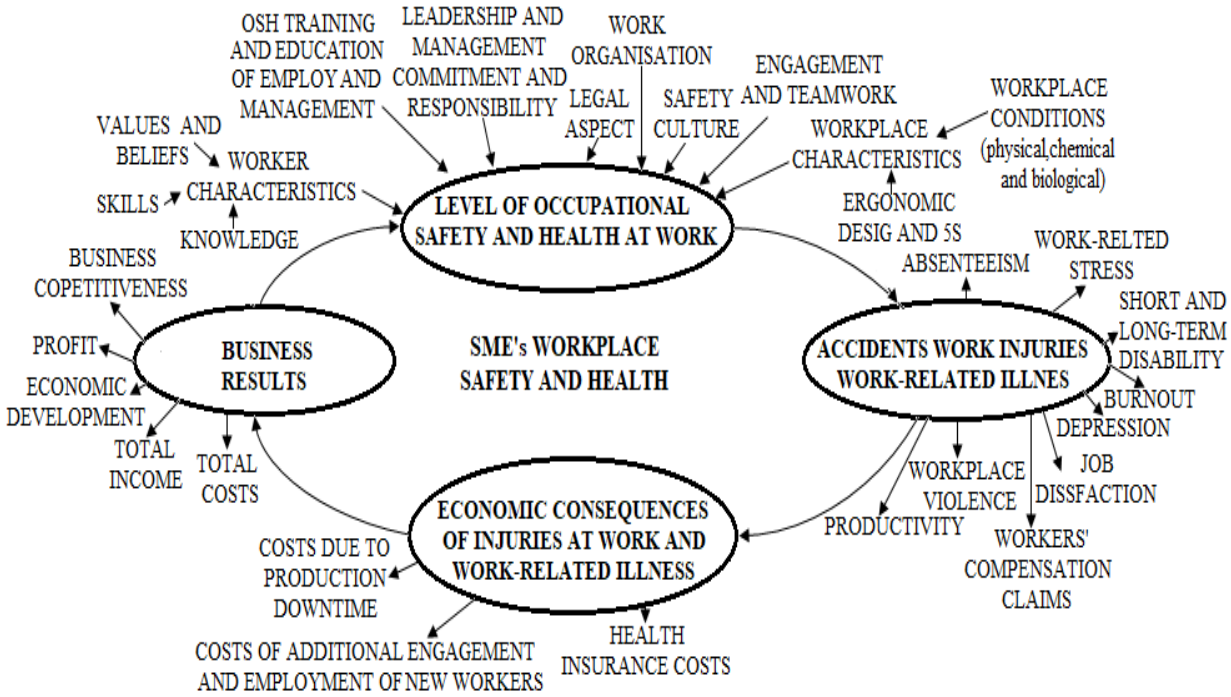


Fig. 1. Model for the occupational safety and health improvement

The employer is obliged to ensure that the activities performed by workers are adjusted to the physical and mental abilities and capabilities of workers. The management of the company is obliged to systematically monitor and eliminate all potential hazards in the workplace. If an incident occurs, the employer is obliged to visit the location where the incident occurred, collect the necessary data, statements of participants and eyewitnesses, responsible persons and experts in the field of OSH and make records of the event itself.

Management is also responsible for motivating employees to perform activities in a safe manner and applying best safety practices. Managers must ensure that all employees are instructed in occupational safety and health regulations. Top management is required to show leadership and commitment and take responsibility for preventing injuries at work or impairing health, eliminating

hazards and harms in the workplace.SME employees take responsibility for the safe handling of equipment and have an obligation to report to the employer and top management if a problem arises that could jeopardize their safety.

The increase in injuries at work and occupational diseases causes an increase in costs in the company (OSH costs, costs of production downtime, costs related to hiring a new worker, etc.). An increase in these costs leads to an increase in total costs in the company and a decrease in profits and this further leads to a decrease in the investment of financial resources in OSH program. The ISO 45001 standard promotes the importance of implementing preventive measures and programs in order to eliminate or reduce injuries at work, occupational diseases and work-related diseases.Improving OSH in SMEs in Serbia can be achieved by implementing proactive measures, increasing the investment of financial resources in OSH programs, continuous education of employers and employees in this field, etc. In this way, hazards will be eliminated or reduced and the safety, health and well-being of workers in the work environment will be improved.

Continuous implementation of training and coaching of workers will contribute to the prevention of reckless and unsafe performance of activities. Setting clear instructions for safe work on machines and equipment will prevent injuries at work. Providing personal protective equipment and encouraging employees to use it minimizes the risk of injuries at work and occupational diseases.

Improving the safety and health of workers is based on a legal framework. Safety and health at work is determined by the conventions of the International Labor Organization (ILO), European Union directives and the Lisbon Treaty. The area of safety and health at work in Serbia is regulated by the Law on Safety and Health at Work and bylaws.

4. CONCLUSION

This paper presents an integralmodel of OSH improvement that points to a causal link between four dependent variables: the level of occupational safety and health, occupational injuries, the economic consequences of occupational injuries and work-related illness, and business results.Improving OSH in SMEs reduces injuries at work and occupational diseases, detects and eliminates or reduces hazards that can endanger life, safety and worker health.Improving OSH in SMEs in Serbia can be achieved by implementing proactive measures, increasing the investment of financial resources in OSH programs, continuous education of employers and employees in this field.

5. REFERENCES

[1] Spicer, D., Sadler-Smith, E.:*Organizational learning in smaller manufacturing firms*, International Small Business Journal, 24 (2), 2006.

[2] Muller, P., Caliandro C., Peycheva V., Gagliardi D., Marzocchi C., RamloganR., Hope, K.: *Annual report on European SMEs 2014/2015*, The European Commission, Directorate -General for Internal Market, Industry, Entrepreneurship and SMEs, 2015.

[3] Sertić, Ž., *Report on small and medium-sized entreprises and enrepreneurship for 2014*, Belgrade: The Ministry of Economy, 2015.

[4] Kongtip P., Yoosook W., Chantanakul S.:*Occupational health and safety management in small and medium-sized enterprises: An overview of the situation in Thailand*, Safety Science 46, 2008.

[5] European Agency for Safety and Health at Work, available at: http://osha.europa.eu/en/publications/reports

[6] *Occupational risk prevention in SMEs in Europe*-thematic report, Eurogip, 2009.

[7] Savković M., Đapan M., Mačužić I., Todorović P., Radenković M., Vukićević A., Mijović N.: *Barrierrs, challegnes and opportunities to improve occupational health and safety management in small and medium enterprises in Serbia: case study approach*,pp. 369-377, 13 th International quality conference-quality festival 2019, Kragujevac, 29 May - 1 June 2019.

[8] Lansdown T., Deighan C., Brotherton C.:*Health and safety in the small to medium sized enterprise*, Heriot Watt University for the Health and Safety Executive, 2007.

Authors: **Marija Savković, Prof. dr Marko Đapan, Prof. Dr Ivan Mačužić, Arso Vukićević, Miloš Jovičić,** University of Kragujevac, Faculty of Engineering, Sestre Janjić str. 6, 34000 Kragujevac, Serbia, Tel/fax: +381 34331-772

E-mail: marija.savkovic@kg.ac.rs
djapan@kg.ac.rs
ivanm@kg.ac.rs
arsokg@yahoo.com
milos.jovicic@gmail.com

ETIKUM 2021

INTERNATIONAL SCIENTIFIC CONFERENCE
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Savković, M., Jovičić, M., Vukićević, A., Mačužić, I., Todorović, P.

RESEARCH ON THE POSSIBILITY OF IMPROVING THE SAFETY AND HEALTH AND EFFECTIVENESS OF WORKERS WHO PERFORM MANUAL WORK ACTIVITIES USING EXOSKELETONS

Abstract: *The main focus of the paper is to explore the possibilities of improving the occupational safety and health and effectiveness of workers who perform manual work in the automotive industry using industrial exoskeletons. Exoskeletons are mechanical devices that workers carry and that support workers and strengthen their physical abilities (strength and endurance) when performing difficult, manual and physically demanding tasks that cannot be automated (such as lifting loads and handling loads, positioning and using tools, handling objects, etc.), and enable them to perform their work activities more effectively.*

The analysis of numerous examples from practice concluded that the use of exoskeletons contributes to the reduction of injuries at work and the improvement of the general health of workers through the reduction of musculoskeletal disorders, neck, shoulder, back pain, stress and fatigue. Also, the application of industrial exoskeletons increases the efficiency, productivity and effectiveness of workers.

Key words: *Effectiveness, Exoskeletons, Improving safety and health*

1. INTRODUCTION

One of the important goals of modern companies is to improve the safety and health of workers. This goal is achieved through reduction of occupational injuries, occupational diseases and diseases related to work and creating prerequisites for full physical, mental and social well-being of employees.

The application of new innovative technologies of Industry 4.0 and the automation and digitalization of production processes contribute to the improvement of working conditions and the improvement of safety and health of workers [1]. Despite the automation and digitization of the process, many workers who performing manual, repetitive and physically demanding work activities are still exposed to physical strain (more than 30% of workers in the EU face this problem). Also, 63% of workers perform activities that involve repetitive movements and 46% of workers perform activities in non-ergonomic body positions [2].

Exoskeletons are one of the innovative supporting technologies of the fourth industrial revolution, which is applied to provide help and support to workers who are exposed to physical load while performing daily repetitive and physically demanding work activities in non-ergonomic body positions. Workers who perform these activities are exposed to the dangers of musculoskeletal disorders due to frequent bending, twisting, body strain, manual handling of large and awkward objects and loads.

Musculoskeletal disorders are one of the most common occupational diseases, considering that these diseases affect millions of workers globally. Also, in the European Union, more than 40% of workers experience pain in the lower back, neck and shoulders that occur as a result of performing these professional tasks [2]. An analysis of numerous studies has concluded that performing 70% of repetitive work tasks in industry such as assembly of components and parts can cause musculoskeletal disorders and 60% of physically demanding professional activities performed by workers cause back and shoulder pain [3].

This is especially pronounced in the automotive industry, where workers perform repetitive, tedious professional tasks in non-ergonomic positions over a long period of time, which negatively affects their health [4]. Musculoskeletal disorders make it difficult and in some cases impossible to perform professional tasks and are one of the main causes of workers' absence from work and can lead to temporary or permanent incapacity for work.

Taking into account the fact that musculoskeletal disorders cause high costs for employers and the state as a whole, due to the costs of sick leave, costs associated with rehabilitation of injured workers and the cost of hiring and training replacement workers, modern companies show great interest in applying innovative Industry 4.0 technologies to reduce workers' exposure to risk factors that can cause

musculoskeletal disorders. Exoskeletons, unlike other Industry 4.0 technologies used to reduce the physical workload of workers (eg collaborative robots), do not require large financial investments and therefore find application in the industrial environment.

The paper is structured as follows: after the introduction, exoskeletons are presented in detail and several examples from the practice of applying exoskeletons in industry are given. After that, the paper points out the possibilities of improving the occupational safety and health and effectiveness of workers who perform manual work activities using exoskeletons in an industrial environment. Concluding remarks are given in the conclusion.

2. INDUSTRIAL OCCUPATIONAL EXOSKELETONS

The appearance of the first exoskeletons is related to the period 1960-1970. These wearables were first used in the military to improve the physical capacity and strength of soldiers, and medicine to provide support to people with disabilities or handicapped people during the rehabilitation period and later began to be used in industrial environments.

Exoskeletons began to be used preventively in industry (production, construction, mining, etc.) in order to improve the health of workers when other preventive measures did not prove effective in reducing fatigue and physical exertion of workers and reducing musculoskeletal disorders.

Exoskeletons are mechanical and medical support devices that have the role of providing support and assistance to workers in performing difficult, manual and physically demanding work tasks that cannot be automated. Exoskeletons support the musculoskeletal system, applying the principle of mechanics. In this way, they contribute to the prevention or reduction of the risk of musculoskeletal disorders due to the performance of difficult manual tasks such as manipulation, lifting and carrying heavy objects.
Exoskeletons enhance the physical abilities of workers (e.g., strength and endurance), reduce the compression of force on the lower back, shoulders, elbows, and joints, and thus protect workers from injury to these parts of the body. The use of exoskeletons reduces fatigue and strain on the muscular system of workers and improves their general health. They provide support to the worker's body during positioning or tool use. Also, exoskeletons support to workers who have some physical deficiency. Exoskeletons make it easier for workers to perform activities with their arms raised above their heads for extended periods of time (such as when using a drill overhead or in the process of assembling components and parts) (Figure 1.).

Fig. 1. Ford 75 ExoVest exoskeleton [5]

Exoskeletons are classified into passive (their goal is to provide support and protection) and active (they have a role to increase strength and endurance of workers). Active exoskeletons use starters (mechanical components that consist of electric motors or have hydraulic or pneumatic drive, etc.) to support the movement and activities of workers, give them extra strength and endurance, and increase their performance. An example is the active exoskeleton for the upper body, which was used in Fiat in Italy to provide support to the hands of workers so that workers could lift heavy objects with ease. In this way, the load on the joints and muscles is reduced and the health condition of the workers is improved.

Unlike active passive exoskeletons use the force of a spring or shock absorber to store energy collected during the movement of workers or perform activities and use it as needed to support the position or movement of workers. For example, when a worker leans forward, energy is collected that later helps him maintain that position or lift his body when lifting an object [6]. So, the power is redistributed in order to protect certain parts of the body.

Passive exoskeletons that support the back are most commonly used in industry and are designed to prevent lower back pain [7]. The passive exoskeleton for the lower part of the body is placed as a "chair" and is applied when workers often change positions or stand for a long period of time. By using this exoskeleton, the load in the legs is reduced and it is easier to adopt the correct positions on the one hand, and on the other hand, the flexibility and mobility of the body parts are maintained.

Also, exoskeletons differ depending on the parts of the body on which they are applied. These

support devices can provide additional strength or support to the lower limbs of workers (exoskeletons applied to the lower body), upper extremities (exoskeletons applied to the upper body) or can provide support to the whole body (both upper and lower extremities). In October 2018, Hyundai Motor Group at the North American plant Hyundai-KIA began testing the Hyundai Vest Exoskeleton, which aimed to reduce pressure on the neck and back of workers, and the Hyundai Chairless Exoskeleton used by workers who have to perform standing activities for a longer period of time. This exoskeleton is placed as a "chair" so that the worker can rest. In this way, the load on the legs and back is reduced and the mobility of the worker is facilitated (Figure 2.).

Fig. 2. Example of an exoskeleton that takes on the role of a "chair" [8]

After the application of these exoskeletons, injuries at work and occupational diseases were reduced and the efficiency and productivity of workers was increased. Exoskeletons enable older workers to perform their work tasks more efficiently. Also, exoskeletons are used by workers who were injured during the rehabilitation period.

Exoskeletons are flexible, ie. they are adapted to the individual characteristics of workers - their age, gender, health status, etc. Exoskeletons also differ depending on the material from which they are built and the accompanying technologies. Rigid exoskeletons, ie. exoskeletons made of rigid materials due to their weight and unnatural body position when worn can cause stress and fatigue. Therefore, exoskeletons made of soft, light and flexible materials are mostly used in the industrial environment.

The use of exoskeletons is regulated by the European Union Machinery Directive (2006/42/EC). Also, the application of exoskeletons must be harmonized with the general international regulations for robots and robotic devices (ISO 10218-1:2011 and ISO 13482:2014). The international standard ISO 8373:2012 (ISO, 2012) is related to the application of robots and robotic devices in an industrial environment.

3. IMPROVING THE SAFETY AND HEALTH AND EFFECTIVENESS OF WORKERS WHO PERFORM MANUAL WORK ACTIVITIES USING EXOSKELETONS

Analysis of numerous studies can conclude that the application of exoskeletons contributes on the one hand to improving working conditions and improving the safety and health of workers and on the other hand to increasing the efficiency and productivity of workers, reducing errors and improving the quality of work. Exoskeletons contribute to the reduction of injuries at work and the improvement of the health condition of workers who perform manual repetitive tasks for a longer period of time in a continuously in an incorrect position [9].

In large production systems such as Toyota, Ford and Boeing, positive effects of exoskeleton application have been observed in the form of reduction of effort and muscle fatigue, reduction of discomfort, reduction of injuries at work and reduction of sick leave costs. Numerous experimental results have shown that the use of exoskeletons in most cases reduces the load on the spine [6]. Also, the application of exoskeletons has resulted in increased worker productivity and improved work quality.

In the past period, there has been an increase in the use of passive exoskeletons on assembly lines. The application of these exoskeletons has led to numerous benefits. For example, after the application of ExoVest exoskeletons in the Ford Motor Company during 2015-2016, there was a reduction in injuries of workers on the production line by 83% [10]. Several scientific research papers have indicated a reduction in muscle fatigue from 10 to 40% after the application of exoskeletons [11, 12]. The study [13] proved the positive effects of the application of exoskeletons on the back muscles (muscle fatigue decreased by 10-25%) and the spine (spine load was reduced by 12-13%).

In some cases, exoskeletons can be used instead of collaborative humanoid robots because, unlike robots, exoskeletons do not require large financial resources and do not need to be programmed.

4. CONCLUSIONS

Workers who perform manual, repetitive,

precise, physically demanding professional activities that cannot be automated (such as material handling, lifting and moving objects) and workers who perform activities in a non-ergonomic body position are often exposed to musculoskeletal disorders. The application of exoskeletons in these workers aims to improve safety and health through the reduction of musculoskeletal disorders, reduction of pain in the neck, shoulders, back, reduction of fatigue and strain of workers. On the other hand, the application of exoskeletons contributes to the improvement of economic indicators in the form of increasing the efficiency and productivity of workers, reducing errors and improving the quality of work.

5. REFERENCES

[1] Aazam, M., Zeadally, S., Harras, K. A.: *Deploying fog computing in industrial internet of things and industry 4.0*, IEEE Transactions on Industrial Informatics, pp. 4674-4682, 14 (10), 2018.

[2] Eurofound: *Fifth European working conditions survey*, Luxembourg: Publications Office of the European Union, 2012.

[3] Aziz, F. A., Ghazalli, Z., Mohamed, N. M. Z., Isfar, A.: *Investigation on musculoskeletal discomfort and ergonomics risk factors among production team members at an automotive component assembly plant*, IOP conference series: materials science and engineering, 257 (1), 2017.

[4] Landau, K., Rademacher, H., Meschke, H., Winter, G., Schaub, K., Grasmueck, M., Schulze, J.: *Musculoskeletal disorders in assembly jobs in the automotive industry with special reference to age management aspects*, International Journal of Industrial Ergonomics, pp. 561-576, 38(7-8), 2008.

[5] *Exoskeletons boost productivity and safety for manufacturers*, available at: https://www.controleng.com/articles/exoskeletons-boost-productivity-and-safety-for-manufacturers/

[6] de Looze, M. P., Bosch, T., Krause, F., Stadler, K. S., O'Sullivan, L. W., *Exoskeletons for industrial application and their potential effects on physical work load*, Ergonomics, pp. 671- 681, 59(5), 2016.

[7] Huysamen, K., Bosch, T., de Looze, M., Stadler, K. S., Graf, E., O'Sullivan, L. W.: *Evaluation of a passive exoskeleton for static upper limb activities*, Applied Ergonomics, pp. 148-155, 70, 2018.

[8] *Industrial exoskeletons expand worker capabilities to help healthcare*, https://www.therobotreport.com/industrial-exoskeletons-expand-capabilities/

[9] Savković, M., Dašić, M., Đapan, M., Vukićević, A., Mačužić, I., Stefanović, M.: *Improving workplace safety using advanced Industry 4.0 technologies*, XI International Conference Industrial Engineering and Environmental Protection 2021 (IIZS 2021), pp. 553-560, Zrenjanin, Serbia, October 07-08, 2021.

[10] Dave B. *Exoskeletons unveiled at Ford manufacturing plant*, 2017, available at: http://www.thedrive.com/sheetmetal/15921/exoskeletons-unveiledat-ford-manufacturing-plant

[11] Abdoli-Eramaki, M., Agnew, M. J., Stevenson, J. M.: *An On-body Personal Lift Augmentation Device (PLAD) Reduces EMG Amplitude of Erector Spinae during Lifting Tasks*, Clinical Biomechanics, pp. 456-465, 21 (5), 2006.

[12] Godvin H. Y., Muramatsu M.: *Wearable Lower-limb Assistive Device for Physical Load Reduction of Caregiver on Transferring Support*, Advanced Intelligent Mechatronics, IEEE/ASME International Conference, pp. 1027-1032, 2013.

[13] Graham, R. B., AgnewM. J., Stevenson, J. M.: *Effectiveness of an On-body Lifting Aid at Reducing Low Back Physical Demands during an Automotive Assembly Task: Assessment of EMG Response and User Acceptability*, Applied Ergonomics, pp. 936-942, 40 (5), 2009.

Authors: **Marija Savković, Miloš Jovičić, Arso Vukićević, Prof. dr Ivan Mačužić, Prof. dr Petar Todorović**, University of Kragujevac, Faculty of Engineering, Sestre Janjić str. 6, 34000 Kragujevac, Serbia, Tel/fax: +381 34 331-772.
E-mail: marija.savkovic@kg.ac.rs
milos.jovicic@gmail.com
arso_ kg@yahoo.com
ivanm@kg.ac.rs
petar@kg.ac.rs

ETIKUM 2021

INTERNATIONAL SCIENTIFIC CONFERENCE
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Cveticanin, L., Ninkov, I.

BENEFITS AND LACKS OF THE SELF-DRIVING CARS INCLUDING THE ASPECT OF ENVIRONMENTAL PROTECTION

Abstract: *Recently in the era of the 4th Industrial Revolution the new Cyber-Physical Systems are developed. One of the most perspective is the self-driving car (SDC) which is expected that would introduce the inovation not only in transprotation but the whole life properties of population. In the paper the expected benefits of the SDC would be considered. Special attention is given to the environmental protection due to decrease of emission and fues consumption of the vehicle. Nevertheless, our investigation show that some inconvenince and barriers for application of SDC may occur. Based on these results improvment in SDC design, manufacturing and operating is suggested.*
Key words: *Self-driving car, environmental protection, benefit of transportation*

1. INTRODUCTION

One of the most important cyber-physical system (CPS) developed during the recent Fourth Industrial Revolution is the self-driving car (SDC). SDC is defined as an autonomous vehicle without driver [1]. Instead of human driver, SDC is operated, navigated and controlled by the artificial intelligent (AI) i.e. with the cyber system which gives decisions based on the data collected by sensors of the car and from passengers. Due to the requirement of the new civilization the intention is to introduce SDCs in the traffic in the whole world as soon as possible. Recently, it can be seen that the technics of the SDC is almost finished. The already produced SDCs are launched and tested on certain public roads in a few countries of the world. SDC is designed to overcome the problems of the conventional cars and to give advantages according to them. In the paper advantages and disadvantages of SDC in comparison to the convencional cars are discussed. It is beleived that SDCs will be accepted if their application will eliminate the most negativ effects of the cars which we use now.

In the paper the aspects of safety and security, environmental protection, social, economics, ethics and legal are considered [2].

2. SAFETY AND SECURITY ASPECTS

The greatest expected benefit in applying SDC is the reduction of traffic accidents and collision, especially, of traffic fatalities and death-accidents [3]. It is proposed that the number of accidents would tremendously decrease and specially the death-ones. The autonomous vehicle excluded many human errors of the driver like tired even sleeping, aggressive drive, inattention, impossibility reacting in time, etc. The statistics made by US government shows that 94% of the vehicle accidents are due to human failures. Connection of SDC with the big data basis enables the AI of vehicle to give the real time decision in the shortest time and to avoid the accident. An advantage could be the use of real-time traffic information and other generated data to determine and execute routes more efficiently than human drivers. The time savings can be invaluable in these situations.

The security aspect of SDC is very important to be considered. The fear of disturbing privacy and uncertain cyber-security may be assumed as the disadvantage of SDC [4]. Namely, in spite of special programs embedded, SDCs may be easily hacked. Criminals may use the data that they retrieve, hacking the vehicle and getting it to perform actions the user is unaware of, unable to undo, and maliciously causing harm to persons in the car. Cyber-criminals can cause minor nuisances (closing or opening windows), or they can create greater threats (disable the functionality of car to read stop signs, causing crash of vehicles, harm passengers), or they can use SDCs for terrorist purposes (transporting and detonating bombs) [5]. The cyber-security in SDC has to be increased before inclusion of vehicle into the traffic.

3. ENVIRONMENTAL IMPACTS AND BARRIERS

One of the biggest polluters of the environment

are land vehicles that use diesel fuel and gasoline as fuel. The problem of air pollution caused by the combustion of fuel in the engine is being addressed by a large number of researchers. A number of measures have been proposed and introduced through laws regulating permitted pollution for vehicles. Modern tendency in the production of new SDC, as an autonomous vehicle, is believed to alleviate and contribute to air pollution problems. It is expected that SDC technology would decrease the energy use in engines and decrease the pollution or would use another type of power which is not the pollutant. Uncertainty about the environmental pollution caused with SDC mainly depends on the following factors Liu *et al* (2019a): type of the driving fuel, consumption of fuel to specific weight of SDC, driving style and distance-fuel consumption.

3.1 Improvemnt in engine and driving style

Due to improvement in automation of SDC with convention engines, progress in fuel consumption is expected. For minimizing the pollution and improving the fuel economy in SDC driven with convention fuel the drive cycle has to be optimized. In addition, the car has to move at the constant speed controlled with the automatic system. SDC stops and slows down less and the velocity of motion is almost constant. For automated car acceleration and deceleration would be much smoother than that done by the human driver. SDCs would be able to accelerate and brake more efficiently, meaning higher fuel economy from reducing wasted energy typically associated with inefficient changes to speed. It would decrease the fuel consumption for 4-10 percent and the carbon emission, too.

3.2 Consumption of fuel to specific weight of SDC

For SDC it is expected that the number of crashes would be smaller than in the case of manually driven cars. It allows the weight of the vehicle to be decreased. The lighter is the vehicle, the fuel consumption is smaller. The emission of CO_2 is also decreased.

Light SDCs may be efficiently driven with electric current. The electrically powered SDC would not pollute the air directly, but it need recharging infrastructure, which is not developed at the moment. However, since SDCs are going to rely on electricity to operate, the demand for lithium batteries would increase.

Similarly, sensors and high-speed internet connectivity require higher auxiliary power from vehicles, which manifests as greater power draw from batteries. The larger battery requirement causes a necessary increase in supply of these type of batteries for the chemical industry. The production of lithium batteries is connected with serious environment pollution.

3.3 Distance-fuel consumption

An aspect of environmental protection and pollution minimizing is by decrease of miles of travel with SDC. However, there is the dilemma and skepticism whether the travel distances would decrease. Namely, it is expected that convenience of the SDC would encourage the consumers to travel more because of the comfort, ease of travel, ability to multitask, but also reduced stress in driving, and this would destroy the results of improvement done by automation. There is the fear that the kilometers of drive would be longer than at the moment, too, due to the fact that some persons with disabilities, old persons, non-drivers, etc., would use the SDCs and increase the travelling distanced. People will be able to commute longer distances because of the comfort of SDCs. It would increase the fuel consumption and environment pollution.

The improvement in vehicle energy efficiency does not necessarily translate to net reduction in energy consumption and positive environmental outcomes. So, the consequences of application of SDC on global energy demand and emissions are highly uncertain, and heavily depend on the combined effect of changes in consumer behavior, policy intervention, technological progress and vehicle technology.

4. SOCIAL ASPECTS

SDCs open the social dilemma of autonomous vehicles [6] and the future impact of these vehicles in general [7]. The questions are oriented toward: travel behavior and demands in SDC, inclusion old and disabled persons, non-drivers and also children, joy of drive and car – sharing.
SDC may be be prepared for multipurpose usage (business and/or leisure) and to be comfortable not only for transport but also relaxation, sleep, and even work [8]. SDC could be redesigned for long-distance travel or as fully equipped bedroom, for example. It is believed that due to benefits of SDC most of passengers would chose the drive with this vehicle instead of short-distance flight.
SDCs will have a severe impact on the mobility options of persons that are not able to drive a vehicle themselves: children, senior citizens, non-

drivers and persons with disabilities. It is expected that using SDC the transportation of elders but also disabled persons would be simplified and the dependence on caretakers would be decreased.
Incorporation of SDC in the traffic is expected to decrease the urbanization due to solved transport-net. Some people would rent far away from the city centers because commuting would be at reduced cost.

In the near future the driver interactions with the vehicle will be less common and in the more distant future the responsibility for drive will lie entirely with the vehicle. Passengers have to believe in reliability of SDC and pay less attention to the road. Due to improved comfort, ease of travel, ability to multitask and also reduced stresses in driving it is expected that the people would accept to ride SDC. Nevertheless, there are some social barriers to SDC. Some drivers are not ready to give up of the joy of driving. The other social barrier to SDC is the share-trip. For better efficiency of SDC it is expected that the passengers would share the trip in SDC. Not all persons are ready to share the car during driving especially with strangers. It is extremely evident in the era of global pandemic situation.

5. ECONOMIC IMPACT

SDC is believed that would have a significant influence on the economic transformation. Economic impacts of SDC are connected with luxury vehicle business, choice of fuel (electricity and power), job loses of professional drivers, change of infrastructure, increasing of traffic on roads, etc.

In 2016 the US Highway Association reported that only 5% of available road space was taken up by manually driven cars and the capacity of cars per hour per lane was about two thousand. It is predicted that the introduction of SDC would increase the capacity up to eight thousand (due to vehicle increased speed), or even to 12 thousand for 100% connected vehicles using vehicle-to-vehicle communication, traveling safely at 120 km/h and following distance of about 6 m of each other. However, this optimization of road exploitation requires very sophistical software and nets connections between cars and infrastructure and new road signalization.

If the transport with SDCs would act, the number of personal cars necessary for transport passengers would be reduced and the fuel consumption would decrease which would have a big economic consequence. At the other side, SDC powered by electricity require recharging infrastructure which has to be built. The same requirement is for refueling infrastructures for SDCs with fuel cells.

Recently, it is reported that manually driven cars are used only 4-5% of the time and the remaining time are parked. Introducing the SDCs into passenger transport the efficiency of vehicle use would be drastically improved, as the autonomous vehicle as a taxi can drive continuously. The parking time and also the number of parking places would be drastically decreased. For non-personal SDC the parking place can be removed from roadside and the city would be free up for other properties like parks, recreational areas, buildings etc. Location of the parking can be outside the city where land is cheaper.

It is found that SDCs would make many jobs redundant [9]. A direct impact of widespread adoption of automated vehicles is the loss of driving-related jobs, job losses in public transit services, etc. SDCs is expected to have small number of accidents and the number of crash repair shops and employees in these shops would decrease.

6. SOME DOUBTS IN BENEFITS

It is expected that SDC would reduce the number of cars that would be individually owned the so called ‘personal-owned cars’ and would be replaced by taxi/pooling and other car-sharing services. It would disrupt the standard model of car ownership and dramatically reduce the size of the car production industry.

As collisions are less likely to occur, and the risk for human errors is reduced significantly, the repair industry will face an enormous reduction of work that has to be done on the reparation of cars. At the other side, as the autonomous vehicle must have proper maintenance and the technical data of the vehicle are visible, the prediction for replacing parts (mainly mechanical) can be predicted and scheduled by reparatory industry.

There is the doubt about air pollution and consumption of conventional fuel due to uncertainty of kilometers of drive. If the short-distance drive would be included (people will not to be pedestrians or ride bicycle), as it is obtained as the result of interview, riding kilometers would increase and the pollution and fuel consumption would increase. Scholars and people have opposite opinion in the matter.

Inclusion of SDC would attack the health of population [10]. Due to comfort in driving, people would not go on foot or ride bicycle, but would

arrange many short-distance trips. They would not be pedestrians and would decrease the everyday walking.

As an unexpected conclusion about traffic without fatal accidents is that there would be a reduction in organs available for transplant.

The SDC, as the electric vehicle, was considered from the viewpoint of environment protection. However, it is found that the use of electric vehicles are an attack on the safety of pedestrians and those riding bicycle or motorcycle. The reason is that the noise of electric vehicle is of low level and does not attract the attention to other traffic contributors. To overcome the problem the additional noise have to be produced and incorporated.

7. FINAL REMARKS

Based on the results of previous analysis it can be concluded that there would be a great difficulty in transition of privately owned cars to shared SDCs. The primary reason is that the most of population is not ready to change the life style. Popularization and dissemination of knowledge about SDC is urgently necessary if it is expected the success of the project.

SDCs in traffic would: reduce accidents but also congestion and jams and give better traffic organization, increase human mobility, special of those who currently are unable to drive (elders, non-drivers, disabled, children), ride would be in modern vehicle which are very comfortable and adopted for long-distance trips, work, relaxation, better time spend, etc.

Problem of lithium batteries as environment pollution is the new one which has to be solved

Level of safety and security in SDCs has to be increased best to protect data and privacy by introducing corresponding algorithms. It need also valid legalization in this topic which will decrease the risks and challenges related to safety, legal liability, security and especially cybersecurity.

Significant infrastructure changes have to be done in signalization, in vehicle – infrastructure and in power stations for electric cars and fuel batteries. Centers for directing and monitorins of SDC traffic have to be developed. The need for car-drivers would be stopped, but new professions like operators of SDC and IT technicians for modulating the vehicle, operating with infrastructures, etc. would be introduced. At the moment the legal regulation is not justified with technical aspects and has to be adopted and modified to SDC. New rules for SDC producing and operating have to be prepared according to safety and security requests. Predicting future is uncertain, but uncertainty is a natural element of planning and forecasting.

8. REFERENCES

[1] Society of Automotive Engineers (SAE) International: Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles, *Standard* J3016_201806, USA, 2018.

[2] Ryan, M.: *The future of transportation: ethical, legal, social and economic impacts of self-driving vehicles in the year 2025*, Science and Engineering Ethics, 26(3), 1185-1208, 2020.

[3] Liu, P., Zhang, Y., He, Z.: *The effect of population age on the acceptable safety of self-driving vehicles*, Reliability Engineering and System Safety 185, 341-347, 2019.

[4] Stevens, T.: *cybersecurity: New directions in theory and methods*, Politics and Governance, 5(2), 1-4, 2018.

[5] Kyriakidis, M., Happee, R., De Winter, J.C.F.: *Public opinion on automated driving: Results of an international questionnaire among 5000 respondents*, Transportation Research Part F: Traffic Psychology and Behaviour 32, 127–140, 2015.

[6] Bonnefon, J.F., Shariff, A., Rahwan, I.: *The social dilemma of autonomous vehicles*, Science 352, 6293, 1573–1576, 2016.

[7] Marletto, G.: *Who will drive the transition to self-driving? A socio-technical analysis of the future impact of automated vehicles*, Technological Forecasting & Social Change 139, 221-234, 2019.

[8] Fagnant, D.J. & Kockelman K. (2015) *Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations*, Transportation Research Part A 77, 2015.

[9] Benedikt, F.C., Osborne, M.A.: *The future of employment: How susceptible are jobs to computerisation?* Technological Forecasting and Social Change 114, 254–280, 2017.

[10] Wickens, C.D., Dixon, S.R. : *The benefits of imperfect diagnostic automation: A synthe-sis of the literature*, Theoretical Issues in Ergonomic Science, 8(3), 201-212, 2007.

Authors: **Livija Cveticanin,** University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia.

Ivona Ninkov, Doctoral School of Safety and Security Sciences, Obuda University, Nepszinhaz u. 8, Budapest, Hungary

E-mail: cveticanin@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Dakić, N., Reljić, V., Dudić, S., Milenković, I., Komar, N.

SMANJENJE NEGATIVNIH UTICAJA SISTEMA VAZDUHA POD PRITISKOM NA ŽIVOTNU SREDINU OPTIMIZACIJOM DUŽINE PNEUMATSKIH CREVA

Rezime: *Prilikom projektovanja novih i adaptacije postojećih sistema vazduha pod pritiskom, važno je voditi računa o energetskoj efikasnosti i zaštiti životne sredine. Jedan od načina kojim se postiže povećanje energetske efikasnosti i smanjenje negativnih uticaja sistema vazduha pod pritiskom na životnu sredinu je i smanjenje dužine pneumatskih creva između aktuatora i njima pripadajućih komandnih razvodnika. U ovom radu je prikazano da, iako jednostavna i jeftina za implementaciju, ova metoda može značajno doprineti rešavanju prethodno navedenih problema.*

Ključne reči: *Dužina pneumatskih creva, Emisija CO_2, Energetska efikasnost*

1. UVOD

Savremenim proizvodnim sistemima, usled potrebe za minimizacijom negativnih uticaja na okolinu i zaštitu životne sredine, smanjenjem emisije CO_2, kao i obezbeđivanjem uštede energije, a posledično i novca, nameće se kao imperativ povećanje energetske efikasnosti. Energetska efikasnost može se definisati kao skup organizovanih aktivnosti u okviru definisanog sistema koje za cilj imaju uštedu ulazne energije, smanjenje emisije štetnih gasova, i troškova proizvodnje i predstavljena je jednačinom 1 [1]:

$$E_k[\%] = \frac{E_u - E_g}{E_u} \cdot 100\% \qquad (1)$$

gde su E_u, E_k i E_g ulazna energija, korisno utrošena energija i energija gubitaka, respektivno. Iz prikazane jednačine može se zaključiti da je povećanje energetske efikasnosti moguće postići bilo obezbeđivanjem korišćenja minimalne potrebne količine ulazne energije za ostvarivanje zahtevanih izlaznih veličina, bilo težnjom za eliminacijom gubitaka energije u sistemu.

U savremenim proizvodnim sistemima, veoma često se sreću sistemi vazduha pod pritiskom (pneumatski sistemi). To su sistemi koji korišćenjem vazduha pod pritiskom kao radnog medijuma omogućavaju vršenje različitih operacija rada poput pakovanja, stezanja, pomeranja, bušenja, sečenja, sortiranja i slično [2].

1.1 Energetska efikasnost sistema vazduha pod pritiskom

Većina primena sistema vazduha pod pritiskom je energetski neefikasna iz razloga što se tek deo proizvedenog vazduha pod pritiskom iskoristi za obavljanje efikasnog rada.

Povećanje energetske efikasnosti ovih sistema sa stanovišta njihove upotrebe može se obezbediti na više načina [1]:

- detekcijom i saniranjem mesta curenja vazduha pod pritiskom;
- pravilnim izborom komponenti i odgovarajućeg upravljanja;
- regulacijom radnog pritiska u aktuatorima u zavisnosti od mase predmeta rada kojim se rukuje [3] ili smanjenjem radnog pritiska u povratnom (neopterećenom) hodu aktuatora;
- rekuperacijom vazduha pod pritiskom [4];
- upravljanjem uz primenu širinsko impulsne modulacije [5] itd.

U ovom radu, u laboratorijskim uslovima rada, ispitan je uticaj smanjenja dužine pneumatskih creva na energetsku efikasnost sistema, a posledično i na životnu sredinu. Naime, u najvećem broju slučajeva, sistem vazduha pod pritiskom je realizovan na način da se aktuatori i svi odgovarajući signalni elementi postave na mesto vršenja operacije rada, dok se upravljački elementi, poput elemenata za obradu signala (kao što su, na primer, logički ventili) i komandnih razvodnika, postavljaju u razvodni orman. Ovakav način realizacije predstavlja tzv. centralizovani način upravljanja. To znači da je u nekim slučajevima potrebno koristiti pneumatska creva velike dužine za spajanje aktuatora sa komandnim razvodnicima, što dalje uslovljava veću potrošnju vazduha pod pritiskom. Drugačiji način rasporeda pneumatskih komponenti može se realizovati izmeštanjem komandnih razvodnika izvan razvodnog ormana, bliže aktuatoru, čime se dobija tzv. decentralizovani način upravljanja. Na ovaj način smanjuje se dužina pneumatskih creva, čime se smanjuje i zahtevana količina vazduha pod pritiskom što dovodi do potencijalno značajne uštede energije.

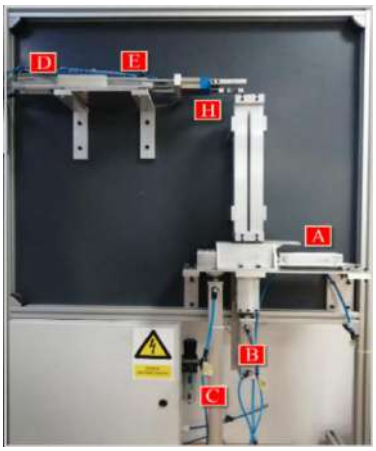
Radi ispitivanja uticaja smanjenja dužine pneumatskih creva na energetsku efikasnost

sistema, odnosno na životnu sredinu, izvršena je transformacija centralizovanog upravljačkog sistema u decentralizovani i analizirani su rezultati dobijeni merenjem potrošnje vazduha pod pritiskom u ova dva slučaja.

2. EKSPERIMENTALNA POSTAVKA

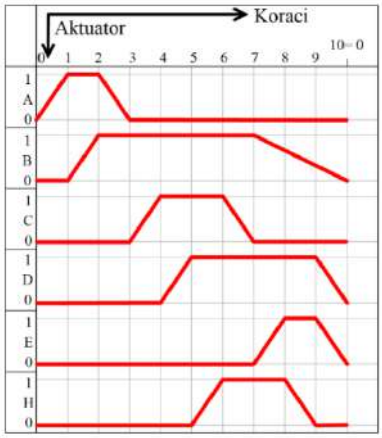
2.1 Pneumatski kružni manipulator

Za ispitivanja koja su prikazana u ovom radu korišćen je pneumatski kružni manipulator (slika 1), koji je razvijen na Fakultetu tehničkih nauka u Novom Sadu i čija je uloga simuliranje kontinualnog procesa rada kakvi postoje u savremenim proizvodnim sistemima.



Sl. 1. Pneumatski kružni manipulator [3]

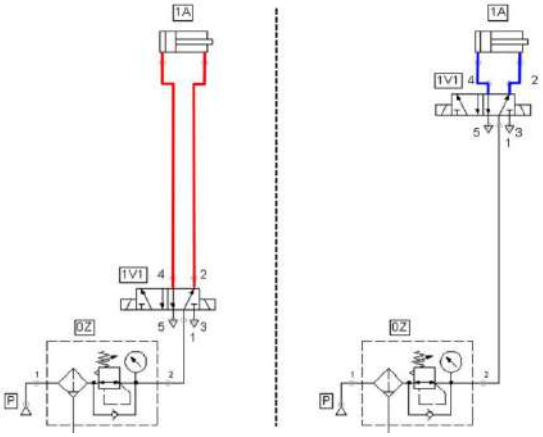
Manipulator se sastoji od pet pneumatskih cilindara dvosmernog dejstva (slika 1, pozicije A-E), jedne pneumatske hvataljke (slika 1, pozicija H), vertikalnog privremenog skladišta za predmete rada i pripadajuće mehaničke konstrukcije sa integrisanim razvodnim ormanom (slika 1, donji levi ugao). Radi lakšeg razumevanja rada manipulatora dijagram put-korak kružnog manipulatora dat je na slici 2.



Sl. 2. Dijagram put-korak pneumatskog kružnog manipulatora

2.2 Transformacija centralizovanog upravljačkog sistema u decentralizovani

Kao što je već prethodno napomenuto, smanjenjem dužine creva između komandnih razvodnika i aktuatora dolazi do potencijalno značajnog smanjenja potrošnje vazduha pod pritiskom jer je, osim komora samih aktuarora, tokom rada sistema, vazduhom pod pritiskom potrebno napuniti i odgovarajuća pneumatska creva, kao i razvodne elemente. To znači da bi se smanjenjem dužine pneumatskih creva između komandnog razvodnika i aktuatora smanjila i zapremina koju je neophodno napuniti vazduhom pod pritiskom. Razlika između dužine creva u slučaju kada su komandni razvodnici smešteni u razvodni orman (kao što je u slučaju pneumatskog kružnog manipulatora prikazanom na slici 1, odnosno u slučaju centralizovanog načina upravljanja), i u slučaju kada su komandni razvodnici izmešteni što je moguće bliže aktuatorima (decentralizovani način upravljanja), ilustrativno je, za jedan cilindar, prikazana na pneumatskoj upravljačkoj šemi (slika 3).



Sl. 3. Prikaz dužine pneumatskih creva:
a) Centralizovani način upravljanja;
b) Decentralizovani način upravljanja [1]

Radi lakšeg razumevanja, na slici 4 prikazan je jedan od načina izmeštanja komandnog razvodnika iz razvodnog ormana i njegovog postavljanja direktno na cilindar (cilindar A sa slike 1).

Sl. 4. Komandni razvodnik postavljen na cilindar

3. REZULTATI

Kako bi se utvrdile stvarne vrednosti potrošnje vazduha pod pritiskom za jedan radni ciklus, radi dobijanja tačnijih rezultata, izvršeno je merenje protoka vazduha pod pritiskom za 12 ciklusa rada kružnog manipulatora pomoću AirBox uređaja kompanije Festo [6]. Iz dobijenih vrednosti protoka, potrošnja vazduha pod pritiskom je izračunata korišćenjem jednačine 2:

$$Q = \frac{1}{2}\sum_{i=1}^{n}(t_i - t_{i-1})\,(q_i + q_{i-1}) \qquad (2)$$

gde je:

Q – ukupna potrošnja vazduha pod pritiskom (Nl);

t_i – vreme merenja (s);

t_{i-1} – prethodno vreme merenja (s);

q_i – vrednost protoka vazduha pod pritiskom u trenutku t_i ($\frac{\mathrm{Nl}}{\mathrm{min}}$);

q_{i-1} – vrednost protoka vazduha pod pritiskom u trenutku t_{i-1} ($\frac{\mathrm{Nl}}{\mathrm{min}}$).

Vrednosti protoka vazduha pod pritiskom tokom vremena za slučaj centralizovanog pneumatskog sistema prikazane su grafički na slici 5. Prosečna vrednost potrošnje vazduha pod pritiskom, dobijena kao aritmetička sredina broja ciklusa, tokom jednog ciklusa rada manipulatora za prikazani slučaj iznosi Q = 12,14 Nl.

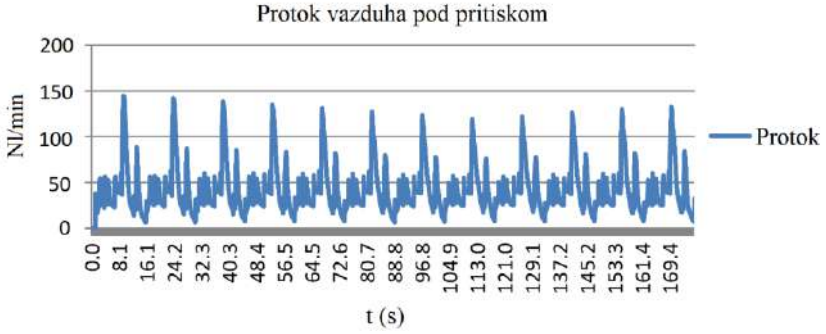
Nakon modifikacije sistema i transformacije u decentralizovani način upravljanja smanjenjem dužine pneumatskih creva, izvršeno je ponovno merenje protoka vazduha pod pritiskom i dobijene vrednosti grafički su prikazane na slici 6. Prosečna vrednost potrošnje vazduha pod pritiskom tokom jednog ciklusa rada manipulatora, ponovo dobijena kao aritmetička sredina broja ciklusa, u ovom slučaju iznosi Q = 9,25 Nl.

Na ovaj način, smanjenjem dužine creva i izmeštanjem komandnih razvodnika iz razvodnog ormana što je moguće bliže aktuatorima, ostvarena je ušteda u potrošnji vazduha pod pritiskom od ΔQ = 2,82 Nl po jednom radnom ciklusu, što procentulano iznosi cca 23%.

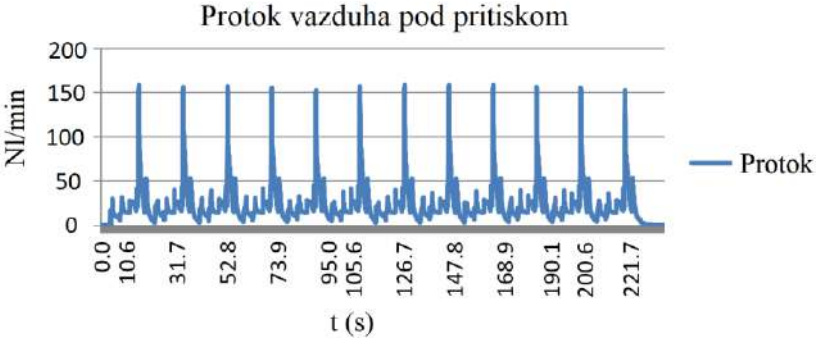
4. DISKUSIJA

Kako bi se odredio doprinos prikazane metode za uštedu vazduha pod pritiskom povećanju energetske efikasnosti sistema ovog tipa i smanjenju negativnih uticaja na životnu sredinu potrebno je analizirati slučaj kao da je prikazani sistem bio implementiran u okviru nekog proizvodnog sistema u industriji.

U prikazanom slučaju, kao što se može zaključiti sa slika 5 i 6, vreme trajanja radnog ciklusa kružnog manipulatora iznosi cca t = 15 s. Ovo znači da bi, ukoliko bi manipulator radio 225 radnih dana godišnje u po dve smene dnevno u trajanju od 7,5 h, mogao da izvrši 810 000 ciklusa godišnje. Ušteda u potrošnji vazduha pod pritiskom koja bi se, primenom metode smanjenja dužine creva, u tom slučaju mogla ostvariti jednaka je cca 2 284,2 $\frac{\mathbf{Nm^3}}{\mathbf{god}}$.



Sl. 5. Vrednosti potrošnje vazduha pod pritiskom za slučaj centralizovanog sistema



Sl. 6. Vrednosti potrošnje vazduha pod pritiskom za slučaj decentralizovanog sistema

Prosečna cena vazduha pod pritiskom iznosi 0,025 $\frac{€}{Nm^3}$, a troškovi električne energije u ukupnim troškovima proizvodnje vazduha pod pritiskom utiču sa cca 40% [7], odakle se zaključuje da troškovi električne energije iznose cca 0,01$\frac{€}{Nm^3}$. Uzimajući u obzir prosečnu cenu industrijske električne energije (0,1 $\frac{€}{kWh}$), zaključuje se da se prilikom proizvodnje vazduha pod pritiskom utroši cca 0,1 $\frac{kWh}{Nm^3}$. Na osnovu ovog podatka, kao i podataka o potencijalnoj ukupnoj uštedi vazduha pod pritiskom dobijenoj smanjenjem dužine pneumatskih creva (cca 2 284,2 $\frac{Nm^3}{god}$), zaključuje se da bi ukupne potrebe za električnom energijom bile smanjene za 228,42 kWh na godišnjem nivou.

Ako se uzme u obzir činjenica da količina CO_2 koja se emituje pri proizvodnji električne energije u Republici Srbiji iznosi 0,72 $\frac{kg}{kWh}$ [8], dolazi se do zaključka da bi se primenom ove metode na pneumatskom kružnom manipulatoru, smanjila emisija CO_2 za 164,46 $\frac{kg}{god}$.

5. ZAKLJUČAK

U ovom radu prikazan je uticaj smanjenja dužine pneumatskih creva na energetsku efikasnost sistema vazduha pod pritiskom i životnu sredinu. Eksperimentalnim putem na test postrojenju nazvanom pneumatski kružni manipulator, u laboratorijskim uslovima rada dokazano je da se, izmeštanjem komandnih razvodnika iz komandnog ormana i njihovim postavljanjem što je moguće bliže aktuatorima, smanjuje potrošnja vazduha pod pritiskom, čime se smanjuju potrebe i za električnom energijom a samim tim i emisija CO_2.

Uštede koje je moguće ostvariti su procentualno varijabilne (u ovom slučaju, ostvarena je ušteda od 23%) i zavise od karakteristika samog sistema, načina rada, troškova proizvodnje vazduha pod pritiskom itd. U slučaju realnih uslova rada u industrijskim postrojenjima (veći broj aktutora, veće zapremine aktutora i slično), procenat uštede energije, kao i smanjenje emisije CO_2 bi bili još veći i značajniji, tim pre što predložena metoda ne zahteva velika novčana ulaganja. Dodatno, još bolji rezultati mogu se ostvariti kombinacijom metode smanjenja dužine creva sa još nekom metodom za povećanje energetske efikasnosti sistema vazduha pod pritiskom.

6. REFERENCE

[1] Dudić, S., Šešlija, D., Milenković, I., Šulc, J., Reljić, V.: *Energetska efikasnost pneumatskih sistema*, Univerzitet u Novom Sadu, Fakultet tehničkih nauka, Novi Sad, 2021. (u štampi)

[2] Šešlija, D.: *Automatizacija procesa rada – pneumatske komponente i sistemi*, Univerzitet u Novom Sadu, Fakultet tehničkih nauka, 2020.

[3] Dudić, S., Reljić V., Šešlija D., Dakić N., Blagojević V.: *Improving Energy Efficiency of Flexible Pneumatic Systems*, Energies., 14(7): 1819,2021. https://doi.org/10.3390/en14071819

[4] Šešlija, M., Reljić, V., Šešlija, D., Dudić, S., Dakić, N., Jovanović, Z.: *Reuse of Exhausted Air from Multi-Actuator Pneumatic Control Systems*, Actuators, 10(6):125, 2021. https://doi.org/10.3390/act10060125

[5] Šešlija, D., Čajetinac, S., Blagojević, V., Šulc, J.: *Application of pulse width modulation and by-pass valve control for increasing energy efficiency of pneumatic actuator system*, Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering, 232(10), p.p. 1314-1324, 2018.

[6] Festo: *Air Box Type GHDA-FQ-M-FDMJ-A—Operating Instructions*, Festo, Esslingen, Germany, 2006.

[7] Dudić, S., Šešlija, D.: *Prilog identifikaciji troškova proizvodnje vazduha pod pritiskom*, Zbronik radova 30. konferencije HIPNEF sa međunarodnim učešćem, p.p. 155-160, Vrnjačka Banja, Mašinski fakultet, Niš, Savez mašinskih i elektrotehničkih inženjera i tehničara Srbije, 24-26. maj, 2006.

[8] https://www.sunearthtools.com/tools/CO2-emissions-calculator.php, pristupljeno 15.10.2021.

Autori: **Msc. Nikolina Dakić, Doc. dr Vule Reljić, Prof. dr Slobodan Dudić, Prof. dr Ivana Milenković, Msc. Nenad Komar,** Univerzitet Novi Sad, Fakultet Tehničkih Nauka, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2350, Fax: +381 21 454-495.

E-mail: nikolinadakic@uns.ac.rs
vuketa90@uns.ac.rs
dudic@uns.ac.rs
ivanai@uns.ac.rs
nenadkomar@gmail.com

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Adamović, S., Rajs, V., Adamović, D., Pinćjer, I., Tomić, I., Mihailović, A., Dramićanin, M.

ELEKTROKOAGULACIONO UKLANJANJE HAZARDNIH ANJONSKIH SURFAKTANATA IZ OFSET EFLUENTA

Rezime: *Za tretman ofset efluenta u cilju uklanjanja anjonskih surfaktanata odabran je elektrokoagulacioni metod. Efikasnost elektrokoagulacionog tretmana otpadnog sredstva za vlaženje procenjena je na osnovu smanjenja apsorbance anjonskih surfaktanata pri tačno definisanim vrednostima međuelektrodnog rastojanja, gusine struje, operativnog vremena i vrste elektrodnog materijala. Najveća efikasnost (80,3%) postignuta je pri sledećoj konfiguraciji elektrokoagulacinih parametara: sistemu sa četiri gvozdene elektrode, međuelektrodnom rastojanju od 1 cm, gustini struje od 8 mA* cm^{-2} *i operativnom vremu od 60 minuta.*

Ključne reči: *Elektrokoagulacija, ofset sredstvo za vlaženje, efluent, anjonski surfaktanti*

1. UVOD

Surfaktanti (površinski aktivne materije ili tenzidi) su organske supstance koje se dodaju grafičkim materijalima (sredstvu za vlaženje, grafičkim bojama, itd.) jer se dobro adsorbuju na graničnoj površini faza i smanjuju površinski napon [1]. Spadaju u grupu amfifilnih supstanci jer poseduju bipolarnu hemijsku strukturu [2], odnosno, njihovi se molekuli sastoje od polarnog i nepolarnog dela. Međutim, samo oni amfifili koji imaju manje ili više uravnotežen polarni i nepolarni deo predstavljaju surfaktante, jer imaju sposobnost da migriraju na graničnu površinu faza [3].

Surfaktanti se primenjuju u proizvodima različitih industrijskih grana i u sredstvima za domaćinstvo i ličnu higijenu [2]:

- U kozmetičkoj industriji različiti proizvodi (kreme, emulzije, karmini, maskare, boje za kosu, itd.) sadrže surfaktante, jer omogućavaju interakciju sa ljudskom kožom.
- Surfaktanti u tekstilnoj i industriji vlakana obezbeđuju: ravnomernu disperziju pigmenata u rastvoru za bojenje, dobro prodiranje datog rastvora u vlakna i pravilno taloženje pigmenata na površini samog vlakna.
- U metaloprerađivačkoj industriji surfaktanti se koriste kao sredtva za čišćenje metalnih površina, i kao sastojci raznih emulzija za podmazivanje i hlađenje.
- Kao važno pomoćno sredstvo za isporuku aktivnih sastojaka (rastvora, emulzija, gel kapsula ili tableta) kroz različite organske membrane u organizmu, surfaktanti se koriste u farmaceutskoj industriji.
- U prehrambenoj industriji (proizvodnji hleba, majoneza, sladoleda, itd.) surfaktanti se dodaju da bi proizvodi dobili odgovarajuće karakteristike.
- Surfaktanti se u obliku sapuna i deterdženata upotrebljavaju za čišćenje različitih površina, predmeta, kao i ambalaže koja će sadržati krajnji proizvod.
- U grafičkoj industriji surfaktanti, kao komponente sredstva za vlaženje, smanjuju njegov površinski napon i na taj način rešavaju problem sa vlaženjem štamparske forme tokom samog procesa ofset štampe. Takođe, smanjivanjem površinskog napona surfaktanti tokom proizvodnje grafičkih boja omogućavaju vezivu da bolje kvasi i disperguje pigmente. Surfaktanti su i emulgatori jer obrazuju i podstiču stvaranje emulzije naročito kod ofset grafičkih boja [1], učestvuju u formiranju štampajućih i neštampajućih elemenata na ofset štamparskoj formi i upotrebljavaju se kao antipenušavci [4].

Otpadno ofset sredstvo za vlaženje je toksično i potencijalno štetano za životnu sredinu što zahteva njegov tretman pre odlaganja. Zato je u radu ispitana mogućnost i efikasnost elektrokoagulacionog uklanjanja emergentnih anjonskih surfaktanata iz ofset efluenta sa ciljem smanjivanja njegovog potencijalno negativnog uticaja na grafičku okolinu.

2. EKSPERIMENTALNI DEO

2.1 Otpadno ofset sredstvo za vlaženje

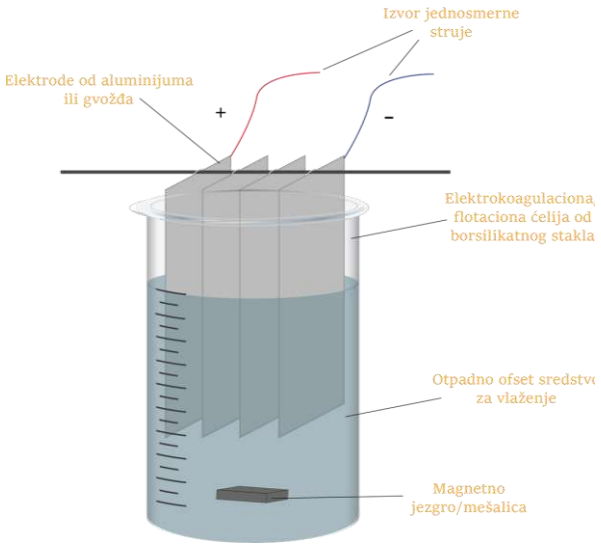
Analizirano otpadno ofset sredstvo za vlaženje (OOSV) u količini od 20 L uzorkovano je u ofset štampariji na teritoriji Novog Sada. OOSV je tečnost svetlo-sive boje, blago alkoholnog mirisa, temperature 23ºC, sa blago kiselim karakterom (pH vrednosti je 5,8) i sa inicijalnom apsorbancom

(A_o) od 18,73. Navedeni parametri su određeni: vizuelno, organoleptički mirisom, Hg termometrom, prema standardnoj EPA 150.1 metodi [5] i ASTM D2330-02 metodi [6], redom.

2.2 Elektrokoagulacioni tretman ofset efluenta

Elektrokoagulacioni tretman OOSV sproveden je u šaržnom reaktoru (slika 1) koji se sastoji iz [7]:

- izvora jednosmerne struje sa integrisanim potenciometrom i galvanometrom,
- elektrokoagulacione ćelije (od borsilikatnog stakla, zapremine 250 mL),
- sistema od četiri gvozdene (Fe) ili četiri aluminijumske (Al) elektrode (dimenzija: 10 x 5 x 0,1 cm),
- magnetne mešalice sa magnetnim jezgrom i
- ofset efluenta.



Sl. 1. Elektrokoagulacioni šaržni reaktor

Priprema Fe ili Al elektroda i uklonjanje pasivnog sloja sa površine elektroda sprovedeni su kroz sledeće faze [7]:

- 1. faza: mehanička obrada elektroda abrazivnim papirom;
- 2. faza: ispiranje poliranih elektroda sa dejonizovanom vodom;
- 3. faza: hemijska obrada elektroda u rastvoru hlorovodonične kiseline (5 mol/L) u vremenu od 10 minuta;
- 4. faza: ispiranje elektroda posle hemijske obrade sa dejonizovanom vodom;
- 5. faza: sušenje elektroda.

Elektrokoagulacioni tretman ofset efluenta sproveden je na sledeći način: 220 mL OOSV i 0,50 g natrijum-hlorida (za dodatno sprečavanje pasivizacije elektroda) odmereni su u elektrokoagulacionoj ćeliji. Fe elektrode su postavljene vertikalno u ćeliju sa međuelektrodnim rastojanjem od 1 cm. Samo su spoljne elektrode povezane sa izvorom jednosmerne struje, a jačina struje je podešena na 0,32 A što odgovara gustini struje od 8 mA cm^{-2}, jer je efektivna površina elektroda 40 cm^2. Tokom elektrokoagulacionog tretmana obezbeđeno je mešanje uzorka OOSV na magnetnoj mešalici brzinom od 450 rpm [7]. Ista preocedura tretmana sprovedena je i za sistem sa četiri Al elektrode.

U određenim operativnim vremenima od 1, 5, 10, 20, 40 i 60 minuta uzorci zapremine 15 mL sakupljani su pipetom iz ćelije u kivete kako bi se procenila efikasnost elektrokoagulacionog tretmana uklanjanja anjonskih surfaktanata iz OOSV. Nakon 60 minuta sakupljeni uzorci su centrifugirani na 2000 rpm tokom 15 minuta. Potom su apsorbance anjonskih surfaktanata određene spektrofotometriski na talasnoj dužini od 618 nm. Na kraju su efikasnosti elektrokoagulacionog uklanjanja anjonskih surfaktanata iz OOSV, pri tačno definisanim operativnim parametrima sistema izračunate prema formuli (1), [7]:

$$E_{Fe/Al} = \frac{A_o - A_t}{A_o} \cdot 100 \qquad (1)$$

gde su: $E_{Fe/Al}$ – efikasnosti elektrokoagulacionog tretmana za Fe ili Al sistem elektroda u %, A_o i A_t – apsorbance na 618 nm anjonskih surfaktanata u OOSV pre i posle elektrokoagulacionog tretmana u određenom vremenu, redom.

3. REZULTATI I DISKUSIJA

Svetlo-siva boja OOSV se nije promenula ni posle 48 sati. Kako tamno siva ili crna boja efluenta nastaje usled stvaranja sulfida metala koji se formiraju u anaerobnim uslovima [8], nepromenjenost boje ukazuje da sulfidi metala nisu prisutni u ofset efluentu.

Blago alkoholni miris OOSV je očekivan zbog prisustva alkohola ili glikola koji smanjuju površinski napon polaznog sredstva za vlaženje i omogućavaju bolje kvašenje štamparske forme [1].

Uredba o graničnim vrednostima emisije zagađujućih materija u vode i rokovima za njihovo dostizanje Republike Srbije [9] i Dopuna navedene Uredbe [10] definišu parametre za otpadnu vodu koja potiče iz štamparija za sledeće proizvodne procese: montažu i reprodukciju, štampanje pisama, ofset, sito i duboku štampu. Prema navedenim Uredbama Republike Srbije efluenti koji se ispuštaju u recipijent nakon tretmana moraju da imaju pH vrednost u granicama od 6,5 do 8,5. Dobijena pH vrednost OOSV (5,8), koja pokazuje slabo kiseli karakter

ofset efluenta, nije u zakonskim granicama i ukazuje na neophodnost neutralizacionog tretmana OOSV pre ispuštanja u grafičko okruženje.

Inicijalna apsorbanca anjonskih surfaktanata u OOSV pre elektrokoagulacionog tretmana je 18,73. Zbog velike važnosti prisustva anjonskih surfaktanata u sredstvu za vlaženje, zarad postizanja kvalitetne ofset štampe sa jedne strane i nedostatka granične vrednosti za surfaktante prema navedenim Uredbama Republike Srbije sa druge strane, neophodno je sprovesti elektrokoagulacioni tretman OOSV u cilju njegovog bezbednog odlaganja u životnu sredinu.

Prema NORMAN organizaciji za praćenje i biomonitoring novih ekoloških supstanci, surfaktanti, boje, lakovi i teški metali, koje koristi grafička industrija, spadaju u emergentne supstance [11]. Dakle, surfaktanti kao emergentne supstance, moraju biti ukonjeni iz OOSV pre njegovog ispuštanja u grafičko okruženje (sanitarni sistem ili prirodni recepijent).

Rezultati efikasnosti elektrokoagulacionog uklanjanja anjonskih surfaktanata iz OOSV u sistemima sa četiri Fe (E_{Fe}) ili četiri Al elektrode (E_{Al}) na međuelektrodonom rastojanju od 1 cm, pri gustini struje od 8 mA cm^{-2} i za oparativna vremena (t) od 1, 5, 10, 20, 40 i 60 minuta, prikazani su u tabeli 1.

Tabela 1. Efikasnosti uklanjanja anjonskih surfaktanata iz OOSV u sistemima sa Fe i Al elektrodama za ispitivane operativne parametre

		Fe elektrode		Al elektrode	
t (min)	A_o	A_t	**E_{Fe} (%)**	A_t	**E_{Al} (%)**
1	18,73	13,15	**29,8**	15,01	**19,9**
5		10,11	**46,0**	11,63	**37,9**
10		8,81	**53,0**	10,51	**43,9**
20		5,75	**69,3**	9,11	**51,4**
40		3,94	**79,0**	5,95	**68,2**
60		3,69	**80,3**	5,63	**69,9**

Rezultati elektrokoagulacionog tretmana OOSV (tabela 1) pokazuju da se sa primenom Fe elektroda već posle 5 minuta efikasnost uklanjanja anjonskih surfaktanata povećala 1,5 puta (35,2%). U odnosu na efikasnost posle 1. minuta, efikasnosti za 10, 20, 40 i 60 minuta su se povećale: 1,8 (43,8%), 2,3 (57%), 2,7 (62,3%) i 2,7 puta (62,9%), redom. Dobijeni rezultati pokazuju da sa porastom operativnog vremena rastu i efikasnosti uklanjanja anjonskih surfaktanata iz OOSV primenom Fe elektroda, ali da porast nije linearan. Takođe, uočava se da je ravnotežno operativno vreme 40 minuta, jer se posle 60 minuta efikasnost uklanjanja anjonskih surfaktanata iz OOSV povećala svega 1,6%, a sa ekonomskog aspekta elektrokoagulacionog tretmana poželjno je kraće operativno vreme.

Efikasnosti elektrokoagulacionog uklanjanja anjonskih surfaktanata iz OOSV sa sistemom od četiri Al elektrode su od 19,9 do 69,9% za interval operativnog vremena od 1. do 60. minuta (tabela 1). U odnosu na efikasnost posle 1. minuta, efikasnosti za 5, 10, 20, 40 i 60 minuta su se povećale: 1,9 (47,5%), 2,2 (54,7%), 2,6 (61,3%), 3,4 (70,8%) i 3,5 puta (71,5%), redom. Kao i u slučaju sa četiri Fe elektrode i u sistemu sa četiri Al elektrode, efikasnosti uklanjanja anjonskih surfaktanata rastu sa porastom operativnog vremena, ali ne linearno. Takođe, i za sistem sa četiri Al elektrode kao i za sistem Fe elektroda uočava se da je ravnotežno operativno vreme 40 minuta za koje se postiže efikasnost od 68,2%. Posle 60 minuta efikasnost uklanjanja anjonskih surfaktanata iz OOSV se povećala svega 2,4%, pa je poželjno odabrati kraće operativno vreme.

Analizirajući uticaj vrste materijala elektroda na efikasnost elektrokoagulacionog uklanjanja anjonskih surfaktanata iz OOSV uočava se da Fe elektrode imaju veću efikasnost u odnosu na Al elektrode. Za operativna vremena od 1, 5, 10, 20, 40 i 60 minuta efikasnosti Fe elektroda u odnosu na Al elektrode su veće 33,2; 17,6; 17,2; 25,8; 13,7 i 12,9%, redom.

Prvi razlog za veću efikasnost Fe u odnosu na Al elektrode je tri puta veća ekvivalentna masa gvožđa (1041 mg Ah^{-1}) u odnosu na aluminijum (335,6 mg Ah^{-1}). Dakle, teorijski više koagulanata proizvodi anoda od Fe u odnosu na anodu od Al, pri istim operativnim uslovima [12]. Drugi razlog za veću efikasnost Fe u odnosu na Al žrtvene anode je veći potencijal oksidacije Fe (-0,447 V) u odnosu na Al (-1,662 V) zbog čega se Fe većom brzinom oksiduje u odnosu na Al [13].

4. ZAKLJUČAK

OOSV zabog neadekvatne slabo kisele pH vrednosti (5,8) zahteva neophodan tretman neutralizacije pre ispuštanja u sanitarni sistem ili prirodni recepijent. Takođe, prisustvo anjonskih surfaktanata u OOSV, koji se prema NORMAN organizaciji svrstavaju u emergentne supstance, iziskuje sprovođenje adekvatnog tretmana ofset efluenta pre njegovog ispuštanja u grafičko okruženje.

Eksperimentalni rezultati rada pokazuju da se elektrokoagulacioni tretman OOSV sa odabranom konfiguracijom parametara (četiri Fe ili Al elektrode na međusobnom rastojanju od 1 cm, pri gustini struje od 8 mA cm^{-2} i operativnim vremenima od 1, 5, 10, 20, 40 i 60 minuta) može uspešno primeniti za uklanjanje anjonskih

surfaktanata iz ofset efluenata.

Rezultati efikasnosti elektrokoagulacionog uklanjanja anjonskih surfaktanata iz OOSV pokazuju da:

- Sa primenom Fe elektroda, za operativna vremena od 1. do 60. minuta, efikasnosti uklanjanja anjonskih surfaktanata rastu do 80,3%;
- Efikasnosti uklanjanja anjonskih surfaktanata sa Al eletrodama u rastu do 69,9% sa porastom operativnog vremena od 1. do 60. minuta;
- Sa porastom operativnog vremena rastu i efikasnosti uklanjanja anjonskih surfaktanata i sa Fe i sa Al elektrodama, ali porast u oba sistema nije linearan;
- U sistemu sa četiri Al elektrode kao i u sistemu Fe elektroda, ravnotežno operativno vreme tretmana je 40 minuta;
- Fe u odnosu na Al elektrode imaju veću efikasnost uklanjanja anjonskih surfaktanata iz OOSV, jer Fe anode imaju tri puta veću ekvivalentnu masu (proizvode više koagulanata) i veći potencijala oksidacije (pa se brže oksiduju).

5. REFERENCE

[1] Prica, M., Adamović, S.: *Grafički materijali*, FTN Izdavaštvo, Novi Sad, 2017.

[2] Myers, D.: *Surfactant Science and Technology*, John Wiley and Sons. Inc, Hoboken, New Jersey, 2006.

[3] Vapa, I.: *Uticaj dužine hidrofobnog segmenta homolognih polisorbata na termodinamičke parametre binarnih mešovitih micela polisorbata i tritona x-100*, Univerzitet u Novom Sadu, Medicinski Fakultet, Novi Sad, 2016.

[4] Prica, M., Adamović, S.: *Hemija u grafičkom inženjerstvu*, FTN Izdavaštvo, Novi Sad, 2019.

[5] Environmental Protection Agency, EPA 150.1 Method (1982) pH, Electrometric Method, Methods for the Chemical Analysis of Water and Wastes (MCAWW) (EPA/600/4-79/020), Revision 1982a.

[6] ASTM test method D 2330-02 (2002) Standard test method for methylene blue active substances, ASTM International, USA.

[7] Adamović, S.: *Elektrokoagulacioni i adsorpcioni tretmani efluenata u grafičkim procesima ofset štampe*, Univerzitet u Novom Sadu, Fakultet tehničkih nauka. Novi Sad, 2016.

[8] Povrenović, D., Knežević, M.: *Osnove tehnologije prečišćavanja otpadnih voda*, Tehnološko-metalurški fakultet, Beograd, 2013.

[9] Službeni glasnik RS („Sl. glasnik RS“, br. 67/2011 i 48/2012) Uredba o graničnim vrednostima emisije zagađujućih materija u vode i rokovima za njihovo dostizanje, Ministarstvo energije, razvoja i zaštite životne sredine Republike Srbije, 2012.

[10] Službeni glasnik RS („Sl. glasnik RS“, br. 1/2016) Uredba o izmenama i dopunama uredbe o graničnim vrednostima emisije zagađujućih materija u vode i rokovima za njihovodostizanje, Ministarstvo energije, razvoja i zaštite životne sredine Republike Srbije, 2016.

[11] NORMAN - Network of reference laboratories, research centres and related organisations for monitoring of emerging environmental substances, NORMAN Association, 2019, URL: https://www.norman-network.net, (Pristupljeno, 20.08.2021.)

[12] Chou, W.-L., Wang, C.-T., Huang, K.-Y.: *Effect of operating parameters on indium(III) ion removal by iron electrocoagulation and evaluation of specific energy consumptio*, Journal of Hazardous Materials, 167, p.p. 467-474, 2009.

[13] Moussavi, G., Majidi, F., Farzadkia, M.: *The influence of operational parameters on elimination of cyanide from wastewater using the electrocoagulation process*, Desalination, 280, p.p. 127-133, 2011.

ZAHVALNICA

Rad je podržan od stane Ministarstva prosvete, nauke i tehnološkog razvoja kroz projekat broj 451-03-68/2020-14/200156: “Inovativna naučna i umetnička istraživanja iz domena delatnosti Fakulteta tehničkih nauka”.

Autori: **Doc. dr Savka Adamović, Van. prof. dr Vladimir Rajs, Van. prof. Dragan Adamović, Doc. dr Ivan Pinćjer, Doc. dr Ivana Tomić, Asistent MSc Bojan Banjanin, Van. prof. dr Aleksandra Mihailović, Doc. dr Miroslav Dramićanin,** Univerzitet u Novom Sadu, Fakultet tehničkih nauka, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2634.
E-mail: adamovicsavkas@uns.ac.rs
vladimir@uns.ac.rs
draganadamovic@uns.ac.rs
pintier@uns.ac.rs
tomic@uns.ac.rs
zandra@uns.ac.rs
dramicanin@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Tot, R.

INFRACRVENA SPEKTROSKOPIJA U GEOTERMALNIM ISTRAŽIVANJIMA

Rezime: *Infracrvena spektroskopija (IRS) je metoda koja se koristi za identifikaciju minerala na osnovu njihovog spektralnog odziva na infracrvenu svetlost. IRS zasnovana na tačkama (spot-based IRS) često se koristi kao analitička metoda geotermalne industrije, dok je infracrvena spektroskopija slike (IRIS) tek nedavno uvedena. IRIS ima osetljivost u identifikaciji raznih minerala, zajedno sa stepenom kristalnosti, propusnosti i utvrđivanju litologije, ove informacije su važne za geotermalna istraživanja i predstavljaju veliki doprinos u geotermalnoj industriji i eksploataciji. Pogotovo kada se zna da istražni radovi predstavljaju najveći rizik uspešnosti pri razvoju geotermalnih postrojenja, a sa razvojem metoda analiza tla se smanjuje rizik i povećava uspešnost.*

Ključne reči: *geotermalna istraživanja, IRS, IRIS, spektroskopija*

1. UVOD

Pun ciklus geotermalnog razvoja nekog postrojenja traje odo 5 – 10 godina, tako da ona sama po sebi ne predstavlja brzo rešenje da se dođe do električne energije. Pored toga postoje i mnogi rizici kao što su: rizik od završetka ili odlaganje, rizik da neko preuzme tržište ili slično, tržišna potražnja i cena energenta, operativni rizici i zakonske regulative i mnogi drugi rizici [1].

Program pomoći u upravljanju energetskim sektorom, Grupa Svetske banke (Energy Sector Management Assistance Program (ESMAP), The World Bank Group (WBG)), je razvoj geotermalnih projekata podelila u osam faza: anketa, istraživanje, probno bušenje, planiranje i studija izvodljivosti, bušenje, konstruisanje, pokretanje, rad i održavanje. Svaka od ovih faza ima i cenu svog izvođenja, koje su vremenski promenljive i opadaju kako se ide po fazama. Na početku istraživanja, a posebno faza probnog bušenja može se smatrati najrizičnijim delom razvoja geotermalnog projekta [1]. Stoga je geotermalno istraživanje tla jedan od presudnih faktora koji utiču na uspešnost i isplativost geotermalnog postrojenja, a jedna od metoda istraživanja tla, odnosno njene analize je infracrvena spektroskopija.

2. MINEROLOŠKE ANALIZE U GEOTERMALNIM ISTRAŽIVANJIMA

HTA (hydrothermal alteration - hidrotermalna izmena) minerala predstavlja važan izvor informacija za karakterizaciju geotermalnih sistema. Formiranje određenog HTA minerala može doći samo pod posebnim uslovima, kao što je npr. stabilni temperaturni rasponi, propustljivost stena, sastav fluida. Razumevanje prostorne raspodele HTA unutar geotermalnih sistema može pružiti uvid u termičke, propusne i hemijske karakteristike sistema. Poređenjem ovih karakteristika može se otkriti konfiguracija kako hidrotermalni fluidi teku i cirkulišu unutar sistema [2].

Svaka mineraloška analitička metoda ima svoje granice detekcije, kao što su veličina zrna, zastupljenost i hemijski sastav. Da bi se dobio što bolji uvid koristi se više metoda kao što su binokularna mikroskopija, petrografija, rendgenska difraktrometrija, a osamdesetih je uveden spot-based IRS (infracrvena spektroskopija zasnovana na tačkama) koji je u stanju da identifikuje minerale na osnovu njihovih spektralnih karakteristika na VNIR (visible to near infrated – vidljivo blisko infracrveno) i SWIR (short-wave infrared – kratko talasno infracrveno) zračenjima [2]. Spot-based IRS pokazao se da je osetljiv na minerale gline i minerale koji sadrže amonijum [3].

IRIS (infrared imaging spectroscopy – infracrvena spektroskopija slike) je prvobitno razvijena kao metoda za daljinsko detektovanje iz vazduha. U poređenju sa spot-based IRS, IRIS može proizvesti ne samo spektralne informacije, već i vizualizaciju uzorka i njegove prostorne obrazce [2].

Vrste HTA minerala koji se javljaju u geotermalnim sistemima su relativno slični od jednog do drugog sistema, ali se njihovi obrasci distribucije jako razlikuju među sistemima. Njihova pojava zavisi od formiranja i stabilnosti HTA minerala u geotermalnim sistemima, što je funkcija: (1) temperature, (2) sastava fluida, (3) propustljivosti i poroznosti, (4) vrste stena, (5) protoka vode i vreme reakcije i (6) pritisaka [4]. Pošto hidrotermalni fluidi stupaju u interakciju sa

okolnim stenama, tip stena takođe doprinosi određivanju HTA mineralnih sklopova. Iako hidrotermalni fluidi prolaze kroz sličnu hemijsku reakciju iako je sastav stenskih zidova različit, uočeno je da postoje varijacije u nastalim mineralnim sklopovima. Međutim glavni kontrolni faktor ovih tipova stena je odnos vode i stena (odnos W/R – woter/rock). Promene u odnosu W/R ukazuju na promene rastvaranja i ravnoteže stena i rezultat promenama u hemijskom sastavu hidrotermalnih fluida (kao i mineralnih sklopova HTA) [2]. Mapiranje minerala može otkriti pravac strujanja hidrotermalnih fluida. Neki minerali se mogu pojaviti na različitim temperaturama, ako se promeni jedan ili više faktora koji kontrolišu HTA. Na primer, kaolinit se normalno formira na površinskoj ili plitkoj dubini na niskim temperaturama. Međutim, može se formirati i na većoj dubini gde je temperatura iznad 100 ºC ako odnos voda/stena premašuje minimalni potrebni odnos. Ovaj minimum je funkcija temperature fluida, što je veća temperatura, to je veći odnos koji je potreban [2]. Sa dužim vremenom interakcije voda/stena stvara se više HTA minerala i menjaju se i svojstva hidrotermalnih fluida. Razumevanje istorije ovih promena od suštinskog je značaja za geotermalno istraživanje i eksploataciju. Stoga se, pored distribucije minerala, koristi i koncept parageneze minerala (tj. nauka koja proučava okolinu i prilike pod kojima su postali pojedini minerali i gleda da utvrdi zakone po kojima to biva) [5].

3. INFRACRVENA SPEKTROSKOPIJA

Infracrvena spektroskopija identifikuje minerale na osnovu njihovog spektralnog odziva na dolazeću svetlost na različitim talasnim dužinama. Svetlosni izvor emituje fotone koji se reflektuju sa uzorka, a senzor ih hvata kao vrednosti refleksije. Minerali će apsorbovati određeni broj ovih fotona. Spektralni položaj, intenzitet, oblik apsorbovanih karakteristika razlikuju se od minerala do minerala, u zavisnosti od hemijskog sastava i strukture minerala [6].

Infracrvena spektroskopija pokriva širok spektar talasnih dužina. Apsorpcija fotona u svakom opsegu uzrokovana je različitim procesima. VNIR pokriva talasne dužine od ~ 400-1300 nm. Minerali koji imaju spektralna svojstva u VNIR-u su uglavnom minerali koji sadrže gvožđe. Minerali koji sadrže nikl, bakar, mangan, hrom takođe mogu pokazati apsorpcione karakteristike u ovom opsegu. U SWIR ~ 1300-2500 nm, izaziva se spektralni odziv vibracionim procesima određenih molekularnih veza, uključujući OH, H_2O, AlOH, FeOH, MgOH i CO_3 molekula [6].

Na dužim talasnim dužinama od SWIR-a, odnosno na LWIR (long-wave infrared – dugo infracrveno zračenje) mogu se identifikovati minerali iz silikatnih, karbonatnih, sulfidnih, sulfatnih, oksidnih i hidroksidnih grupa [7]. Silikatni minerali, uključujući kvarc i feldspat, glavni su mineralni sastojci u geotermalnim sistemima sa vulkanskim poreklom i pokazuju svoje osnovne karakteristike u ovom opsegu talasnih dužina [2].

Jedna od prednosti IRS -a u odnosu na druge je da može identifikovati ne samo kristalne, već i amorfne materijale, kao što je opal, koji može da bude indikator prisustva vode [6].

Spot-based IRS je ručni instrument koji proizvodi jedan spektar za približno 1-2 cm površine. Ova vrsta IRS obično radi analizu na VNIR i SWIR talasnim dužinama.

IRIS je razvijena metoda analize koja je proširenje IRS-a na licu mesta. To je adaptacija infracrvene spektroskopije snimanja iz vazduha, instrument za snimanje koji proizvodi spektralnu vizualizaciju objekta. Pošto se spektri generišu prema prostornom položaju objekta, mogu se tražiti određene spektralne karakteristike i locirati njihov položaj unutar objekta. Korišćenjem dijagnostičkih spektralnih karakteristika ciljnih minerala, može se izvršiti tehnika/algoritam obrade slike za mapiranje minerala. Uzimajući u obzir sve HTA minerale koji mogu biti prisutni, IRIS se može koristiti za razlikovanje hidrotermalno izmenjenih stena od novijih stena [2,6].

Slično IRIS-u koji vrši merenje iz vazduha, laboratorijski IRIS proizvodi spektar za svaki piksel skeniranih slika. Zbog toga će se manje uobičajeni minerali moći više identifikovati sve dok oni (spektralno) dominiraju barem jednim pikselom na IRIS slici.

Kao što je rečeno svaka analiza ima svoje granice, tačnije prednosti i mane. Spot-based IRS može da detektuje opal, ali može i da detektuje kvarc koji nazivaju i „hidrirani kvarc“, ali ne može da detektuje većinu silikata [8].

Iako su brojni radovi predlagali korišćenje spot-based IRS za identifikaciju litologije, to nije uvek izvodljivo, pogotovu u geotermalnim sistemima čijom litologijom dominiraju vulkanske stene sličnog hemijskog i mineralnog sastava. Iako nije posebno pogodan za identifikaciju litoloških jedinica, prethodni radovi pokazuju da ovaj tip analize može identifikovati mnoge važne minerale u geotermalnim sistemima, uključujući minerale gline, muskovit, alunit, hlorit, biotit, karbonate, epidot, aktinolit , topaz, gips, anhidrit, andaluzit, hematit, opal, zeolit i minerale koji sadrže amonijum i mnoge druge [8].

Epidot i aktinolit su minerali koji su među

indikatorima temperature, ali se nalaze u maloj količini, utvrđeno je da IRIS metoda koja analizira jezgro geotermalnih bušilica može da ih uspešno detektuje [2].

Primećeno je da rezultati IRIS-a uzoraka sa jezgra i reznice nisu identični. Moskovit, epidot, kaolinit i feldspat identifikovani su samo u jezgrama bušilice. Ovi različiti rezultati tumačeni su kao neizbežni efekti tretmana bušenja i uzorkovanja. Neizbežni efekti tretmana bušenja i uzorkovanja uključuju: (1) gubitak određenih minerala tokom transporta sa podzemne površine radi sakupljanja ili pranja; (2) hidratacija minerala usled izloženosti bušenim vrelim muljom i (3) homogenizacija i dominacija određenih minerala i/ili litologija u reznicama. Ovaj poslednji efekat dovodi do generisanja više mešanih mineralnih spektara i manje uobičajenih materijala koji se maskiraju češćim mineralima [2].

4. PRIMER IRIS REZULTATA SA GEOTERMALNIH BUŠAČKIH ISEČAKA

Kao primer može se navesti IRIS analiza koja je urađena na geotermalnim bušotinama na geotermalnom polju vulkanskog porekla na Sumatri u Indoneziji. Hiperspektralne SWIR slike su dobijene pomoću Specim SWIR 3 spektralne kamere (Sl. 1.). Kamera je pričvršćena na Specim LabScanner 100 × 50 stanicu za snimanje opremljenu sa spoljnim izvorom svetlosti. Instrument meri kratkotalasno infracrveno svetlo (1,0 – 2,5 μm) u 288 spektralnih opsega i 384 prostornih piksela. Slike se generišu postepeno pomeranjem uzorka na postolju za skeniranje ispod linijskog skenera tokom snimanja slike. Rezolucija slike (veličina pojedinačnog piksela) koje se koriste u ovom podešavanju je 0,26 mm. Vizuelnim poređenjem spektara slike sa spektralnom bibliotekom USGS-a (U.S. Geological Survey – SAD geoleoški pregled) otkriveno je 13 čistih minerala i šest mineralnih smeša, jedan spektar drveta i tri spektra koji još nisu definitivno dodeljeni mineralnoj fazi. Slika 2. prikazuje spektar refleksije za svaku od ovih klasa minerala [2].

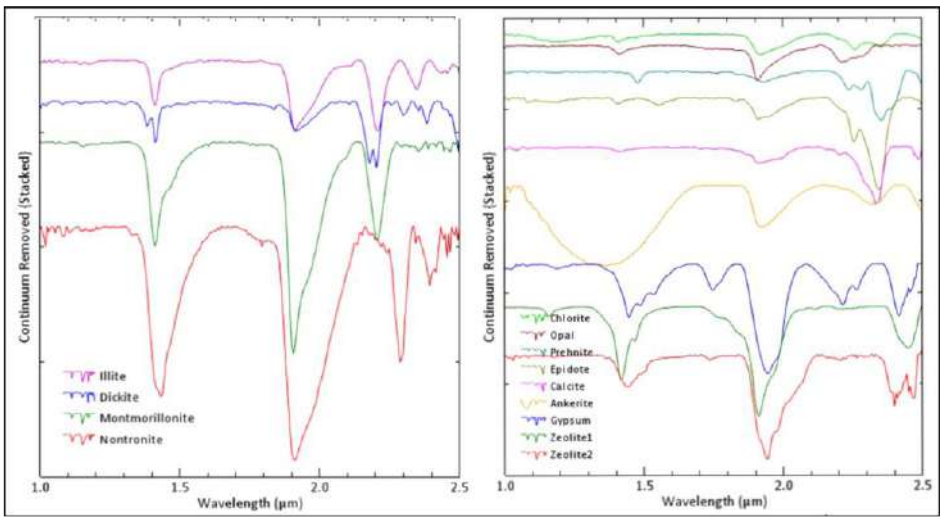
Poređenjem svakog piksela slike sa spektrima u takozvanoj „spektralnoj biblioteci“ (Sl. 2.), može se primeniti izbor algoritma klasifikatora za dodeljivanje svakog piksela slike klasi minerala na osnovu njegovog spektralnog odziva. Slika 3. prikazuje rezultate klasifikacije bušotina iz tri različita dubinska intervala iste geotermalne istražne bušotine. Sa mineralnih karti generisanih IRIS-om možemo lako posmatrati mineraloške promene sa dubine ~ 50 m na ~ 500 m dubine (Sl. 3.). Dominantni minerali prelazi iz dikita u najplićem uzorku u smektit na ~ 260 m dubine i na kraju u hlorit i ilit na dubini ~ 520 m. S obzirom da je skeniranje uzoraka pomoću IRIS instrumenta brzo i ne zahteva nikakav sofisticiran tretman, moguće je analizirati stotine uzoraka dnevno [2].

Sl. 1. Spektralna kamera Specim SWIR 3 pričvršćena na stanicu za snimanje Specim LabScanner 100 × 50

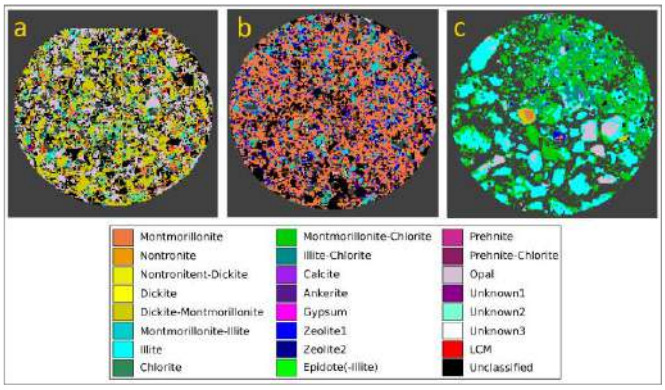
4. ZAKLJUČAK

Geotermalna industrija je tek počela da prihvata IRIS. Prethodna istraživanja na geotermalnim poljima pokazuju da IRIS može dobiti i kvalitativne i kvantitativne parametre. Kvalitativni parametar uključuje prostorne odnose između HTA minerala. Visoka prostorna rezolucija IRIS-a čini vidljivim prostorne odnose između HTA minerala. Kvantitativni parametri koji se mogu dobiti putem IRIS-a uključuju bogatstvo minerala i promenu talasnih dužina karakteristika apsorpcije. Iz karti minerala generisanih IRIS-om može se izračunati procentualna površina minerala zasnovana na pikselima, koja takođe odražava prividnu količinu minerala. Prednost IRIS-a u odnosu na druge metode je ta što omogućava analizu velikih skupova podataka, a ne samo ograničene površine ili dela uzoraka.

IRIS metoda u bliskoj budućnosti, sa njenim razvojem i usavršavanjem algoritama prepoznavanja može značajno doprineti geološkim istraživanjima, a pogotovo geotermalnim istraživanjima, koja su presudna za izradu geotermalnih postrojenja, koja poslednjih godina dobijaju na sve većem značaju što se tiče obnoviljvih izvora energije i koja su prepoznata kao održivi i ekološki izvor električne i toplotne energije.



Sl. 2. Reprezentativni spektri 13 minerala identifikovanih IRIS-om uzeti iz pojedinačnih piksela. Levo: spektri minerala gline, desno: spektri minerala koji nisu glina



Sl. 3. Mineralne karte uzoraka sa: (a) 57-60 m dubine; (b) 261-264 m dubine; (c) 522-525 m dubine

6. REFERENCE

[1] Loksha, V., Gehringer, M.: *Geothermal Handbook : Planning and Financing Power Generation*, The International Bank for Reconstruction, Washington DC, USA, 2012.

[2] Savitri, K. P., Hecker, C., Meer van der, F. D., Sidik, R. P.: *VNIR-SWIR infrared (imaging) spectroscopy for geothermal exploration: Current status and future directions*, Geothermics, vol. 96, p. 102178, January 2021.

[3] Simpson, P. M., Rae, J. A.: *Short-wave infrared (SWIR) reflectance spectrometric characterisation of clays from geothermal systems of the Taupō Volcanic Zone, New Zealand*, Geothermics, vol. 73, p.p. 74–90, May 2018.

[4] Browne, P., Ellis, A. J.: *The Ohaki-Broadlands hydrothermal area, New Zealand; mineralogy and related geochemistry*, American Journal of Science, vol. 269, no. 2, p.p. 97–131, Sep. 1970.

[5] Utami, P., Widarto, D. S., Atmojo, J. P., Kamah, Y., Browne, P. R. L. ,Warmada I. W.: *Hydrothermal Alteration and Evolution of the Lahendong Geothermal System, North Sulawes*i, World Geothermal Congress 2015, p.p. 1-10, Melbourne, IGA, Melbourne, Australia, 19-25 April 2015.

[6] Rencz, A.N., Ryerson, A.R.: *Manual of Remote Sensing, Remote Sensing for the Earth Sciences*, John Wiley & Sons in Cooperation with American Society for Photogrammetry and Remote Sensing, New York,1999.

[7] Schodlok, M. C., Green, A., Huntington J.: *A reference library of thermal infrared mineral reflectance spectra for the HyLogger-3 drill core logging system*, Australian Journal of Earth Sciences, vol. 63, no. 8, p.p. 1–9, Oct. 2016.

[8] Calvin, W. M., Pace, E. L.: *Mapping alteration in geothermal drill core using a field portable spectroradiometer*, Geothermics, vol. 61, p.p. 12–23, 2016.

Autori: **Rudolf Tot,** Univerzitet Novi Sad, Fakultet Tehničkih Nauka, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 60 70 70 983
E-mail: totrudolf@gmail.com

ETIKUM 2021

INTERNATIONAL SCIENTIFIC CONFERENCE
NOVI SAD, SERBIA, DECEMBER 2-4, 2021

Mirosavljević, Z., Knežević, V., Batinić, B., Ilić Mićunović, M.

RECIKLAŽA I PRERADA NEOPASNOG INDUSTRIJSKOG OTPADA OD POLIMERNIH MATERIJALA – PRAKTIČNI PRIMER

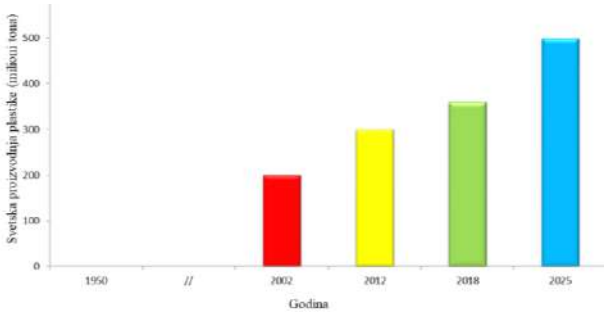
Rezime: *Reciklaža plastičnog otpada predstavlja važan korak u cirkularnoj ekonomiji. U radu su prikazani praktični primeri firme „RKS kompoziti“ koji se odnose na preradu i reciklažu neopasnog industrijskog otpada od polimernih materijala sa akcentom na polipropilen, polietilen i polivinilhlorid (PP, PE, PVC). Predstavljeni proces reciklaže podrazumeva postupke sortiranja i pranja, mlevenja, aglomeracije i regranulacije plastičnog otpada sa ciljem dobijanja regranulata sa kontrolisanim fizičko-hemijskim i mehaničkim osobinama.*

Ključne reči: *plastični otpad, polimerni materijali, reciklaža*

1. UVOD

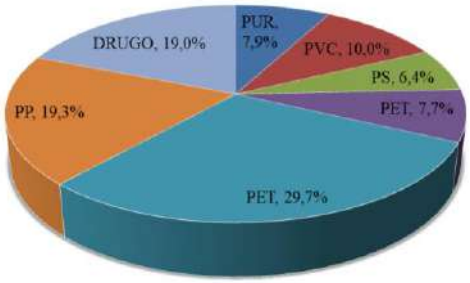
Razvoj industrije rezultira ne samo mnogim proizvodima korisnim za ljudske aktivnosti, nego i velikim količinama otpada u životnoj sredini jer se upotrebljeni proizvodi odlažu/bacaju posle čovekove aktivnosti. Ovi otpadi uključuju otpadne gasove, tečni otpad i čvrsti otpad [1], [2], [3]. Plastični otpad je reprezentativan primer otpadnog proizvoda kao posledice industrijskog razvoja, i njegovo odlaganje u životnu sredinu izaziva ozbiljne ekološke probleme. Potrošnja proizvoda od plastike je značajno povećana tokom poslednjih nekoliko decenija. Postoji mnogo razloga za primenu proizvoda od plastike. To su, između ostalih, niska cena sirovina, mala masa i različite mogućnosti prerade. Pored toga, specifična potrošnja energije po jedinici proizvoda je mnogo manja kod plastike nego kod drugih materijala koji se koriste kao ambalaža. Plastična ambalaža je materijal sa najvećom stopom rasta u prethodnoj deceniji.

Plastični materijali su neophodni u modernim društvima. Trenutno, oni su neizostavni deo svakodnevnog života ljudi i primenjuju se u raznim industrijama, kao što su građevinarstvo, zdravstvo, industrijama elektronskih komponenti, poljoprivreda, automobilska industrija i industrije za proizvodnju ambalaže [4]. Potražnja za plastikom nastavlja da raste zahvaljujući odličnim prednostima plastike, kao što su praktičnost, izdržljivost, otpornost na eroziju, lakoća obrade i niske cene [5]. Kao što je prikazano na Sl. 1, od 1950. globalna proizvodnja plastike je rasla složenom godišnjom stopom rasta od 8,4 %; godišnja proizvodnja plastike bila je 360 miliona tona u 2018. a proizvodnja plastike se procenjuje na 500 miliona tona 2025 [6].



Sl. 1. Trend rasta proizvodnje plastike [6]

Proizvodnja plastike uglavnom obuhvata proizvodnju polietilena (PE), polipropilena (PP), polivinil hlorida (PVC), polietilen tereftalata (PET), poliuretana (PUR) i polistirena (PS) kao što je prikazano na Sl. 2. [7]. Shodno tome, generisani plastični otpad takođe potiče iz gore navedenih osnovnih vrsta plastike.



Sl. 2. Procentualni udeli potražnje različitih vrsta plastike [7]

Jedan od razloga zašto je reciklaža plastike korisna je taj što proces proizvodnje zahteva značajnu upotrebu fosilnih goriva. Studije su pokazale da između 7 i 8 % fosilnih goriva na svetu se koriste za proizvodnju plastike. Ovo, možda, ne zvuči mnogo, ali ipak iznosi nekoliko miliona tona godišnje. Gledajući globalno, 2016. godine proizvedeno je 335 miliona tona plastičnih

materijala [8], a očekuje se da će ova cifra porasti na 1124 miliona tona 2050. godine [9]. Shodno tome, kako bi se izbeglo korišćenje fosilnih resursa, reciklaža plastike se ističe kao važan korak u tranziciji cirkularne ekonomije [10].

Polipropilen (PE) se smatra najsvestranijim i najlakšim polimerom. Može se podvrgnuti širokom rasponu proizvodnih procesa, na primer, ekstruzija opšte namene, brizganje, ekspanziono livenje i ekstruziono duvanje. Ima razne primene kao što su: pakovanje porošačkih dobara, plastični delovi u određenim industrijama, uključujući i automobilsku industriju, kao i tekstilnu industriju [11]. Očekuje se da će globalna proizvodnja na tržištu polipropilena dostići 155,57 milijardi dolara 2026. godine [12]. Industrija ambalaže ima najveću potražnju za propilenom i stoga se očekuje da će tržište rasti u budućnosti. Visoka zatezna čvrstoća, bolja završna obrada površine, vrhunska svojstva barijere i niska cena definišu polipropilen kao idealan proizvod za primenu u pakovanju određenih proizvoda [11].

Polietilen (PE) odnosno polietilenske cevi su poznate po svojim isplativim rešenjima u primeni kod cevovoda, npr. za vodu i kanalizaciju, distribuciju prirodnog gasa, industrijsku, rudarsku, deponijsku, pomorsku i električnu primenu [13]. Globalno, potražnja za polietilenskim smolama u 2018. procenjena je na 164 milijarde dolara, što je eskaliralo na 4,0% godišnje [14]. Poboljšanja će odgovarati ukupnom svetskom ekonomskom rastu, vođenom rastom potrošačke potrošnje i industrijske delatnosti. Polietilen spada u najčešće korišćene plastike, zbog svoje prilagodljivosti, niske cene, lake obrade i mogućnosti recikliranja. Međutim, upotreba polietilena se polako ograničava i smanjuje. Na primer, glavna primena polietilena je kod proizvodnje plastičnih kesa čija proizvodnja progresivno postaje predmet ekoloških procedura i zabrana [15].

Polivinilhlorid (PVC) je termoplastični polimer koji se široko koristi zbog svoje izdržljivosti, pristupačnosti i obradivosti. To je opšta plastika za sve namene koja se široko koristi u građevinarstvu, ali i u mnogim potrošačkim proizvodima.

Otpad od plastike smatra se upotrebljivim za reciklažu ukoliko nisu izmenjena njegova fizičko-hemijska svojstva. Upravo, kao jedan od primera reciklaže plastičnog otpada, u radu će biti predstvaljen primer prerade i reciklaže neopasnog industrijskog otpada od polimernih materijala i to polipropilen, polietilen i polivinilhlorid (PP, PE, PVC).

2. METODOLOGIJA

Plastične mase dobijaju se procesom polimerizacije ili hemijskog vezivanja monomera u polimere. Veličina i struktura molekula polimera određuju osobine plastičnog materijala. Plastične mase se dele na termoplastične i termoreaktivne. Termoplastične mase reaguju na promenu temperature i zagrevanjem omekšaju, a hlađenjem se vraćaju u prvobitno stanje. Termoreaktivne mase na povišenoj temperaturi prvo postanu plastične, a potom otvrdnu, te ne mogu omekšati i rastopiti se i ponovo se oblikovati. Najčešće termoplastične mase su polimeri na bazi polivinilhlorida (PVC), polietilena (PE), polipropilena (PP), poliamida (PA), polistirola (PS), akrilobutadien stirola (ABS), poliuretana, polikarbonata i dr. Termoreaktivne mase su polieterske i epoksidne smole, aminoplasti, bakelit (fenolasti) i dr.

U osnovi, plastika se proizvodi u vidu granula, praha (pudera), tečnosti i rastvora. Primenom toplote i pritiska ovi materijali se oblikuju u finalni plastični proizvod.

2.1 Postupak reciklaže polimernih materijala

U nastavku će biti izložen praktičan primer dobijanja gotovog proizvoda preradom neopasnog industrijskog otpada od polimernih materijala (PP, PE, PVC) u okviru firme RKS kompoziti d.o.o.

Sa ciljem da se omogući jednostavnija, brža i ekonomičnija reciklaža industrijskih otpadnih plastičnih masa, razvijen je poces reciklaže koji podrazumeva sledeće postupke:

- sortiranja,
- usitnjavanja,
- pranja,
- aglomeracije i
- regranulacije plastičnog otpada.

Pre sortiranja, otpad se doprema kamionima u različitim oblicima upakovan u velikim plastičnim kesama ili presovan u balama pogodnim za istovar i manipulaciju viljuškarom. Istovar se vrši na platou operatera pomoću viljuškara gde se privremeno skladišti kako bi se obezbedile potrebne količine za reciklažu. Na Sl.3. prikazan je proces prikupljanja i sortiranja sakupljenog polimernog otpada u okviru proizvodnog pogona. Iskustveni podaci pokazuju da generator otpada kada generiše više vrsta plastičnog otpada napravi propust u razvrstavanju na mestu generisanja pa tako dođe do mešanja različitih vrsta otpada. Za proces recikliranja plastike veoma je bitno da plastični otpad bude razvrstan po vrstama, a u okviru iste vrste otpada po fizičkim svojstvima kao što su boja, gustina i slično. Takođe, postoje komadi odbačene plastike koja u sebi sadrže

različite vrste plastičnih materijala koje je potrebno razdvojiti. Sortiranje otpada vrši se ručno. Upakovani otpad se prethodno rastrese na veću površinu kako bi se lakše uočile različite vrste otpada, a potom se vrši razdvajanje odnosno sortitiranje.

Sl. 3. Prikupljeni polimerni otpad

Sečenje plastičnog otpada vrši se na mašini za sečenje (Sl.4.). Operacija sečenja se primenjuje kada su u pitanju plastične folije, i drugi plastični komadi koji po gabaritima ne mogu da se ubace u koš mlina. Sečka se sastoji od pokretne trake, valjka za uvlačenje plastičnih komada i noža za sečenje. Sečka se dozira ručno. U cilju usitnjavanja otpada vrši se mlevenje, tehnološka operacija kojom se vrši usitnjavanje plastičnog otpada do željene veličine. Cilj usitnjavanja je povećanje specifične površine usitnjenog otpada.

Pranje plastičnog otpada je najprikladnije nakon završnog usitnjavanja. Predmetni plastični otpad je po pravilu zaprljan raznim mehaničkim primesama koje je neophodno ukloniti pre ponovne upotrebe. Usitnjavanjem se povećava kontaktna površina, a pored toga se i u toku samog mlevenja deo nečistoća mehaničkim putem ukloni. Proces pranja se odvija u kadi za pranje (Sl.4.). Kada za pranje je opremljena centralnim vijkom sa perforiranim lopaticama. Pahuljice iz mlina se pomoću transportne trake ubacuju u korito kade koja je prethodno napunjena vodom. Rotacijom centralnog vijka lopatice zahvataju pahuljice i vrše mešanje istih. Trenjem pahuljice od pahuljicu dolazi do uklanjanja nečistoća. Pored mešanja, centralni vijak ima zadatak i da vrši transport pahuljica od početnog dela kade do izlaznog dela. Na kraju kade se nalazi perforirani valjak pomoću kojeg se sa površine vode vrši izuzimanje pahuljica koje se potom dalje transportuju u kontinualnu centrifugu radi izdvajanja vode od pahuljica nakon pranja plastike. Takođe se koriste i hidrocikloni, koji su ekonomičan i efikasan uređaj za odvajanje različitih vrsta plastike iz mešavine plastike, kao i za uklanjanje nečistoća.

Za sušenje plastičnih pahuljica koristi se rotaciona sušara u obliku cilindra. Na Sl.4. prikazani su procesi usitnjavanja i pranja otpada, sa ciljem uklanjanja nečistoća i pripreme sirovine za dalji proces prerade, granulacije i dobijanja regranulata i gotovog proizvoda (Sl.5.).

Sl. 4. Usitnjavanje i pranje otpada

Pakovanje osušenih pahuljica vrši se u džambo vreće. Pakovanje pahuljica se vrši poluautomatski tako što se prethono džambo vreća navuče na cev za punjenje na silosu. U toku pakovanja radnik treba da kontroliše punjenje kako bi se izbeglo prepunjenje. Kada se džambo vreća napuni, zaposleni ručno zatvara dotok pahuljica iz silosa zavezuje džambo vreću a potom se ista viljuškarom odvozi u prostor za skladištenje reciklata [16].

Cilj predloženog primera reciklaže jeste da se dobije regranulat sa kontrolisanim fizičko – hemijskim i mehaničkim svojstvima. Regranulat je moguće proizvoditi po specijalnim specifikacijama.

Sl. 5. Granulacija i proizvodnja gotovog proizvoda

3. REZULTATI

Reciklažom i preradom neopasnog industrijskog otpada od polimernih materijala (PP, PE, PVC) dobijeni su regranulati sa kontrolisanim fizičko-hemijskim i mehaničkim osobinama i

određeni gotovi proizvodi.

Za dobijanje PP regranulata, na liniji za preradu reciklirane plastike, izvršena je granulacija materijala od polipropilena i polietilena. Dobijen je proizvod kontrolisanog i konstantnog kvaliteta (Sl.6.). PP regranulat ima široku primenu u procesima brizgranja i ekstrudiranja. Neki od proizvoda koji se dobijaju preradom PP regranulata su: kofe, kante, kontejneri, vezivo, vreće itd.

Sl. 6. PP regranulat

PE regranulat dobija se granulacijom materijala od polipropilena i polietilena (LDPE, HDPE). LDPE, polietilen niske gustine, se primenjuje za čvrste i fleksibilne elemente ambalaže kao što su poklopci za tegle, čepovi za flaše i slično. Najpopularnija primena LDPE-a je za folije za kese, materijale za pakovanje, za folije za plastenike i u poljoprivredi uopšteno. HDPE, polietilen visoke gustine, ima širok sprektar primene: boce, štipaljke za veš, različite drške i ručice, kao i ekstremno tanke folije odlične čvrstine. Na Sl.7. prikazan je izgled PE regranulata.

Sl. 7. PE regranulat

PVC regranulat ima primenu u proizvodnji kablova, đonova za obuću, baštenskih creva, patosnica, vodovodnih materijala, lajsni, igračaka i mnogih drugih proizvoda. Na Sl. 8. dat je prikaz PVC regranulata u raspoloživim bojama.

Sl. 8. PVC regranulat

Kompaundi se dobijaju mešanjem polimernog materijala sa raznim puniocima, modifikatorima i aditivima tokom procesa kompaundiranja. Ukoliko postoji potreba za tim, mogu se menjati svojstva proizvoda kompaundiranjem i dobiti granulat vrhunskog i ponovljivog kvaliteta (Sl. 9.). Svojstva koja se mogu prilagoditi su na primer: MFR, termostabilnost, specifična težina, tvrdoća, sakupljanje i mnoga druga.

Sl. 9. Kompaundi

Kao gotovi proizvodi od regranulata izdvajaju se PP trake i PP vezivo, prikazani na Sl.10.

Sl. 10. PP trake i vezivo

PP trake koristi se za vezivanje paketa, kutija, gajbi i sl. Najviše se primenjuje u industriji kao siguran način da se obezbedi paleta ili pakovani proizvod. Tehnologija kojom se proizvodi traka obezbeđuje proizvodnju različitih dimenzija i boja. Standardne boje su crna i bela, ali se mogu proizvesti i crvena, plava, žuta i mnoge druge

boje. PP vezivo odnosno polipropilensko vezivo se najviše koristi u poljoprivredi za baliranje sena, slame i sl. Proizvodi su UV stabilizirani, tako da materijal neće degradirati pri izlaganju sunčevoj svetlosti. Utvrđeno je da PP vezivo ima odlične mehaničke osobine. Pri proizvodnji se konstantno vrši testiranje i provera prekidne čvrstoće i prekidnog izduženja dobijene fibrilizirane trake od koje se namotavanjem dobija vezivo.

4. ZAKLJUČAK

Ispitivanjem tržišta utvrđeno je da se u Srbiji reciklaža plastičnog materijala vrši najčešće tako što se vrši separacija otpada, zatim presovanje, usitnjavanje, pranje i ekstruzija do granulata, koji se dalje pakuje i prodaje drugim firmama ili izvozi u inostranstvo. U ovom radu pokazana je mogućnost dobijanja konkretnih proizvoda koji su funkcionalni i koji su se bez problema našli na tržištu. U okviru firme „RKS kompoziti“ d.o.o. ceo proces reciklaže je zaokružen, jer je u proizvodnom procesu izvršena transformacija ulaznog plastičnog predmeta, koji je otpad, u izlazni plastični premet, nove forme, koji dobija nov život (PP trake i PP vezivo) i ima široki opseg primene i veliku potražnju na tržištu.

Kada se pomene termin reciklaža, sa ekonomskog aspekta se odmah kreira odgovor „Ne isplati se.“ ali sa ekološkog aspekta se vrlo često uzima u obzir ova opcija za tretiranje i rešavanje otpada. Ništa nije idealno, kao što ni materijal koji dolazi na reciklažu nije idealan. Zadatak na nama je da pronađemo, kako ekonomski tako i ekološki, najprihvatljiviji način za rešavanje ovog problema jer će se na taj način smanjiti negativni uticaj industrije polimera na životnu sredinu, uz ostvarivanje potencijalne ekonomske dobiti.

5. REFERENCE

[1] Tang, Z., Li,W., Tam, V.W.Y., Xue, C.: *Advanced progress in recycling municipal and construction solid wastes for manufacturing sustainable construction materials*, Resour. Conserv. Recycl, X, p. p. 6, 2020.

[2] Zhang, K., Shi, H., Peng, J., Wang, Y., Xiong, X., Wu, C., Lam, P.K.S.: *Microplastic pollution in China's inland water systems: a review of findings, methods, characteristics, effects, and management*, Sci. Total Environ., 630, p. p. 1641-1653, 2018.

[3] Zhao, Y., Tan, Y., Feng, S.: *Does reducing air pollution improve the progress of sustainable development in China?*, J. Clean. Prod., 272, 2020.

[4] Anuar Sharuddin, S.D., Abnisa, F.,Wan Daud,W.M.A., Aroua, M.K.: *A review on pyrolysis of plastic wastes*, Energy Convers. Manag., 115, p. p. 308-326. 2016.

[5] Wong, S.L., Ngadi, N., Abdullah, T.A.T., Inuwa, I.M.: *Current state and future prospects of plastic waste as source of fuel: a review*, Renew. Sustain. Energy Rev., 50, p. p. 1167-1180. 2015.

[6] PlasticsEurope: *An Analysis of European Plastics Production, Demand and Waste Data*, Plasticsethe Facts 2019, 2019.

[7] Rodrigues, M.O., Abrantes, N., Goncalves, F.J.M., Nogueira, H., Marques, J.C., Goncalves, A.M.M.: *Impacts of plastic products used in daily life on the environment and human health: what is known?*, Environ. Toxicol. Pharmacol., 72, p. p. 239. 2019.

[8] PlasticsEurope and EPRO (European Association of Plastics Recycling & Recovery Organisations), Plastics the facts, 2017.

[9] EMF (Ellen MacArthur foundation): *The new plastic economy – rethinking the future of plastics*, 2016.

[10] EC (European Commission): *Closing the loop - An EU action plan for the Circular Economy*, 2015.

[11] Hu S, Shan J, Zhang Q, Wang Y, Liu Y, Gong Y, et al.: *Selective formation of propylene from methanol over high-silica nanosheets of MFI zeolite*, Appl Catal A Gen, 2012.

[12] Gahleitner M, Paulik C.: *Polypropylene and other polyolefins. In: Brydson's*, Plast. Mater. eighth ed., 2017.

[13] American Water Works Association: *PE Pipe :design and installation*, p.p. 151, 2006.

[14] Grommes D, Reith D.: *Determination of relevant mechanical properties for the production process of polyethylene by using mesoscale molecular simulation techniques*, Soft Mater , p. p. 1–20, 2020.

[15] Ronca S.: *Polyethylene*, In: Brydson's Plast. Mater. eighth ed., ScienceDirect, p.p. 247–278, 2017.

[16] *Radni plan postrojenja za skladištenje i tretman neopasnog otpada*, RKS KOMPOZITI DOO, Maršala Tita 45, Čelarevo, 2017.

Autori: **dr Zorica Mirosavljević, Van. prof. dr Bojan Batinić, Doc. dr Milana Ilić Mićunović,** Univerzitet u Novom Sadu, Fakultet Tehničkih Nauka, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2386.

MSc Vladimir Knežević, RKS KOMPOZITI DOO, Maršala Tita 45, Čelarevo

E-mail: zoricamirosavljevic@uns.ac.rs

knezevic@rkskompoziti.rs
bojanbatinic@uns.ac.rs
milanai@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Kovačić, I., Kanović, Ž., Rajs, V., Rakarić, Z.

O METASTRUKTURAMA SA UGRAĐENIM HOMOGENIM APSORBERIMA

Rezime: *Lake noseće inženjerske konstrukcije, poput rešetki, su često izložene vibracijama širokog frekvencijskog opsega. Novi pristup pasivnoj kontroli ovih vibracija donosi praktično rešenje bez dodavanja mase, a podrazumeva korišćenje delova same konstrukcije tako da igraju ulogu vibracionih apsorbera. Fokus ovog istraživanja je na eksperimentalnoj analizi ponašanja metastrukture posebne geometrije, napravljene 3D štampom kao lake konstrukcije sa ugrađenim homogenim apsorberima, kao i konstrukcije bez aktivnih apsorbera u cilju poređenja amplitudno-frekvencijskih karakteristika i određivanja frekvencijskog opsega u kome je postignuto smanjenje amplitude vibracija. Osim toga, razmatrani su i odgovarajući mehanički modeli u cilju objašnjenja fenomenologije uticaja apsorbera. Date su smernice za unapređenje postojećeg dizajna i buduća istraživanja.*

Ključne reči: *metastruktura, vibracioni apsorber, kontrola vibracija*

1. UVOD

Nisko-frekvencijska buka i vibracije se javljaju u prirodi i industriji, štetno utičući na životnu sredinu, zdravlje ljudi i rad različitih inženjerskih sistema. Njihovo ublažavanje se postiže snižavanjem sopstvene frekvencije sistema, odnosno korišćenjem velikih masa ili malih krutosti. Međutim, velika masa je nepovoljna za lake noseće konstrukcije jer ih preopterećuje; mala krutost izaziva velike deformacije, što je neprihvatljivo za precizne mašine, aero i avio strukture. Stoga su potrebna poboljšana rešenja za širokopojasne primene. Jedno od savremenih rešenja podrazumeva dizajn tzv. metastruktura. Metastrukture se nadovezuju na koncept metamaterijala, kod kojih se jedinstvenom kombinacijom geometrije i karakteristika materijala integrišu elementi u osnovnu strukturu sa ciljem ostvarivanja željenih karakteristika dinamičkog odziva, pri čemu se te karakteristike fundamentalno razlikuju od onih koje imaju sastavni elementi i od onih koji već postoje u prirodi, a primenljive su na različitim skalama.

U pionirskim radovima [1, 2] su proučavani lokalno rezonantni sistemi napravljeni od olovnih sfera presvučenih gumom. Rad [3] se bavi vibracijama aluminijumske grede sa periodično pričvršćenim gumenim i bakarnim prstenovima kao apsorberima vibracija, dok rad [4] analizira vibracije aluminijumske metastrukturne ploče sa anizotropnim inkluzijama. U radu [5] je ispitivana rešetkasta struktura obogaćena dodatnim apsorberima od volframa i gume. Međutim, ovakvi dodaci metastrukturama imaju veliku težinu, što ograničava njihove potencijalne inženjerske primene kod lakih konstrukcija. Brz razvoj naprednih proizvodnih tehnologija, kao što je 3D štampa, pružio je mogućnost lakog i brzog pravljenja složenih struktura, uključujući i metastrukture male težine. U radu [6] su proučavane uzdužne vibracije metastrukturnog štapa sa periodičnim apsorberima napravljenim 3D štampom od polimera. U radu [7] su analizirane transverzalne vibracije u metastrukturnoj gredi čiji su listovi laminati, a jezgro je pena sa ugrađenim apsorberima. U radu [8] je predložen metastrukturni panel napravljen od ugrađenih rezonatora i sendvič panela.

Zajednička odlika svih gore izloženih rešenja je korišćenje principa osnovne strukture i apsorbera kao masa u masi ili masa na masi. Međutim, sve njih odlikuje različitost materijala tih masa: apsorbera i osnovne strukture. Inman sa saradnicima je ponudio drugačiji koncept [9, 10], kod kog su apsorberi i osnova napravljeni od istog materijala čineći kontinualnu jednokomadnu metastrukturu, što znatno uprošćava i pojeftinjuje proces proizvodnje. U ovom radu je detaljno analiziran ovaj koncept u smislu mehaničkog modelovanja i eksperimentalnog ispitivanja metastrukture napravljene 3D štampom.

2. KONCEPTI I REALIZACIJA

2.1 Koncept za diskretan mehanički sistem

U sistemu koga čini oscilator modelovan masom m vezan za linearnu oprugu krutosti k na koji dejstvuje spoljašnja prinudna harmonijska sila frekvencije Ω, ovaj oscilator kao diskretan sistem sa jednim stepenom slobode, može da bude u rezonanciji kada je njegova sopstvena frekvencija $\omega=(k/m)^{1/2}$ jednaka frekvenciji prinude $\omega=\Omega$ [11]. U rezonanciji dolazi do znatnog porasta njegove

amplitude, što je nepovoljno. Međutim, ako se na osnovni oscilator kolinearno sa pravcem njegovog oscilovanja doda podešeni linearni oscilator čija je sopstvena frekvencija ω_d jednaka frekvenciji prinude $\omega_d=\Omega$, osnovni oscilator neće oscilovati, tj. dodatni oscilator će za sistem biti apsorber na toj frekvenciji Ω, koja je u prvobitnoj verziji sistema bila rezonantna [11]. U slučaju postojanja prigušenja, amplituda osnovne mase neće biti nula, već će imati relativno malu vrednost, što je svakako povoljnije od rezonantne amplitude u slučaju bez dodatne mase.

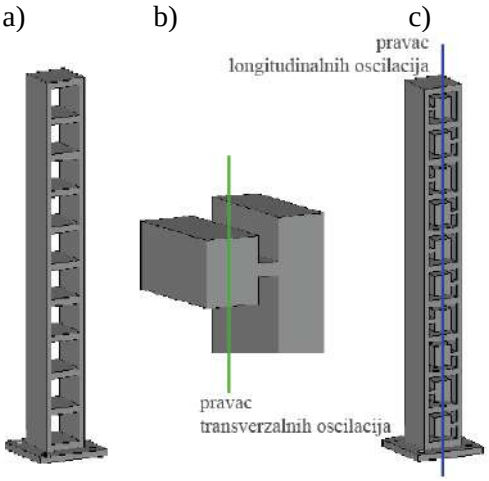
2.2 Proširenje koncepta na kontinualnu metastrukturu

Teorijski koncept za diskretan sistem izložen u sekciji 2.1 – korišćenje dodatnog oscilatora za smanjivanje amplitude osnovnog oscilatora, je modifikovan u radovima [9, 10] za dizajn metastrukture sa Sl. 1, uz nekoliko bitnih razlika:

i) Osnovna struktura (Sl. 1a) je kontinualan, a ne diskretan sistem. Dakle, nema jedan, već beskonačan broj stepeni slobode kretanja.
ii) Ne postoji jedan, već niz distribuiranih unutrašnjih oscilatora, koji će igrati ulogu apsorbera (Sl. 1b).
iii) Ovi oscilatori su homogeni i integrisani u osnovnu strukturu, čineći sa njom jednokomadnu metastrukturu (Sl. 1c).
iv) Unutrašnji oscilatori vrše transverzalne oscilacije (Sl. 1b) koje su kolinearne sa longitudinalnim oscilacijama metastrukture (Sl. 1c) koje treba da ublaže.
v) Svaki unutrašnji oscilator je identičan i podešava se tako da njegova prva modalna (rezonantna) frekvencija transverzalnih oscilacija bude jednaka prvoj modalnoj frekvenciji longitudinalnih oscilacija metastrukture.

2.3 Praktična realizacija

Izloženi koncept omogućuje izradu metastrukture sa simetričnom, ponavljajućom strukturom. Osnovna struktura je šupljeg kvadratnog poprečnog preseka (Sl. 1a), a unutrašnji oscilatori imaju oblik konzola sa dominantnom masom na vrhu konzole (Sl. 1b). Oni se integrišu u vertikalne zidove osnove i daju metastrukuturu (Sl. 1c). Jedan unutrašnji oscilator sa Sl. 1b i metastruktura sa Sl. 1c su napravljeni 3D štampom (Fused Filament Fabrication) sa rezolucijom 0.1 – 0.3 mm i ispunom 100% od materijala Acrylonitrile butadiene styrene (ABS) čije su karakteristike: Jangov moduo elastičnosti E=1490 MN/m^2 i gustina materijala ρ=1.05 g/cm^3. Visina metastrukture je 351,5 mm. Ostale dimenzije su definisane prema radu [9].

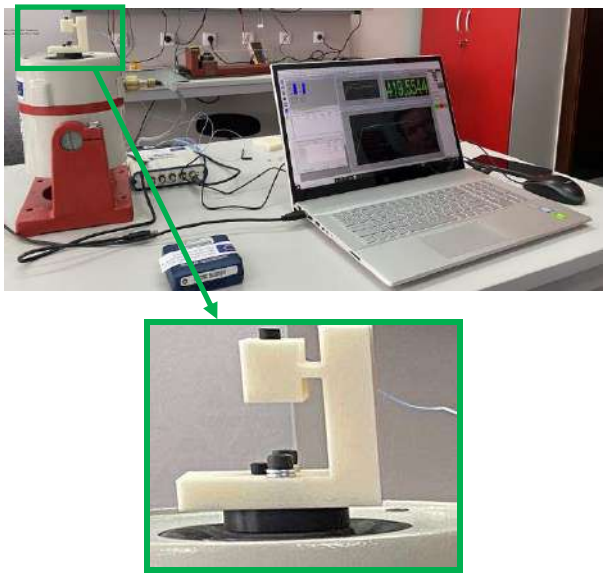


Sl. 1. a) Osnovna struktura; b) Apsorber; b) Metastruktura

3. EKSPERIMENTALNA ANALIZA

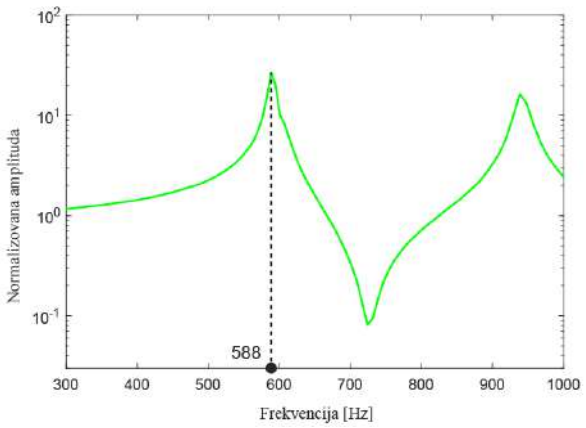
U cilju ispitivanja longitudinalnih oscilacija metastrukture, ona je izložena pobudi baze u vertikalnom pravcu. Pobuda je kreirana i odziv beležen sistemom za vibraciona testiranja (Sl. 2a), koji uključuje LDS vibrator tip V408,10/32UNF; LDS pojačavač tip LPA100; akcelerometar tip 4534-B; COMMETUSB kontroler tip COM-200 i programski paket SCO-107 za 'Sine, Random & Shock' pobude (primenjen je prvi tip pobude).

Najpre je element sa Sl. 1b postavljen na sistem za vibraciona testiranja (Sl. 2).



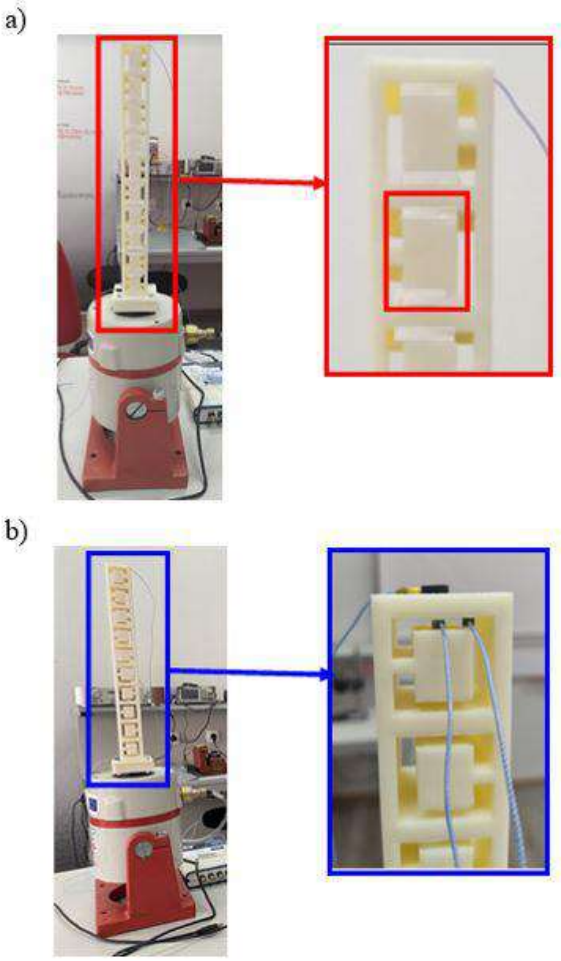
Sl. 2. Eksperiment sa jednim samostalnim apsorberom

Zahvajujući akcelerometru postavljenom na vrhu, prikazanom na uvećanom delu Sl. 2, dobijena je amplitudno-frekvencijska karakteristika (AFK) prikazana na Sl. 3. Uočava se da prva modalna frekvencija transverzalnih oscilacija samostalnog apsorbera iznosi 588 Hz.



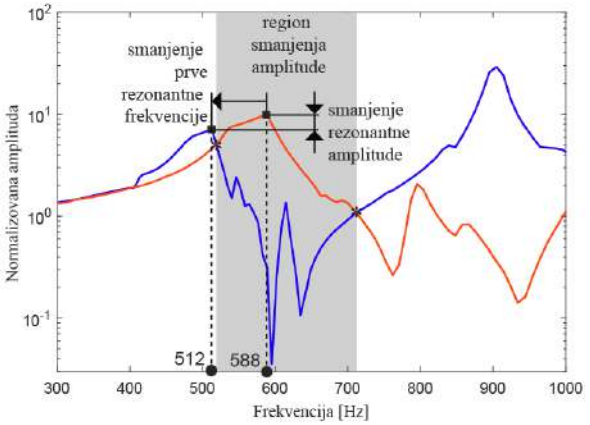
Sl. 3. AFK za samostalan apsorber

Zatim je testirana metastruktura sa Sl. 1c u dve konfiguracije: sa blokiranim apsorberima (Sl. 4a) i aktivnim apsorberima (Sl. 4b).



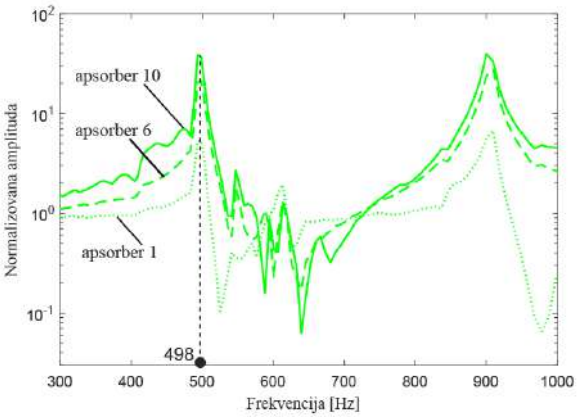
Sl. 4. Eksperimenti sa metastrukturom u kojoj su apsorberi: a) blokirani; b) aktivni

Kako je prikazano na uvećanom desnom delu Sl. 4a, blokiranje apsorbera je izvršeno umetanjem stiropora između njih i horizontalnih površina strukture iznad i ispod koncentrisanih masa apsorbera. Postavljanjem akcelerometra na vrh obe konfiguracije, dobijene su AFK prikazane na Sl. 5. Uočava se da prva modalna frekvencija metastrukture sa blokiranim apsorberima (crvena AFK) iznosi 588 Hz, tj. identična je prvoj modalnoj frekvenciji transverzalnih oscilacija samostalnog apsorbera (Sl.3), te se zaključuje da je podešavanje frekvencija uspešno izvršeno. Kod konfiguracije sa aktivnim apsorberima (plava AFK), prvi rezonantni vrh (označen crnim kvadratom) se pomera ka nižoj frekvenciji, tj. na 512 Hz, a smanjuje mu se i amplituda. Metastruktura sa aktivnim apsorberima ima manju amplitudu u odnosu na onu sa blokiranim, u vrlo širokom frekvencijskom regionu od približno 200 Hz (osenčeni region na Sl. 5).



Sl. 5. AFK za slučaj metastrukture sa blokiranim apsorberima (crvena linija) i aktivnim apsorberima (plava linija)

Nadalje, određene su i AFK za prvi (najniži), šesti i deseti (vršni) apsorber i upoređene međusobno (Sl. 6). Njihove amplitude na prvoj rezonantnoj frekvenciji su različite, što je očekivana posledica njihovog različitog položaja po visini metastrukture. Ova frekvencija iznosi 498 Hz i niža je od sopstvene frekvencije samog apsorbera označene na Sl. 3 za 90 Hz.



Sl. 6. AFK za prvi, šesti i deseti apsorber

Međutim, kako se sa Sl. 6 uočava, njihovo

ponašanje na frekvencijama višim od prve rezonantne frekvencije se razlikuje, a nakon toga prati trend AFK metastrukture sa Sl. 5. Ovo ukazuje da apsorpciona svojstva svakog apsorbera pojedinačno nisu u potpunosti iskorišćena.

4. ZAKLJUČAK

U ovom radu su postavljene osnove istraživanja kontrole vibracija metastruktura koje se kreiraju integrisanjem vibracionih apsorbera u samu konstrukciju, a prave se 3D štampom. Ovaj prilaz ima višestruke prednosti u odnosu na rasprostranjene konvencionalne prilaze koji podrazumevaju da se apsorberi naknadno postavljaju na postojeću konstrukciju kao dodatne mase. Ove dodatne mase su nepovoljne za lake konstrukcije, a zahtevaju i rad za naknadnu montažu, što ima negativan ekonomski efekat.

U radu je objašnjen osnovni teorijski koncept apsorbera i njihovog proširenja na kontinualne metastrukture koje vrše longitudinalne oscilacije, a imaju integrisan niz apsorbera čije transverzalne oscilacije imaju višestruke povoljne efekte na vibracije vrha metastrukture: prvi rezonantni vrh se pomera na nižu frekvenciju, smanjuje mu se amplituda, a metastruktura sa aktivnim apsorberima ima smanjenu amplitudu u širokom frekvencijskom opsegu od približno 200 Hz.

Eksperimentalni rezultati za apsorbere na različitim položajima na metastrukturi su ukazali da bi ih, zarad njihove veće efikasnosti, trebalo projektovati tako da budu različitih sopstvenih frekvencija, te da obuhvate više modalnih frekvencija metastrukture, tj. da budu multimodalni, što je cilj budućih istraživanja. Osim toga, od interesa je odrediti i optimalan broj apsorbera za maksimalnu širinu frekvencijskog opsega u kom se smanjuje amplituda. Od značaja je i dizajn apsorbera koji će imati istovremeno povoljno dejstvo za longitudinalne, transverzalne i torzione oscilacije metastrukture.

5. POSLEDNJE NAPOMENE

Ovaj rad je rezultat istraživačko-razvojnog projekta „Izolacija buke i vibracija posredstvom nelinearnih metastruktura“, koji je započeo 1. 7. 2021. godine, a koji finansiraju Ministarstvo nauke i tehnologije Narodne Republike Kine i Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije.

6. REFERENCE

[1] Liu, Z.: *Locally resonant sonic materials*, Science, 289, p.p. 1734-1736, 2000.

[2] Sheng, P., Zhang, X.X., Liu, Z., Chan, C.T.: *Locally resonant sonic materials*, Physica B Condensed Matter, 338, p.p. 201-205, 2003.

[3] Yu, D., Liu, Y., Wang, G., Zhao, H., Qiu, J.: *Flexural vibration band gaps in Timoshenko beams with locally resonant structures*, Journal of Applied Physics, 100, Art. No. 124901, 2006.

[4] Zhu, R., Liu, X.N., Huang, G.L., Huang, H.H., Sun, C.T.: *Microstructural design and experimental validation of elastic metamaterial plates with anisotropic mass density*, Physical Review B, 86, Art. No. 144307, 2012.

[5] Zhu, R., Liu, X.N., Hu, G.K., Sun, C.T., Huang, G.L.: *A chiral elastic metamaterial beam for broadband vibration suppression*, Journal of Sound and Vibration, 333, p.p. 2759-2773, 2014.

[6] Qureshi, A., Li, B., Tan, K.T.: *Numerical investigation of band gaps in 3D printed cantilever-in-mass metamaterials*, Scientific Reports, 6, Art. No. 28314, 2016.

[7] Chen, J.S., Sharma, B., Sun, C.T.: *Dynamic behaviour of sandwich structure containing spring-mass resonators*, Composite Structures, 93 p.p. 2120-2125, 2011.

[8] Yu, T., Lesieutre, G.A.: *Damping of sandwich panels via three-dimensional manufactured multimode metamaterial core*, AIAA Journal, 55, p.p. 1440-1449, 2017.

[9] Hobeck, J.D., Laurent, C.M.V., Inman, D.J.: *3D Printing of metastructures for passive broadband vibration suppression*, Proceedings of the 20th International Conference on Composite Materials, Copenhagen, 19-24 July 2015.

[10] Reichl, K.K., Inman, D.J.: *Lumped mass model of a 1D metastructure for vibration suppression with no additional mass*, Journal of Sound and Vibration, 403, p.p. 75-89, 2017.

[11] Kovacic, I., Radomirovic, D.: *Mechanical Vibrations: Fundamentals with Solved Examples*, John Willey & Sons, 2017.

Autori: **Prof. dr Ivana Kovačić, dr Željko Kanović, vanredni prof., dr Vladimir Rajs, vanredni prof., dr Zvonko Rakarić, vanredni prof.,** Univerzitet Novi Sad, Fakultet Tehničkih Nauka, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2241.
E-mail: ivanakov@uns.ac.rs
kanovic@uns.ac.rs
vladimir@uns.ac.rs
zvonko@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Agarski, B., Ilić Mićunović, M., Budak, I., Vukelić, Đ.

IZBOR ODGOVARAJUĆIH AKTIVNOSTI IZ BAZE PODATAKA KOD ANALIZE INVENTARA ŽIVOTNOG CIKLUSA

Rezime: *Ocenjivanje životnog ciklusa je standardizovana i detaljna metoda za procenu uticaja ljudskih aktivnosti na životnu sredinu. S obzirom na veliki broj informacija i podataka koje je potrebno obraditi prilikom ocenjivanja životnog ciklusa, primena računara, specijalizovanih softvera i baza podataka je neophodna za dobijanje verodostojnih i uporedivih rezultata. U radu je razmatran postupak izbora skupova podataka (aktivnosti) iz baze podataka inventara životnog ciklusa pri modeliranju ocenjivanja životnog ciklusa u softveru. Predloženo je pet koraka za postupak izbora skupa podataka iz baze inventara životnog ciklusa: izbor plana proizvodnog sistema, izbor naziva aktivnosti, izbor sistema modelovanja, izbor geografskom područja i tržišta i izbor jediničnih ili sistemskih procesa. Prikazani postupak izbora odgovarajućih skupova podataka iz baze inventara životnog ciklusa može se primeniti u različitim softverima i bazama za podršku ocenjivanju životnog ciklusa. U rezultatima prikazana je primena na izbor električne energije i niskolegiranog čelika i diskutovane su različite mogućnosti.*
Ključne reči: *aktivnost, baza podataka, inventar, ocenjivanje životnog ciklusa*

1. UVOD

Ocenjivanje životnog ciklusa (engl. life cycle assessment - LCA) postaje naročito značajno u oblasti upravljanja zaštitom životne sredine i vrednovanja uticaja na životnu sredinu nakon objavljivanja međunarodnog standarda ISO 14040 1997 godine [1]. Nakon toga, postepeno su objavljivani i ostali standardi vezani za LCA a svakako najznačajniji su trenutno važeći ISO 14040 (2006) Upravljanje zaštitom životne sredine - Ocenjivanje životnog ciklusa - Principi i okvir [2] i ISO 14044 (2006) Upravljanje zaštitom životne sredine - Ocenjivanje životnog ciklusa - Zahtevi i uputstva za primenu [3]. Za primenu LCA potrebna je upotreba računara čime se osigurava dobijanje uporedivih i verodostojnih rezultata. Računar omogućava pretragu i obradu informacija iz specijalizovanih baza podataka za inventar životnog ciklusa (engl. life cycle inventory - LCI). Baze podataka pružaju informacije o različitim ljudskim aktivnostima i procesima. Termini proces, aktivnost ili skup podataka u LCI bazi podataka koriste se za predstavljanje prosečnih proizvodnih inventara na određenom geografskom području.

Istraživanje izbora odgovarajućih setova podataka za LCI je aktivna tema u oblasti LCA. Meron i drugi [4] su razvili metodologiju za izbor seta podataka koji predstavlja nedostajuće setove podataka bolje od podrazumevanih setova u LCI bazi podataka u smislu bolje aproksimacije uticaja na životnu sredinu. Ingwersen i ostali [5] su predložili procese premošćavanja koji predstavljaju vezu između dva postojeća procesa kako bi omogućili korisnicima da integrišu nove setove podataka. Evropska komisija je razvila Look@LCI softver za analizu LCI setova podataka [6] za Environmental Footprint metodu koja služi za označavanje o zaštiti životne sredine tipa III. Khoo i drugi [7] su razmatrali faktore pri izboru podataka za LCI za potrebe hemijske industrije kao što su: izvor informacija, granice sistema/područje primene, procesni i tehnički detalji, potpunost i uporedivost podataka, reprezentativnost, lokaciju-specifičnosti područja, transparentnost, reproduktivnost.

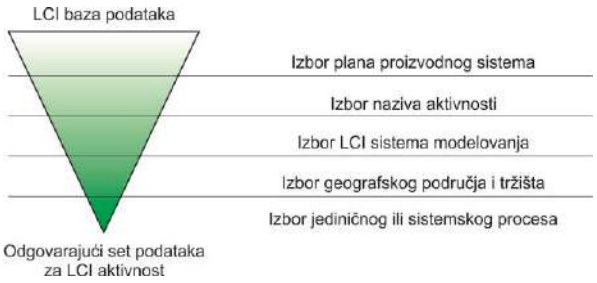
U nastavku rada opisan je postupak izbora skupova podataka (aktivnosti) iz LCI baze podataka. Na osnovu predloženog postupka izbora skupova podataka prikazana je primena na primeru izbora niskolegiranog čelika i električne energije iz LCI baze podataka.

2. METODE

Pri izboru odgovarajućih skupova podataka iz LCI baza treba odlučiti (Slika 1):

1. Da li treba modelirati aktivnosti u prvom planu ili pozadinskom planu?
2. Izbor naziva aktivnosti (proces) koji najverodostojnije opisuje modelirani proces u granicama sistema.
3. Da li primeniti posledično ili opisno modeliranje?
4. Koje geografsko područje i tržište odabrati?
5. Da li treba odabrati jedninični ili sistemski

proces (aktivnost)?



Sl. 1. Izbor odgovarajućeg seta LCI podataka

Pri izboru prvog plana ili pozadinskog plana utiče kvalitet detalja procesa koji se modelira. Prvi plan u proizvodnom sistemu jeste onaj na koji se može direktno uticati i za koji se može doneti odluka. Pozadinski plan se sastoji od procesa na koje ne može direktno da se utiče (npr. dobaljači poluproizvoda) i koji se mogu uzimati kao prosečni podaci regiona i iz LCI baza podataka [8]. Na primer, ako je ispitivani sistem proizvodnja mobilnog telefona, onda će transport materijala biti u pozadinskom sistemu, tj. transport se može odabrati kao generički skup podataka iz LCI baze podataka. Ako je ispitivani sistem transport materijala na određenoj razdaljini, potrebno je detaljno izabrati procese koji opisuju ovaj transport.

Pri izboru aktivnosti u bazi podataka potrebno je odabrati naziv aktivnosti čiji opis verodostojno opisuje aktivnost koja se modelira. Ukoliko ne postoji odgovarajuća aktivnost potrebno je modelirati proces od aktivnosti iz baze na način koji verodostojno opisuje tu aktivnost. Na primer, ako u bazi podataka nije dostupna aktivnost koja opisuje proizvodnju hemijske supstance (paladijum(II)hlorid) onda treba modelirati proces proizvodnje izborom i povezivanjem postojećih aktivnosti u bazi podataka (reakcija paladijuma sa hlorovodoničnom kiselinom proizvodi paladijum(II)hlorid).

Izbor posledičnog (engl. consequentional) ili opisnog (engl. attributional) modeliranje zavisi od cilja i predmeta studije, tačnije od svrhe studije [9]. Ako je potrebno odrediti kako proizvod može uzrokovati uticaje na životnu sredinu i koji je udeo ovog ovih uticaja u celokupnom zagađenju sveta odgovarajuće je opisno modeliranje. Ako je potrebno odrediti šta će se desiti ako se proizvod A zameni proizvodom B i koji se uticaji na životnu sredinu javljanju pri ovoj zameni tada je odgovarajuće primeniti posledični model sistema. Karakteristika opisnog modeliranja je primena alokacije a kod posledičnog modelovanja primenjuje se proširenje granica sistema u cilju izbegavanja alokacije. Opisno modeliranje opisuje trenutno ili predviđeno stanje sa prosečnim vrednostima dobavljačkog lanca u statičnoj antropogenoj sredini [9]. Posledično modeliranje opisuje dobavljački lanac kao očekivanja posledica analiziranih odluka u dinamičnoj antropogenoj sredini koja reaguje na promene kod različitih proizvoda.

Pri izboru geografskog područja i tržišta treba razmotriti na kojem području se dešava (odvija) aktivnost koju modeliramo. Mogu se razlikovati globalni, regionalni ili nacionalni skupovi podataka u LCI bazama. Pored geografskog područja, u LCI bazama mogu se pronaći skupovi podataka tržišnih aktivnosti koje uzimaju u obzir transport dobara, gubitke u transportu i prosečni miks različitih dobavljača što je i česta potreba u praksi. Na primer, ako je potrebno izabrati polietilen tereftalan (PET) granulat tada će tržišna aktivnost „market for PET, RER“ uzimati u obzir prosečne količine koji PET dobavljači proizvode za potrebe na teritorije Evrope (RER je skraćenica za područje Evrope u Ekoinvent bazi), koje takođe uključuje i transport i transportne gubitke.

Jednинični ili sistemski procesi (Da li je potrebna modifikacija ili ne, brzina izračunavanja, detaljnost tumačenja – contribution analysis). Sistemski procesi u LCI su modelirani kao jedna crna kutija dok su jedinični procesi modelirani kao kombinacija više crnih kutija. Sistemski i jedinični procesi daju iste razultate uticaja na ŽS, razlika je da jedinični procesi omogućavaju analizu doprinosa (engl. contribution analysis). Jedinični procesi [10] omogućavaju analizu dobavljačkog lanca jer sadrže veze sa ostalim procesima (aktivnostima) i mogu se koristiti za analizu žarišta uticaja na životnu sredinu (engl. environmental hotspots). Jedinični procesi omogućavaju analizu nesigurnosti. Sistemski procesi se brže izračunavaju na računaru i mogu se primeniti u slučaju poverljivih podataka.

3. REZULTATI

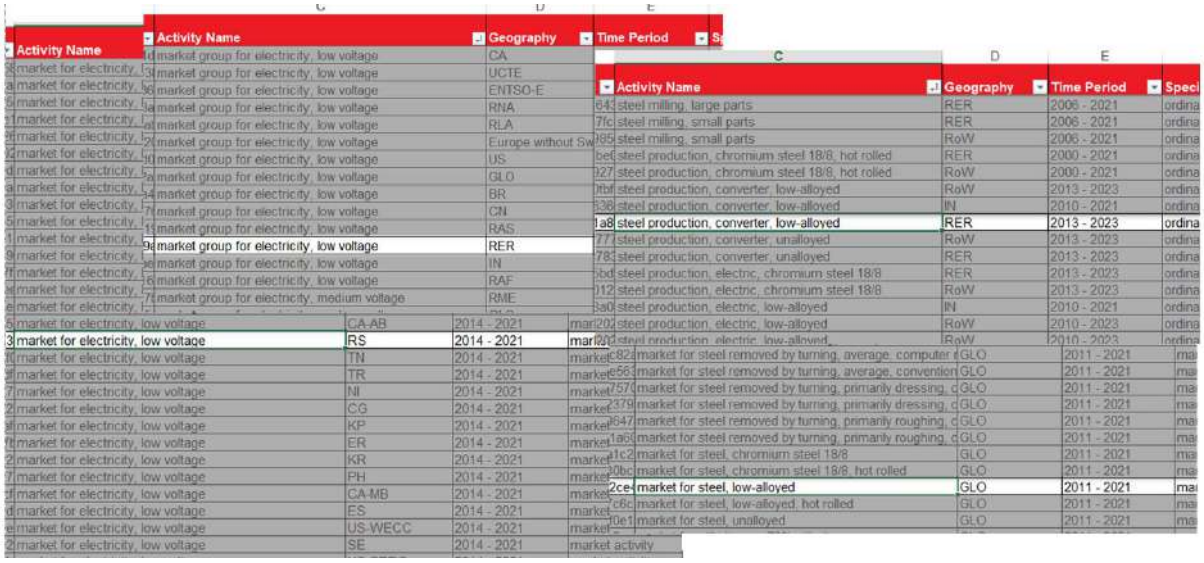
U nastavku biće razmatrani primeri aktivnosti iz Ecoinvent 3.7 LCI baze podataka. Ecoinvent baza sadrži više od 18000 aktivnosti i podržava rad sa više modela sistema: opisni – alokacija isključenje klasifikacijom, opisni – alokacija u tačci zamene, posledični – zamena dugoročno [11]. Nedavno objavljena verzvija 3.8 Ecoinvent LCI baze podataka podržava i opisni – alokacija isključenje prema ISO 15804 sistem modela za potrebe LCA izračunavanja i generisanja oznaka o zaštiti životne sredine tipa III.

S obzirom na to da se čelik i električna energija često koriste u LCA modeliranju, razmatrane su sledeće aktivnosti (slika 2):

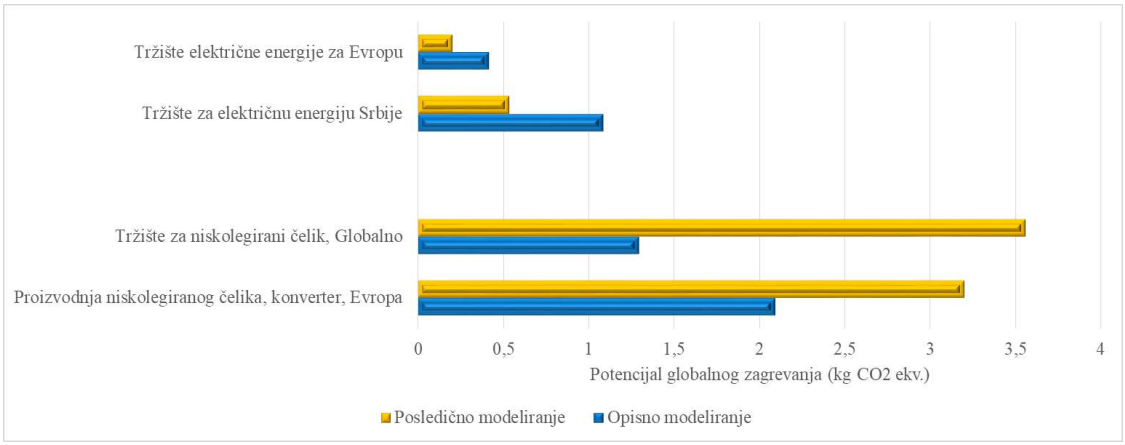
1. Proizvodnja i distribucija električne

energije nisko naponske mreže (ispod 1 kV) za tržište Srbije (market for electricity, low voltage | Cutoff, S - RS);
2. Proizvodnja i distribucija električne energije nisko naponske mreže (ispod 1 kV) za tržište Evrope (market group for electricity, low voltage | Cutoff, S - RER);
3. Proizvodnja i distribucija niskolegiranog čelika (market for steel, low-alloyed | Cutoff, S – GLO; steel production, converter, low-alloyed | Cutoff, S – RER);
4. Proizvodnja niskolegiranog čelika (steel production, converter, low-alloyed | Cutoff, S – GLO; steel production, converter, low-alloyed | Cutoff, S – RER).

Za sve četiri aktivnosti predviđena je upotreba u pozadinskom planu kod LCI modeliranja granica sistema, opisno LCI modeliranje, sistemski procesi. Razlika između navedenih aktivnosti je u geografskom području i tržištu, gde su razmatrane Srbija, Evropa i globalno tržište koje podrazumeva prosečne vrednosti iz celog sveta.



Sl. 2. Izbor odgovarajućeg seta LCI podataka: Tržište za električnu energiju niskonaponske mreže (Evropa i Srbija), tržište za niskolegirani čelik (Globalno), proizvodnja niskolegiranog čelika (Evropa)



Sl. 3. Potencijal globalnog zagrevanja za proizvodnju 1 kWh električne energije (za područje Evrope i Srbije) i 1 kg niskolegiranog čelika (Globalno i za Evropu)

Sve četiri aktivnosti analizirane su u openLCA softveru (verzija 1.10.3) sa CML metodom za kategoriju uticaja potencijal globalnog zagrevanja izraženu u kilogramima ekvivalentnog ugljendioksida (kg CO_2 ekv.) za vremenski period od 100 godina. Rezultati su dobijeni za proizvodnju 1 kWh električne energije, za tržište Evrope i Srbije, kao i za proizvodnju 1 kg niskolegiranog čelika na globalnom tržištu i za Evropu (slika 3). Kao što se i može očekivati, rezultati se razlikuju zbog različitih geografskih područja i zbog različitog načina modeliranja. Na primer, uticaj proizvodnje električne energije u Srbiji generiše veći potencijal globalnog zagrevanja od proizvodnje u Evropi. Razlog je što većina izvora električne energije u Srbiji potiče od

spaljivanja uglja u termoelektranama i samim tim predstavlja tehnologiju sa većim uticajem na životnu sredinu od prosečno primenjenih tehnologija za dobijanje električne energije u Evropi. Sa druge strane, ako se posmatraju rezultati proizvodnje niskolegiranog čelika, može se primetiti da opisno i posledično modeliranje može da rezultuje obrnutim rangom uticaja na životnu sredinu. Treba uzeti u obzir da su svi navedeni načini ispravni ali moraju biti dokumentovani u LCA studiji kako bi zainteresovani mogli da uporede dobijene rezultate sa rezultatima drugih studija.

4. ZAKLJUČAK

Izbor odgovarajućih setova podataka iz LCI baza može značajno uticati na LCA rezultate. U nekim slučajevima, na primer kod izbora sistema modelovanja, može se uraditi opisni i posledični LCA kako bi se utvrdilo koji način najbolje reprezentuje ispitivani sistem proizvoda.

Navedeni postupak izbora odgovarajućih aktivnosti može biti koristan za manje iskusne korisnike u LCA. Iako postoje više vodiča za LCA i LCI, s obzirom na trend razvoja LCI baza i novih setova podataka, za korisnike mogu biti od velikog značaja i detaljne smernice za izbor odgovarajućih setova podataka iz LCI baza. Takođe, generalne smernice za izbor setova podataka iz LCI baza moraju biti propraćene sa odgovarajućim praktičnim primerima.

5. LITERATURA

[1] Hunt, R. G., Franklin, W. E.: *LCA – How it came about — Personal reflections on the origin and the development of LCA in the USA.* The International Journal of Life Cycle Assessment volume 1, p.p. 4–7, 1996.

[2] ISO 14040: *Upravljanje zaštitom životne sredine — Ocenjivanje životnog ciklusa — Principi i okvir*, 2006.

[3] ISO 14044: *Upravljanje zaštitom životne sredine — Ocenjivanje životnog ciklusa — Zahtevi i uputstva za primenu*, 2006.

[4] Meron, N., Blass, V., Thoma, G.: *Selection of the most appropriate life cycle inventory dataset: new selection proxy methodology and case study application*. The International Journal of Life Cycle Assessment, 25, p.p. 771–783, 2020.

[5] Ingwersen, W. W., Kahn, E., Cooper, J.: Bridge Processes: *A Solution for LCI Datasets Independent of Background Databases*. The International Journal of Life Cycle Assessment, 23, p.p. 2266–2270, 2018.

[6] Zampori, L., Fazio, S. Diaconu, E.: *User's instructions for 'Look@LCI' software.* Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-98406-8.

[7] Khoo, H. H., Isoni, V., Sharratt, P. N.: *LCI data selection criteria for a multidisciplinary research team: LCA applied to solvents and chemicals.* Sustainable Production and Consumption, 16, p.p. 68–87, 2018.

[8] Herrmann, C., Dewulf, W., Hauschild, M., Kaluza, A., Kara, S., Skerlos, S.: *Life cycle engineering of lightweight structures.* CIRP Annals - Manufacturing Technology, 67, p.p. 651–672, 2018.

[9] Ekvall, T., Azapagic, A., Finnveden, G., Rydberg, T., Weidelma, B., Zamagni, A.: *Attributional and consequential LCA in the ILCD handbook.* International Journal of Life Cycle Assessment, 21, p.p. 293–296, 2016.

[10] https://support.simapro.com/articles/FAQ/How-do-I-choose-between-unit-and-system-libraries/, pristupljeno 09.11.2021.

[11] Frischknecht, R., Jungbluth, N., Althaus, H.-J., Doka, G., Dones, R., Heck, T., Hellweg, S., Hischier, R., Nemecek, T., Rebitzer, G., Spielmann, M.: *The ecoinvent Database: Overview and Methodological Framework.* The International Journal of Life Cycle Assessment, 10, p.p. 3–9, 2005.

Autori: **vanr. prof. dr Boris Agarski, doc. dr Milana Ilić Mićunović, prof. dr Igor Budak, prof. dr Đorđe Vukelić,** Univerzitet Novi Sad, Fakultet Tehničkih Nauka, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, Tel: +381 21 485 2306, Fax: +381 21 454-495.

E-mail: agarski@uns.ac.rs
milanai@uns.ac.rs
budaki@uns.ac.rs
vukelic@uns.ac.rs

ETIKUM 2021 **INTERNATIONAL SCIENTIFIC CONFERENCE NOVI SAD, SERBIA, DECEMBER 2-4, 2021**

Lanc, Z., Zeljković, M., Hadžistević, M., Štrbac, B., Živković, A.

GRANIČNI USLOVI ZA NASTANAK KONTAKTNIH TERMIČKIH OPEKOTINA IZAZVANIH VRUĆIM METALNIM POVRŠINAMA

Rezime: *Kontaktne termičke opekotine (KTO) predstavljaju specifičnu vrstu termičkih povreda koje nastaju pri direktnom kontaktu nezaštićene kože sa vrućim površinama. Vruće metalne površine se često susreću kod mašina i proizvoda sa kojima je zaposleni u kontaktu, zbog čega je neophodno sprovesti procenu rizika od istih. Rizik od KTO umnogome zavisi od težine povrede, koja je uslovljena dubinom, odnosno stepenom KTO i procentom opečene površine u odnosu na ukupnu površinu tela. Kako bi se mogla odrediti težina povrede i kvantifikovati rizik od KTO, neophodno je definisati granične uslove za nastanak različitog stepena KTO, što je ujedno cilj ovog rada.*

Ključne reči: *vruće metalne površine, granični uslovi, stepen KTO*

1. UVOD

Jedna od osnovnih karakteristika savremenog doba jesu rapidne i radikalne ekonomske, privredne i druge društvene transformacije, usled kojih je sve teže prilagoditi se tranzicionim procesima. Ove promene, pored mnogih benefita donose, odnosno generišu nove rizike, kako po bezbednost životne, tako i radne sredine. Tehnički progres je nužno povezan sa rizikom, te ne iznenađuje činjenica da se današnje društvo posmatra kao „društvo rizika“. Definisanje termina rizik umnogome zavisi od konkretnog sistema koji se posmatra, ali uopšteno govoreći rizik se može posmatrati dvojako: sa aspekta uzroka i sa aspekta posledica. Sa aspekta uzroka rizik je funkcija opasnosti i zaštite, dok je sa aspekta posledica rizik funkcija verovatnoće rizičnog događaja i mere njime izazvanog gubitka [1]. U Srbiji je pojam rizik sa aspekta bezbednosti i zdravlja na radu definisan Zakonom o bezbednosti i zdravlju na radu ("Sl. glasnik RS", br. 101/2005, 91/2015 i 113/2017) kao verovatnoća nastanka povrede, oboljenja ili oštećenja zdravlja zaposlenog usled opasnosti. Prema pomenutom zakonu, obaveza svakog poslodavca jeste da, polazeći od načela preventivnih mera, ukoliko ne može da izbegne rizik od povrede na radu, profesionalnog oboljenja ili oboljenja u vezi sa radom sprovede procenu rizika od istih [2]. Procena rizika je najvažniji metodološki korak za adekvatno upravljanje rizikom i zasniva se na analizi verovatnoće nastanka i težini moguće povrede na radu, oštećenja zdravlja ili oboljenja zaposlenog usled izloženosti opasnostima ili štetnostima na radnom mestu. Jedna od opasnosti kojom su zaposleni izloženi na svom radnom mestu jesu vruće metalne površine mašina ili proizvoda sa kojima u slučaju kontakta može doći do nastanka kontaktnih termičkih opekotina (KTO). Nastanak KTO uslovljen je sa dva granična uslova: temperaturom vruće površine T_{KTO} i periodom kontakta sa vrućom površinom D_{KTO}. Međutim, sam stepen KTO nije dovoljan da se definiše težina povrede, kao ključan faktor za procenu rizika od KTO. Težina povrede, odnosno težina KTO zavisi od dubine, tj. stepena KTO i procenta opečene površine u odnosu na ukupnu površinu tela (UPT). Da bi se unapredila postojeća metoda procene rizika od opekotina izazvanih vrućim površinama mašina i proizvoda prema međunarodnom standardu EN ISO 13732-1, neophodno je definisati granične uslove za nastanak različitog stepena KTO i definisati način određivanja težine KTO u zavisnosti od dubine termičke povrede i veličine vruće površine za koju se sprovodi procena rizika. Dakle, suštinski nedostaci procene rizika od opekotina prema pomenutom standardu jesu ti što se procena rizika sprovodi samo u slučaju nastanka I stepena KTO, ne uzima se u obzir dubina povrede niti veličina vruće površine, rizik od KTO se ocenjuje kvalitativno i ne postoji mogućnost određivanja težine KTO. Cilj ovog rada je unapređenje postojeće standardizovane metode procene rizika od opekotina izazvanih vrućim metalnim površinama mašina i proizvoda kroz određivanje težine KTO na osnovu prethodno definisanih graničnih uslova za nastanak KTO. Metalne površine su izabrane zbog najvećeg udela u izradi mašina i proizvoda i zbog toga što su sa aspekta brzine nastanka opekotina metali najrizičnija grupa materijala, zbog svoje sposobnosti provođenja toplote. Definisanje graničnih uslova za nastanak različitog stepena KTO sprovedeno je

na osnovu dostupnih istraživanja za čije potrebe su prethodno usaglašene klasifikacije KTO prema dubini, kako bi poređenje rezultata iz različitih literaturnih izvora bilo moguće.

2. KLASIFIKACIJA KTO PREMA DUBINI

KTO se prema dubini termičke povrede tkiva dele na [3]:

I stepen KTO – kod kojih je oštećen samo epiderm, takozvane površinske KTO;

IIa stepen KTO – kod kojih je oštećen epiderm i površinski (papilarni) derm;

IIb stepen KTO – kod kojih je oštećen epiderm, papilarni derm i duboki (retikularni) derm;

III stepen KTO – kod kojih je uništen ceo derm i potkožno tkivo.

Navedena klasifikacija je ujedno jedna od najčešće korišćenih u istraživačke svrhe. Međutim, kako bi se pojednostavilo definisanje graničnih uslova za nastanak različitog stepena KTO na osnovu dostupnih istraživanja u kojima postoji evidentna razlika u klasifikacijama, za potrebe rada, usvojiće se podela na I, II i III stepen KTO prema Američkom udruženju za opekotine. Prema ovoj podeli, II stepen opekotina objedinjuje IIa i IIb stepen opekotina, a III stepen opekotina podrazumeva i oštećenje dubljih struktura, poput mišića i kostiju, koje je često u literaturi definisano kao IV stepen opekotina.

3. DEFINISANJE GRANIČNIH USLOVA ZA NASTANAK KTO

Da bi se procenio rizik od KTO, neophodno je razumevanje odnosa između temperature vruće površine, perioda kontakta i dubine, odnosno stepena KTO. Istraživanje veze između pomenutih faktora nije novi koncept. U pionirskim radovima Moritz i Henriques utvrđeno je da što je temperatura površine viša, potreban je kraći period kontakta da bi nastala KTO [4]. Njihova istraživanja su utvrdila granične uslove za nastanak nepovratnih epidermalnih povreda i do danas predstavljaju temelj za smernice globalnog programa prevencije opekotina i oparotina. Ova istraživanja, koja služe kao okvir za brojne standarde, uputstva i preporuke kada su u pitanju maksimalno dozvoljene temperature vrućih površina, previdela su težinu povrede kao jedan od ključnih faktora za kvantifikaciju rizika od KTO. Iz tog razloga neophodno je dopuniti rezultate ovih istraživanja novim saznanjima, kako bi se postavila dobra osnova za buduće strategije i zakonsku regulativu, naročito u oblasti bezbednosti mašina i proizvoda kod kojih postoje toplotne opasnosti u vidu vrućih površina. Christine Andrews je 2017. istraživala pomenuti fenomen, sa ciljem da se definišu granični uslovi za nastanak oparotina kod dece. U okviru njenih istraživanja dat je pregled 42 studije sprovedene na svinjskoj koži, gde su nanošene termičke povrede [3]. KTO su nanošene vrućim metalima i najveći broj studija se upravo bavio ovom problematikom. Za definisanje graničnih uslova za nastanak KTO izazvanih vrućim metalima uzete su u obzir studije u kojima je jasno navedeno kojom vrstom metala su nanošene KTO, kao i termičke povrede u vidu oparotina. Oparotine su uzete u obzir iz tog razloga što nema dovoljno istraživanja u kojima je potvrđena razlika između graničnih uslova za nastanak oparotina i KTO izazvanih vrućim metalima. Pored toga, međunarodni standarda EN ISO 13732-1:2010 takođe navodi da se granični uslovi za nepremazane metale mogu usvojiti i za vruću vodu, a kako postoji evidentan nedostatak relevantnih istraživanja u ovoj oblasti, ovo su ujedno jedini raspoloživi podaci. Takođe, autori Ye i De su pokušali, doduše u mnogo manjoj meri, da definišu granične uslove za nastanak različitog stepena KTO, te su i ovi podaci uzeti u razmatranje [5]. U Tabeli 1 su objedinjeni podaci iz istraživanja Christine Andrews koji su u tabeli obeleženi crnom bojom i podaci iz istraživanja Ye i De, označenih ljubičastom bojom. U svojim zaključnim razmatranjima Christine Andrews je ukazala na velike razlike između istraživanja u kojima su nanošene KTO, što se vidi iz Tabele 1. Razlike leže u metodologijama prema kojima su korišćeni ne samo različiti metali, nego i dimenzije vrućih metalnih predmeta, kao i različiti pritisci sa kojima su nanošene termičke povrede. Pored navedenog, poređenje studija je otežano zbog različitih klasifikacija kada je u pitanju dubina termičke povrede, razlika u metodama kao i u vremenu nakon koga su procenjivane dubine termičkih povreda, nedostatka informacija o načinima na koje su sprovođene studije, koji su materijali korišćeni, itd. Međutim, ipak je moguće uspostaviti korelaciju između podataka, ukoliko se interpretiraju na jedinstven način, kao što je prikazano u Tabeli 1. Usled pomenutih nedostataka i razlika u podacima, u Tabeli 1 su sa plavom bojom označeni dopunjeni granični uslovi. S obzirom na to da je poznato da postoji inverzna veza između graničnih uslova, jasno je da stepen KTO raste po kolonama i po redovima, na osnovu čega je popunjen ostatak Tabele 1. Npr. ako je poznato da na 70°C za 1 s nastaje II stepen KTO, pretpostavlja se da to važi za isti period kontakta i za sve više temperature, kao i za sve duže periode kontakta od 1 s.

Tabela 1. Granični uslovi za nastanak KTO i oparotina

D_{KTO} [s]	T_{KTO} [°C]								
	50	60	70	75	80	83	85	90	100
1			II	II	II	II	II	II	I II
2		I	II	II	II	II	II	II	I II
3		I	II	II	II	II	II	II	II
5		II	II	II	II	II	II	II	II
6		II	II	II	II	II	II	II	II II
10		II	II	II	II	II	II	II	II II
11		II	II	II	II	II	II	II	II
12		II	II	II	II	II	II	II	II III
15		II	II	II	II	II	II	II	II III
20		II	I II	II	II II III	III	III	II II III	II II III
21		II	II	II	III	III	III	III	III
25		II	II	II	III	III	III	III	III
30		I II	II	II	II III	III	III	III	II III III
40		II	II	II	III	III	III	III	III
45		II	II	II	III	III	III	III	II III
60	I	II	II	II	III	III	III	III	III
300	II	II	II	II	III	III	III	III	III

Kako za pojedine temperature i periode kontakta važe isti granični uslovi Tabela 1 se može uprostiti, tako da se sa bojama mogu interpretirati različiti stepen KTO (Tabela 2).

Tabela 2. Granični uslovi za nastanak KTO

D_{KTO} [s]	T_{KTO} [°C]				
	50 - 60	60 - 70	70 - 80	80 - 100	100
1					
2 - 5					
5 - 12					
12 - 20					
20 - 60					
60 - 300					
300					

U Tabeli 2 oblasti graničnih uslova su označene bojama tako da: plava oblast predstavlja granične uslove pri kojima neće doći do nastanka KTO; zelena oblast predstavlja granične uslove pri kojima će doći do nastanka I stepena KTO; žuta oblast predstavlja granične uslove pri kojima će doći do nastanka II stepena KTO; crvena oblast predstavlja granične uslove pri kojima će doći do nastanka III stepena KTO. Prema Tabeli 2 I stepen KTO nastaje nakon 1 min na temperaturi od 50°C, a II stepen KTO pri istoj temperaturi tek nakon 300 min. Najniža temperatura za nastanak III stepena KTO iznosi 80°C pri periodu kontakta od 20 s, dok pri temperaturi od 100°C period kontakta je kraći i iznosi 12 s. Kada su poznati granični uslovi za nastanak različitog stepena KTO može se u odnosu na veličinu vruće površine odrediti težina KTO na način opisan u nastavku.

4. ODREĐIVANJE TEŽINE KTO

Američko udruženje za opekotine (engl. American Burn Association – ABA) definisalo je kriterijume za klasifikaciju opekotina prema težini na lake, srednje i teške, u zavisnosti od stepena opekotina, procenta opečene površine u odnosu na ukupnu površinu tela (UPT) i starosne dobi (Tabela 3).

Tabela 3. Težina opekotina prema ABA [6]

Težina opekotina	Kriterijumi
lake	I stepen II stepen < 10% UPT (odrasli) II stepen < 5% UPT (deca i stari) III stepen < 2% UPT
srednje	II stepen 10−20% UPT (odrasli) II stepen 5−10% UPT (deca i stari) III stepen 2−5% UPT
teške	II stepen > 20% UPT (odrasli) II stepen > 10% UPT (deca i stari) III stepen > 5% UPT

UPT kod odraslih osoba iznosi 1,73 m^2 [7]. S tim u vezi, moguće je uspostaviti relaciju između procenta opečene površine i veličine vruće površine P, ukoliko se izračunaju odgovarajući procentualni udeli, prema Tabeli 3. Površina P se u tom slučaju može posmatrati kao veličina vruće površine za koju se sprovodi procena rizika od KTO. Prema Tabeli 3 težina opekotine je definisana prema starosnim grupama, ali se mora uzeti u obzir da stari pripadaju grupi preko 50 godina i da su još uvek radno sposobni, te je neophodno objediniti kriterijume za odrasle, sa jedne strane i decu mlađu od 10 godina i starije od 50 godina, sa druge strane. Na ovaj način moguće je definisati kriterijume za određivanje težine KTO izazvanih vrućim površinama (Tabela 4).

Tabela 4. Težina KTO

Stepen KTO	Veličina vruće površine P [m^2]			
	< 0,0346	od 0,0346 do 0,0865	od 0,0865 do 0,173	> 0,173
I	laka	laka	laka	laka
II	laka	laka	srednja	teška
III	laka	srednja	teška	teška

Prema Tabeli 4 moguće je odrediti težinu povrede bilo kojom metodom procene rizika koja pruža mogućnost kvantifikacije faktora rizika, a samim tim i celokupnog rizika od KTO.

5. ZAKLJUČNA RAZMATRANJA

U radu su na osnovu dostupnih istraživanja na polju nastanka KTO izazvanih vrućim metalima definisani granični uslovi za nastanak različitog stepena KTO. Predloženi granični uslovi predstavljaju samo okvirne granice između I, II i III stepena KTO, čija tačnost ponajviše zavisi od same metodologije istraživanja i procenjivanja dubine termičke povrede. S druge strane, težina KTO definisana je tako da ovaj faktor rizika povezuje ne samo stepen KTO, nego i veličinu vruće površine, što je velika prednost u odnosu na standarizovanu metodu. Klasifikovanjem KTO na lake, srednje i teške, moguće je proizvoljno izabranom metodom procene rizika kvantifikovati težinu povrede kao faktor rizika, a samim tim i nivo rizika od KTO, što je još jedna prednost u odnosu na standard EN ISO 13732-1. Metode procene rizika koje se mogu koristiti u ovu svrhu jesu Kinney, Pilz i Guardmaster metoda, kao i matrične metode, s tim da one ne pružaju mogućnost kvantifikacije rizika. Predložena metodologija procene rizika od KTO suštinski zavisi od istraživanja u oblasti graničnih uslova za nastanak različitog stepena KTO, kako za metale, tako i za druge grupe materijala, što se svakako može smatrati predlogom za dalja istraživanja u ovoj oblasti.

6. REFERENCE

[1] Grozdanović, M., Stojiljković, E.: *Metode procene rizika*, Fakultet zaštite na radu u Nišu, Niš, 2013.

[2] Zakon o bezbednosti i zdravlju na radu, Sl. glasnik Repubile Srbije, br. 101/2005, 91/2015 i 113/2017

[3] Andrews, C., Cuttle, L.: *Comparing the reported burn conditions for different severity burns in porcine models: a systematic review*, Int. Wound J., vol. 14, no. 6, p.p. 1199-1212, 2017.

[4] Moritz, A., Henriques, F.: *Studies of Thermal Injury: II. The Relative Importance of Time and Surface Temperature in the Causation of Cutaneous Burns*, Am. J. Pathol., vol. 23, no. 5, p.p. 695-720, 1947.

[5] Ye, H., De, S.: *Thermal injury of skin and subcutaneous tissues: A review of experimental approaches and numerical models*, Burns, vol. 43, no. 5, p.p. 909-932, 2017.

[6] Vulović, D., Stepić, N.: *Importance of proper initial treatment of moderate and major burns*, Vojnosanit. Pregl., vol. 65, no. 4, p.p. 281-285, 2008.

[7] Heaf, J.: *The origin of the 1 x 73-m2 body surface area normalization: problems and implications*, Clin. Physiol. Funct. Imaging, vol. 27, no. 3, p.p. 135-137, 2007.

Autori: **M.Sc. Zorana Lanc, prof. dr Milan Zeljković, prof. dr Miodrag Hadžistević, doc. dr Branko Štrbac, vanr. prof. dr Aleksandar Živković,** Univerzitet Novi Sad, Fakultet tehničkih nauka, Departman za proizvodno mašinstvo, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia, Tel: 021 485 2306, Fax: 021 454 495.

E-mail: zoranalanc@uns.ac.rs,
milanz@uns.ac.rs
miodrags@uns.ac.rs
strbacb@uns.ac.rs
acoz@uns.ac.rs,

Sponzori konferencije

ETIKUM 2021

PROVINCIAL SECRETARIAT FOR HIGHER EDUCATION AND SCIENTIFIC RESEARCH

Bulevar Mihajla Pupina 16
21108 Novi Sad

Tel: (021) 487 4641
Fax: (021) 456 044
E-mail: secretary@apv-nauka.ns.ac.rs
www.vojvodina.gov.rs/en/autonomous-province-vojvodina

REPUBLIC SERBIA
AUTONOMOUS PROVINCE OF VOJVODINA

UNIVERSITY OF NOVI SAD

Dr Zorana Đinđića 1
21001 Novi Sad
Republic of Serbia
Switchboard: +381 21 485 2000
E-mail: rektorat@uns.ac.rs
www.uns.ac.rs

FACULTY OF TECHNICAL SCIENCES

University of Novi Sad
Faculty of Technical Sciences
Trg Dositeja Obradovića 6
21000 Novi Sad
Republic of Serbia

Tel.: (+381) 21 450 810
(+381) 21 6350 413
Fax: (+381) 21 458 133
E-mail: ftndean@uns.ac.rs
www.ftn.uns.ac.rs

DEPARTMENT OF PRODUCTION ENGINEERING

University of Novi Sad
Faculty of Technical Sciences
Vladimira Perića-Valtera 2
21000 Novi Sad
Republic of Serbia

Secretariat of the Department:
Tel: (021) 450-366, 485-23-20
Fax: (021) 454-495
E-mail: dpm@uns.ac.rs
www.dpm.ftn.uns.ac.rs

ASIP PREVENT DOO NOVI SAD

Novi Sad – grad | Mesto: Novi Sad | Ulica i broj: Privrednikova 8a

Ogranak 1: Ruma, 15. Maj 130, Lokal 13

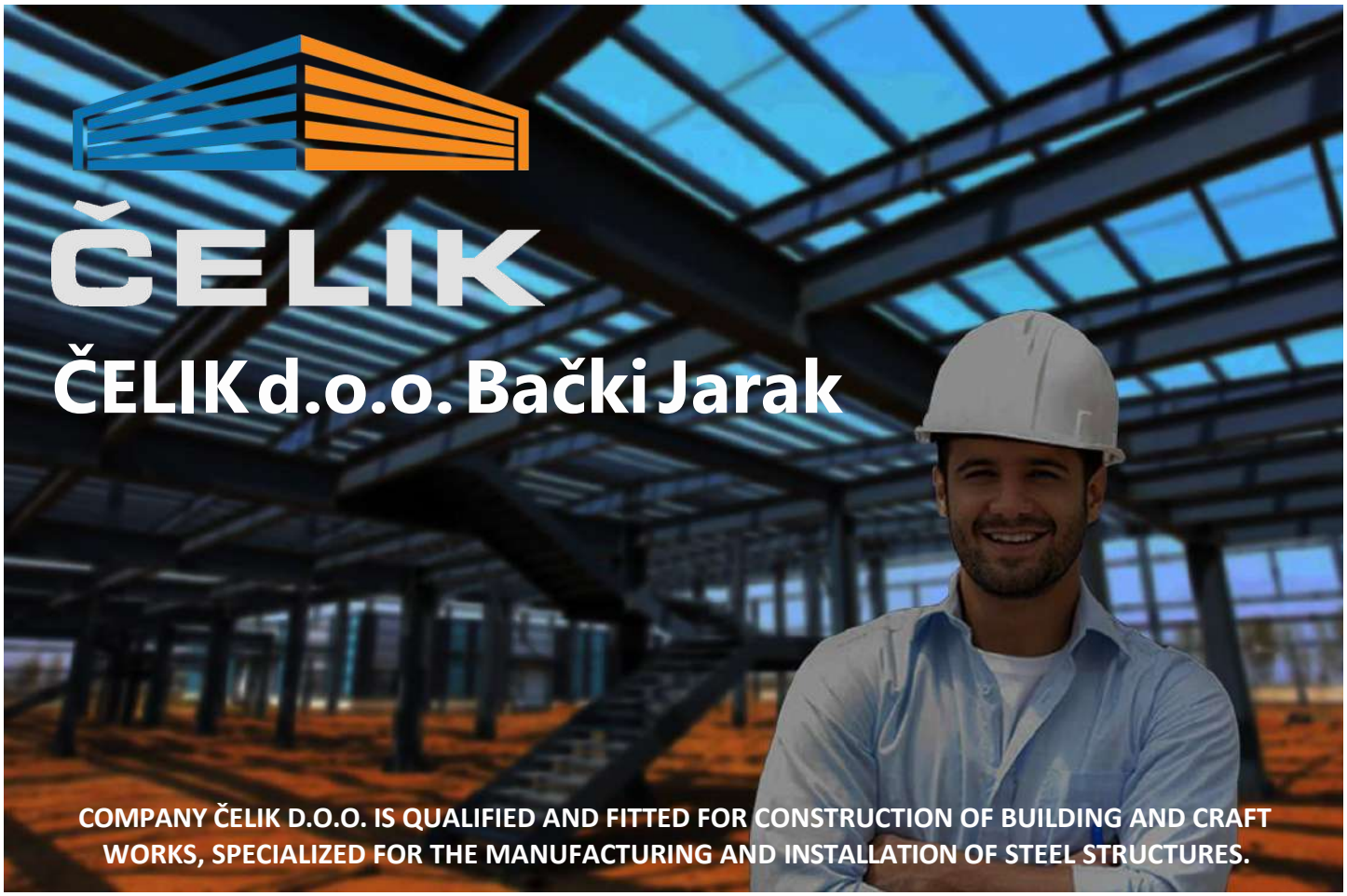
Ogranak 2: Zemun (Beograd), Svetozara Miletića 37a

Ogranak 3: Šabac, Đukanovića sokak 1

Ogranak 4: Bačka Topola, Tolstojeva 25

Datum osnivanja: 11.04.2013.

Јавно предузеће
„Електропривреда Србије”
Балканска 13
11 000, Београд
www.eps.rs
eps@eps.rs



ČELIK DOO
METAL CONSTRUCTIONS – DESIGN, PRODUCTION AND MONTAGE
Novosadska bb, 21234 Bački Jarak,
Srbija

www.celikdoo.rs

Tel: +381(0)21/847-606

E-mail: office@celikdoo.rs

FKL®

Factory of Rolling Bearings and Cardan Shafts

Industrijska zona bb
21235 Temerin
SERBIA

Head of Sales +381 21 6841 222
Foreign Markets +381 21 6841 190
+381 21 6841 205
+381 21 6841 201

www.fkl-serbia.com

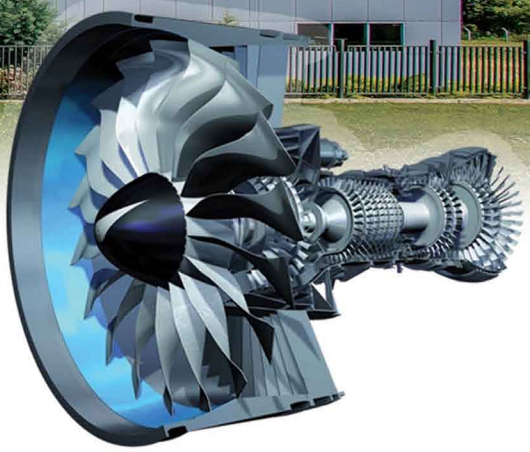
sales@fkl-serbia.com
marketing@fkl-serbia.com

lpo D.O.O. ada

BET SHEMESH ENGINES

PRECISE CASTING PLANT
ADA - SERBIA

* **Precise Casting Plant - LPO DOO Ada was founded in 1978. The facility is in the industrial zone of Ada city.**
* **LPO is an expert in vacuum and air castings of superalloys and stainless steels, such are turbine blades, vanes and complex aerospace parts**



LPO DOO ADA
29. Novembra bb, Ada
Tel.: +381 24 851 807
Fax.: +381 24 851 475
E-mail: preccast@lpo.rs

www.lpo.rs

Peugeot salon automobila
Futoški put
93b, Novi Sad
peugeot@cubi.co.rs

Turbo Servis
Bulevar Vojvode Stepe 36/a, Novi Sad
cubi.metalizacija@gmail.com

Metalizacija i Zavarivanje
Bulevar Vojvode Stepe 36/a, Novi Sad
cubi.metalizacija@gmail.com

Trgovina
Bulevar Vojvode Stepe 36/a, Novi Sad
cubi@cubi.co.rs

Auto Servis
Bulevar Vojvode Stepe 36/a, Novi Sad
cubiautoservis@eunet.rs

Mašinska obrada
Bulevar Vojvode Stepe 36/a, Novi Sad
masinska@cubi.co.rs

TEHNOALAT doo
Pitagorina 1, RS-21000 Novi Sad
T/F +381 21 504 272
M +381 63 71 303 96
djordje@tehnoalat.rs
www.tehnoalat.rs

”MIREN” d.o.o.

PROIZVODNJA
PROCESNE OPREME
I ZAVARIVAČKI RADOVI

24000 Subotica, Višnjička br. 2, Tel.: 024/576-376

TEXO®

www.tehnoexport.rs

FLEXIBLE SOLUTIONS BY **TEHNOEXPORT**

FLEXIBLE SOLUTIONS BY **TEHNOEXPORT**

ADRESA: Jovana Popovića 43, 22320 Inđija
TEL: +381 (0) 22 553 453
FAX: +381 (0) 22 561 417
E-MAIL: office@tehnoexport.co.rs
WEB: www.texo.rs, www.tehnoexport.rs

RKS KOMPOZITI d.o.o
Maršala Tita 45, 21413 Celarevo
tel/fax: + 381 21 761 255
www.rkskompoziti.rs

ISBN 978-86-6022-387-8