



UNIVERSITY OF EAST SARAJEVO
FACULTY OF MECHANICAL
ENGINEERING



7th INTERNATIONAL SCIENTIFIC CONFERENCE



COMETa 2024

***„Conference on Mechanical Engineering
Technologies and Applications“***

PROCEEDINGS

14th-16th November East
Sarajevo, RS, B&H

COMET_a 2024

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Jahorina, B&H, Republic of Srpska



University of East Sarajevo

Faculty of Mechanical Engineering

Conference on Mechanical Engineering Technologies and Applications

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Technicians of Republic of Srpska*

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PREFACE

Mechanical engineering, as one of the basic engineering disciplines, represents the key to understanding and improving many aspects of modern society. From the development of energy-efficient systems, through advanced materials and production technologies, to robotics and automation, mechanical engineering is at the very heart of innovation, which drives the global economy and contributes to a better quality of life. Contemporary trends in mechanical engineering, such as the application of artificial intelligence, additive technology, digital transformation, minimizing the impact of industrial processes on the environment, etc. widely open new horizons and opportunities for our profession. Through mutual cooperation, interdisciplinary approaches and the integration of new technologies, we can find solutions that will shape the future of industry and society. Today, our profession faces numerous challenges, which are the result of accelerated technological development. They are at the same time extremely complex, but also very inspiring and require not only technical expertise, but also creativity, cooperation and a constant desire for new scientific achievements. Therefore, we must be able to recognize and implement new approaches, methodologies and technologies. Moreover, only a holistic approach in the application of knowledge in various engineering fields, and especially in the field of mechanical engineering, is a safe way into the future. Finally, in today's world, which is rapidly changing under the influence of global economic, environmental and social factors, it is important that all of us, who deal with the field of mechanical engineering from various aspects, do not forget our responsibility. In this context, engineering ethics, quality of work and continuous education play a crucial role.

Although the scientific research process is crucial for economic progress, we must not forget the importance of educating new generations of mechanical engineers. The conference COMETA 2024 is precisely an extraordinary opportunity to further encourage young researchers and students to actively engage in scientific activities through the development of their ideas. In this sense, academic institutions have a great responsibility to provide quality education and research programs to future generations.

Recognizing the importance of the broad field of mechanical engineering for the overall industrial development of society, the work of the conference will take place through 5 sections. The program is focused on the following thematic areas:

- Manufacturing technologies and advanced materials,
- Applied mechanics and mechatronics,
- Machine design, simulation and modeling,
- Product development and mechanical systems,
- Energy and thermotechnic,
- Renewable energy and environmental,
- Maintenance and technical diagnostics,
- Quality, management and organization.

Also, as part of the conference program, one round table and two workshops will be held, whose topics relate to the generation of ideas and proposals for future project activities that must inevitably be based on innovation, quality, and upcoming machine technologies, which is actually in accordance with the Development strategy of

science and technology of the Republic of Srpska for the period 2023-2029, in which education, science, technology, research, innovation, and digitization are recognized as key prerequisites for achieving a sustainable economy.

Many experts, researchers, university professors, businessmen and students from various fields of mechanical engineering have registered to participate in this edition of conference COMETa 2024. The topics that will be discussed by the scientific and professional public will certainly contribute to the acquisition of new knowledge and open up a lot of space for future innovations. 77 papers will be published in the Conference proceedings, including 3 plenary lectures. The fact that numerous participants from abroad have been registered for the conference COMETa 2024 this year is especially pleasing.

Namely, 262 authors come from 16 countries. The review team is composed of 53 colleagues from the country and abroad. This is certainly the result of strenuous activities that were aimed at raising the international reputation and visibility of the conference in the regional, but also in the wider academic and scientific research area, which will be one of our primary goals in the future.

We are sure that the work at the conference COMETa 2024 will be fruitful and that each of you, after its end, will leave with new ideas, knowledge and contacts that will contribute to your further professional development. This is an opportunity not only to learn from each other, but also to build the foundations for future research projects and industrial innovations together. In addition, we believe that in the coming days we will have the chance to get to know each other better, discuss common challenges and establish new forms of cooperation. In this sense, we would like to point out that all your proposals and suggestions are more than welcome and will be carefully considered by the Organizing and Scientific Committee in order to improve the organization of the next conferences.

Finally, on behalf of the Organizing and Scientific Committee of the conference COMETa 2024, we express our great gratitude to all authors, reviewers, universities and faculties, business entities, and national and international institutions and organizations that supported the organization of the conference. Special thanks go to the Ministry of Scientific and Technological Development and Higher Education of the Republic of Srpska, the City of East Sarajevo, the Municipalities of East New Sarajevo, East Ilidža and Pale, without whose help the organization and work of the conference certainly could not be at the level that its status deserves.

East Sarajevo, November 13th, 2024.

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Committee

PhD Biljana Marković,
full professor



President of the Organizing
Committee

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Associate Professor



CONTENT

PLENARY LECTURES

1. **Marcin Kamiński**
PROBABILISTIC ENTROPIES IN MECHANICAL ENGINEERING 2
2. **Primož Podržaj**
MODERN APPROACHES IN RESISTANCE SPOT WELDING CONTROL 10
3. **Mladimir Milutinović, Dejan Movrin, Saša Randelović**
SMART TOOLS AND TOOLING DESIGN STRATEGIES FOR IMPROVED PROCESS CONTROL AND PART ACCURACY IN METAL FORMING 22

MANUFACTURING TECHNOLOGIES AND ADVANCED MATERIALS

4. **Mirza Imširović, Uroš Trdan, Damjan Kločar, Drago Bračun, Aleš Nagode, Laurent Berthe, Matija Bušić, Miodrag Milčić, Dragan Milčić, Nataša Zdravković, Aleksija Đurić**
ENHANCING DIRECTED ENERGY DEPOSITED AL5356 THROUGH IN SITU WORKPIECE VIBRATIONS 43
5. **Tatjana Lazović, Pavle Ljubojević, Snežana Čirić-Kostić, Nebojša Bogojević, Marina Dojčinović, Milan Stojanović**
SAMPLE PREPARATION FOR CAVITATION EROSION TESTING OF 3D-PRINTED METAL 51
6. **Aleksandar Vujović, Janko Jovanović, Jelena Šaković-Jovanović, Marko Mumović**
TESTING OF THE MECHANICAL PROPERTIES OF PARK FURNITURE ELEMENTS OBTAINED FROM RECYCLED PLASTIC 59
7. **Marija Matejic, Jovana Markovic, Dragan Lazarevic, Jasmina Skerlic, Milan Radenkovic**
THEORETICAL ANALYSIS OF STATIC AND DYNAMIC STIFFNESS OF THE SUPPORTING STRUCTURE OF MODULAR CLAMPING FIXTURES 65
8. **Jelena Jovanović, Nikola Mitrović, Sandra Gajević, Slavica Miladinović, Jasmina Blagojević, Blaža Stojanović**
INVESTIGATION OF THE IMPACT OF ABRASIVE ACTION ON SURFACE ROUGHNESS AND WORN MASS OF LAMINATED COMPOSITES 74
9. **Miloš Pjević, Mihajlo Popović, Goran Mladenović, Radovan Puzović**
THE POST-PROCESSING METHOD FOR LARGE-SIZED PARTS PRODUCED USING SLA/mSLA TECHNOLOGY 83
10. **Nikola Vorkapic, Branko Kokotovic, Sasa Zivanovic**
CHATTER DETECTION USING SUPPORT VECTOR MACHINE 90
11. **Tatjana Stanivuk, Miroslav Dujmović, Nikola Muslim, Branko Lalić**
ELECTRIC MOTOR STARTERS AND DRIVES 98
12. **Miloš Milovančević, Srđan Stojičić, Mirjana Miljanović, Nikola Simonović, Dragana Trnavac**
OPTIMAL PREDICTORS FOR ABLATION DEPTH IN MICROMACHINING USING EXCIMER LASER BY ADAPTIVE NEURAL FUZZY LOGIC 105

13.	Srđan Stojičić, Milos Milovancevic, Mirjana Miljanović, Nikola Simonović, Dragana Trnavac ASSESSMENT OF CHIP-TOOL INTERFACE TEMPERATURE USING AN ADAPTIVE NEURAL FUZZY INFERENCE SYSTEM	117
14.	Strahinja Djurovic, Dragan Lazarevic, Bogdan Cirkovic, Zivce Sarkocecic, Milan Misic, Marija Matejic PREDICTION OF SURFACE ROUGHNESS WITH MULTIPLE REGRESSION ANALYSIS IN MACHINING PROCESS OF POM MATERIAL	132
15.	Katarina Pejić, Lana Šikuljak, Aleksandar Košarac ADVANCED PARAMETRIC PROGRAMMING OF CNC MACHINES USING CUSTOM MACRO B LANGUAGE	141
16.	Radomir Pojužina, Lana Šikuljak, Aleksandar Košarac SURFACE QUALITY OPTIMIZATION IN MILLING Ti6Al4V TITANIUM ALLOY	149
17.	Selver Smajic ANALYSIS OF DIFFERENT PROCEDURES DURING SAWING LOGS INTO SAWN TIMBER	156

APPLIED MECHANICS AND MECHATRONICS

18.	Vladimir Stojanovic, Vladimir Djordjevic, Ljubisa Dubonjic, Sasa Prodanovic OPTIMAL CONTROL OF A TWO-WHEELED SELF-BALANCING MOBILE ROBOT BASED ON ADAPTIVE DYNAMIC PROGRAMMING	164
19.	Stevan Stankovski, Gordana Ostojić DEVELOPMENT OF TASKS FOR TRAINING IN PLC PROGRAMMING USING GENERATIVE ARTIFICIAL INTELLIGENCE	173
20.	Janani Rajaraman, Saša Prodanović, Sai Phani Chandra Chittaluri, Ljubiša Dubonjić, Vladimir Stojanović ANALYZING AND OPTIMIZING PI CONTROLLER METHODS FOR TWO TANK SYSTEM: A LABORATORY-BASED STUDY	181
21.	Marjan Dodić, Branimir Krstić A LOW FIDELITY MATHEMATICAL MODEL OF A SINGLE ROTOR HELICOPTER IN FORWARD FLIGHT	189
22.	Aleksandar Bodić, Snežana Vulović, Milan Bojović, Jelena Živković, Miroslav Živković IMPROVED STRUCTURAL FATIGUE ANALYSIS USING FEM: DEVELOPMENT OF API SCRIPTS FOR STRESS RANGE CALCULATION	200
23.	Snežana Vulović, Miloš Pešić, Aleksandar Bodić, Marko Toplavić, Miroslav Živković FINITE ELEMENT ANALYSIS OF CYLINDRICAL SURFACE CONTACT	208
24.	Nikolina Dakić, Vule Reljić, Slobodan Dudić, Vladimir Jurošević, Filip Damjanović DESKTOP APPLICATION FOR PNEUMATIC DIDACTIC COMPONENT RECOGNITION	214
25.	Nikola Vučetić, Ranko Antunović, Dejan Jeremić, Nebojša Radić, Imre Zsolt Miklos ALGORITHM FOR ASSESSING THE INTEGRITY OF THE CYLINDER ASSEMBLY	222

26. **Isak Karabegović, Raul Turmanidže, Predrag Dašić**
THE AUTOMOBILE AND ELECTRO/ELECTRONIC INDUSTRY AS
WORLD LEADERS IN THE IMPLEMENTATION OF INDUSTRY 4.0 228
TECHNOLOGIES IN PRODUCTION PROCESSES: REVIEW OF
ROBOT TECHNOLOGY
27. **Dragan Rakić, Vukašin Slavković, Aleksandar Bodić, Milan
Bojović, Miroslav Živković**
USER INTERFACE DEVELOPMENT FOR IDENTIFYING CDP 241
CONSTITUTIVE MODEL PARAMETERS
28. **Cvijetin Mladenović, Aleksandar Živković, Miloš Knežev, Dejan
Marinković, Dejan Lukić**
STABILITY LOBE DIAGRAM OF THE MILLING MACHINING SYSTEM 249
WITH MULTIPLE DOMINANT VIBRATION MODES
29. **Andjela Mitrović, Slobodan Savić, Mladen Josijević, Nebojša
Hristov, Damir Jerković, Djordje Ivković**
DETONATION WAVE CONTOURS IN EXPLOSIVELY FORMED 258
PROJECTILE
30. **Alma Čosić, Adis Dedić, Emir Nezirić, Dejan Jokić**
EXPERIMENTAL ANALYSIS OF KINEMATIC PARAMETERS IN 270
PLANAR MECHANISMS

MACHINE DESIGN, SIMULATION AND MODELING

31. **Stevan Kjosevski, Monika Lutovska, Zoran Trifunov**
CAPACITY OF CONTRIBUTING TO SUSTAINABLE DEVELOPMENT 275
OF CARS WITH DIFFERENT PROPULSION SYSTEMS – WESTERN
BALKAN STUDY
32. **Saša Živanović, Ljubomir Nešovanović, Zoran Dimić, Radovan
Puzović**
SIMULATION OF PARALLEL KINEMATIC MACHINE WITH SPECIFIC 284
SOLUTIONS OF THE PASSIVE TRANSLATORY JOINT
33. **Biljana Marković, Miljan Savić**
ARTIFICIAL INTELLIGENCE (AI) MANAGEMENT SYSTEM, KEY 291
ELEMENTS
34. **Goran Pavlović, Mile Savković, Nebojša B. Zdravković, Goran
Marković, Marko Todorović, Predrag Mladenović**
OPTIMAL DESIGN OF THE HYBRID I-GIRDER OF THE SINGLE- 300
BEAM BRIDGE CRANE
35. **Miloš Josimović, Gordana Bogdanović, Milan Vasić, Mirko
Blagojević**
THE USE OF THE CYCLOIDALDRIVE BLOCK IN THE ANALYSIS OF 308
CYCLOIDAL REDUCER EFFICIENCY
36. **Nikola Babić, Milan Tica**
RESULTS COMPARATION OF ANALYTICAL AND SOFTWARE 316
METHODS OF STEEL STRUCTURE STATIC CALCULATION
37. **Dejan Landup, Eleonora Desnica, Ivan Palinkaš, Luka Đorđević,
Borivoj Novaković**
EXAMPLES OF THE PRACTICAL APPLICATION OF 3D SCANNERS 325
IN PARTS QUALITY CONTROL IN THE AUTOMOTIVE INDUSTRY
38. **Aleksija Djuric, Srđan Samardžić, Biljana Marković, Dragan Milčić,
Damjan Klobčar, Nataša Zdravković, Miodrag Milčić**
EXPERIMENTAL ANALYSIS OF THE BEHAVIOR OF ADHESIVELY 334
BONDED CFRP-ALUMINUM ALLOY AW 5754 H22 JOINTS UNDER
TENSILE-SHEAR LOAD

39. **Nina Anđelić, Vesna Milošević-Mitić, Ana Petrović, Đorđe Đurđević**
A VIEW OF THE INFLUENCE OF CONSTRAINED TORSION ON BEHAVIOUR OF THIN-WALLED CANTILEVER CHANNEL-SECTION AND Z-SECTION BEAMS 342
40. **Srđan Samardžić, Mersida Manjgo, Aleksija Đurić, Biljana Marković, Miroslav Milutinović, Spasoje Trifković**
INFLUENCE OF FIBER ORIENTATION AND MOISTURE ON THE STRENGTH OF SINGLE-LAP ADHESIVE JOINTS OF PA6 GF COMPOSITE 351
41. **Rade Vasiljević**
ANALYSIS OF NODAL LOADS OF THE COLUMN OF A MECHANICAL LIFTS 359
42. **Nikola Milošević, Spasoje Trifković, Miroslav Milutinović, Kulwant Singh**
APPLICATION OF 3D PRINTING IN METAL CONSTRUCTIONS 367

PRODUCT DEVELOPMENT AND MECHANICAL SYSTEMS

43. **Milan Rackov, Siniša Kuzmanović, Ivan Knežević, Waldemar Matysiak, Jakub Hajkowski, Mateusz Barczewski, Mirjana Bojanić Šejat**
THE IMPACT OF EFFICIENCY ON THE SELECTION OF UNIVERSAL GEAR MOTOR REDUCERS 378
44. **Radoslav Tomović, Aleksandar Tomović, Samir Dizdar**
REPLICA OF CRNOJEVIC PRINTING PRESS - THE FIRST PRINTING MACHINE IN THE BALKANS 386
45. **Nenad Kostic, Vesna Marjanovic, Nenad Petrovic, Zivana Jovanovic Pesic**
PREDICTING STRESS CONCENTRATION FACTORS IN TENSION-LOADED SHAFTS USING ARTIFICIAL NEURAL NETWORKS 394
46. **Miloš Matejić, Anđela Perović, Ivan Miletić, Ljubica Mudrić-Staniškovski, Lozica Ivanović**
DESIGN AUTOMATION OF SET SCREW CONNECTION 402
47. **Milica Radovanović, Brankica Čomić, Snežana Dostinić, Budimirka Marinović, Obrad Spaić, Dejan Božić, Dejan Lukić, Mijodrag Milošević**
THE INFLUENCE OF CNC TECHNOLOGY ON PRODUCTION TIME AND PROCESSING QUALITY 409

ENERGY AND TERMOTECHNIC

48. **Valentino Stojkovski, Marija Lazarevikj, Zoran Markov**
MODEL FOR PROSPECTING HIDDEN HYDROPOWER AT EXISTING WATER SUPPLY SYSTEMS 419
49. **Vuko Kovijanić, Uroš Karadžić, Anton Bergant, Igor Aleksić**
TRANSIENT FLOW DURING RAPID FILLING OF HORIZONTAL PIPES WITH TRAPPED AIR 431
50. **Ruzena Kralikova, Ervin Lumitzer, Elena Lukač Jurgovska**
DRONE THERMAL IMAGING: NEW TRENDS AND PERSPECTIVES 439
51. **Djordje Manojlovic, Vesna Jevtic**
FLUE GAS DESULPHURIZATION PLANT WORKING EFFECTS IN THE THERMAL POWER PLANT 446

- 52 **Ivan Popović, Milan Djordjević, Jasmina Skerlić, Vladan Jovanović**
 DETERMINING THE RELIABILITY FUNCTION OF THE THERMAL POWER SYSTEM IN POWER PLANT “KOSTOLAC, BLOCK A2” USING THE WEIBULL DISTRIBUTION 454

RENEWABLE ENERGY AND ENVIRONMENTAL PROTECTION

- 53 **Danijela Nikolić, Minja Velemir Radović, Saša Jovanović, Zorica Đorđević**
 ENERGY ANALYSIS OF SERBIAN BUILDING WITH PV PANELS AND DIFFERENT HEATING SYSTEMS 463
- 54 **Branislav Dudić, Alexandra Mittelman, Branko Štrbac, Borislav Savković**
 SUSTAINABILITY OF GLOBAL LITHIUM-ION BATTERIES 472
- 55 **Srđan Vasković, Gojko Krunić, Aleksandar Anđelković, Mladen Tomić, Marko Romović**
 ASPECTS OF LPG FUEL APPLICATION IN CARS 478
- 56 **Goran Orašanić, Budimirka Marinović, Stojan Simić, Davor Milić, Jovana Blagojević**
 SUSTAINABLE WATER SUPPLY IN THE CONTEXT OF THE GREEN AGENDA FOR THE WESTERN BALKANS 484
- 57 **Jela Vorotović, Goran Vorotović, Đorđe Novković, Milan Lečić, Miloš Januzović**
 TURBULENCE ANISOTROPY IN A COUNTER-FLOW VORTEX TUBE FLOW 491
- 58 **Minja Velemir Radović, Danijela Nikolić, Saša Jovanović**
 ENERGY EFFICIENCY IN THE BUILDING SECTOR IN SERBIA - AN OVERVIEW 499
- 59 **Vesna Mihajlov, Jasmina Pekez, Uroš Šarenac, Ljiljana Radovanović, Mića Djurdjev, Aleksandar Ašonja**
 JUSTIFICATION OF THE APPLICATION OF PHOTOVOLTAIC TRANSFORMATION OF SOLAR RADIATION FOR THE PRODUCTION OF ELECTRICITY FOR THE NEEDS OF PUBLIC INSTITUTIONS 507
- 60 **Milica Kašiković, Uroš Karadžić**
 SELECTION OF THE WATER TURBINE BASED ON ELECTRICITY GENERATION ON SUTJESKA RIVER 515
- 61 **Zaga Trišović**
 RENEWABLE ENERGY EQUIPMENT IN BIOGAS PLANTS 521

MAINTENANCE AND TECHNICAL DIAGNOSTICS

- 62 **Rodoljub Vujanac, Nenad Miloradovic, Snezana Vulovic**
 SOME EXPERIENCES FROM THE PRACTICE ABOUT RESULTS AND IMPORTANCE OF WAREHOUSE RACKING INSPECTIONS 530
- 63 **Josip Radić, Antonija Ereš, Držislav Vidaković, Marijana Hadzima-Nyarko**
 ASSESSMENT OF BUILDING VULNERABILITY THROUGH RAPID VISUAL SCREENING METHOD: CASE STUDY OF SELECTED STREET BLOCKS IN OSIJEK 536

QUALITY, MANAGEMENT AND ORGANIZATION

64	Monika Lutovska, Zoran Trifunov, Izet Zeqiri, Stevan Kjosevski OCCUPATIONAL SAFETY AWARENESS MEASURING TOOL AMONG AGRICULTURAL WORKERS IN NORTH MACEDONIA	544
65	Danijela Tadić, Nikola Komatina, Marija Savković FORECASTING DEMAND TRENDS IN AUTOMOTIVE INDUSTRY: COMPARATIVE ANALYSIS OF EXPONENTIAL SMOOTHING AND REGRESSION ANALYSIS	550
66	Snežana Nestić, Danijela Tadić, Tijana Petrović DETERMINING THE WEIGHTS OF COMMERCIAL CRITERIA FOR INVESTMENT PROJECT EVALUATION BASED ON THE IDOCRIV METHOD	558
67	Aleksandar Aleksić, Ivana Spasenić, Danijela Tadić ASSESSMENT AND SELECTION OF CLOUD SERVICE PROVIDERS FOR HOSTING WEB APPLICATIONS BY APPLYING MADM APPROACH	566
68	Jovana Dragutinovic, Angela Fajsi, Slobodan Morača, Slaviša Moljević, Ranka Sudžum KEY SUCCESS FACTORS OF AGILE TRANSFORMATION IN MANUFACTURING COMPANIES	575
69	Slavenko Stojadinovic, Milos Pjevic, Nikola Slavkovic, Radovan Puzovic 3D SCANNING AND INSPECTION GEOMETRICAL PARAMETERS OF SPROCKET TOOTH PROFILE	581
70	Vlado Medaković, Bogdan Marić OVERALL EFFICIENCY AND EFFECTIVE PERFORMANCE OF PRODUCTION EQUIPMENT – CASE STUDY	587
71	Ivan Mačuzić, Marija Savković, Nastasija Nikolić, Đorđe Milojević APPLICATION OF ROBOTICS SYSTEMS FOR QUALITY INSPECTION IN INDUSTRY	595
72	Radoslav Vučurević, Zdravko Krivokapić, Brankica Čomić THE INFLUENCE RANKING OF DRILLING PROCESS INPUT PARAMETERS ON SURFACE ROUGHNESS	604
73	Dragan Vujović, Pavle Popović, Oto Iker INTELLECTUAL CAPITAL MANAGEMENT IN CONDITIONS OF UNCERTAINTY	613
74	Vasko Milatović, Nikola Šibalić, Aleksandar Vujović MEASUREMENT OF NOISE LEVELS IN THE WORKPLACE	621
75	Belma Fakić, Adisa Burić, Edib Horoz ENSURING THE VALIDITY OF TEST RESULTS TO ENSURE RELIABILITY	629
76	Tamara Koroman, Sanja Kanostrevac-Vidaković ACCREDITATION PROCESS OF THE STANDARD METHOD BAS EN ISO 12156-1 IN THE "SISTEM QUALITA,S" LTD. PALE TESTING LABORATORY	635
77	Ranka Sudžum, Angela Fejsi, Luka Jevtović EVALUATION OF INNOVATION PROJECTS USING INTUITIONISTIC FUZZY TOPSIS METHOD	642

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FINITE ELEMENT ANALYSIS OF CYLINDRICAL SURFACE CONTACT

Snežana Vulović¹, Vladimir Milovanović², Miloš Pešić³, Marko Topalović⁴,
Miroslav Živković⁵

Abstract: The two most common methods for solving contact problems using the finite element method are the Lagrange multiplier method and the penalty method. The Lagrange multiplier method treats contact forces as independent variables (Lagrange multipliers), and the contact non-penetration conditions are exactly satisfied. The penalty method satisfies contact conditions using penalty parameters, and the contact non-penetration conditions are approximately satisfied. The aim of this study is a comparative analysis of contact mechanics which is conducted using the finite element method (FEM). The penalty method is used for contact problem-solving. The primary objective is to evaluate the differences in results and computational efficiency between the two types of finite elements used and to determine the influence of the finite element mesh size on results.

Keywords: Contact mechanics, Cylindrical convex surfaces, Finite element method

1 INTRODUCTION

Contact mechanics plays a critical role in numerous engineering applications, including machine design, automotive engineering, the railway industry, and biomedical implants. Chapter [1] discusses contact phenomena in scenarios like metal formation, vehicle crashes, and gear systems, exploring various solution strategies. It covers one-point contact examples, the variational formulation of contact, finite element discretization, 3D contact formulations, and practical considerations such as

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constraint equations and modeling issues like slave/master body selection and removing rigid-body motions. Understanding how surfaces interact under load is essential for optimizing the performance, durability, and safety of mechanical systems. One of the most effective approaches for analyzing contact problems is the finite element method (FEM) [2], which allows for a detailed simulation of stress distribution, deformation, and pressure between contact surfaces.

The mechanics of Rail-Wheel contact study [3] is a critical area in Railway Engineering, where numerical methods like Finite Element Analysis (FEA) are often used due to limitations in analytical models for complex geometries. This study emphasizes a more accurate 3D FEA approach to Rail-Wheel contact problems, showing strong alignment with real-life scenarios.

As for biomedical implants goes results in the paper [4] show that roughness wavelength and clearance significantly influence pressure distribution and contact area, highlighting the importance of avoiding overly loose or tight hip implants for optimal design, regardless of material combinations.

In contact analysis, two primary methods are employed to enforce contact constraints: the Lagrange multiplier method and the penalty method [5]. The Lagrange multiplier method ensures that contact non-penetration conditions are exactly satisfied by treating the contact forces as independent variables. The penalty method allows for approximate satisfaction of the contact conditions by introducing penalty parameters that penalize constraint violations. Both methods offer unique advantages, with trade-offs in terms of computational complexity, accuracy, and convergence stability.

The authors in [6] conducted research on tetrahedral finite elements, which are simpler to generate compared to 3D hexahedral and shell elements, thereby reducing the required engineering time.

This paper aims to conduct a comparative analysis of contact mechanics using FEM, with a focus on the penalty method for solving contact problems. Two finite element models, one utilizing 3D hexahedral elements and the other using shell elements, were developed to study the contact between cylindrical convex surfaces. These surfaces, tangent at a 90° angle, are subjected to a 50 kN pressure force. The study investigates the impact of varying mesh densities on stress and pressure distribution in the contact region and evaluates the differences in results and computational efficiency between the two types of finite elements. The selected parameters for monitoring the results are stress and pressure in the contact region, as they play a critical role in understanding the mechanical interactions and material behavior under load. These parameters provide insights into potential points of failure, material deformation, and the overall performance of the constructions under operational conditions. In the paper [7] authors examined various FE models with different dimensions, load values, element types, and mesh densities. It focuses on how these variations affect stress values and node displacements in the contact regions while keeping boundary conditions and loading modes consistent across the FE models.

This research provides valuable insights into the accuracy and computational demands of different modeling approaches by comparing the results obtained with varying densities of mesh and element types. The obtained results offer practical recommendations for improving the precision of contact analysis in finite element simulations, particularly in terms of mesh generation and contact region definition. Additionally, the study highlights the impact of mesh density and element type on the overall accuracy and efficiency of the simulations.

2 THEORETICAL BASIS

The Lagrange multiplier method is a strategy for optimizing a function subject to equality constraints. Given an objective function $f(x)$ that needs to be optimized under the constraint $g(x) = 0$, a scalar multiplier λ is introduced. The Lagrange multiplier transforms the constrained optimization problem into an unconstrained one by defining the Lagrangian function $L(x, \lambda)$. Solving this involves finding points where the gradients of the Lagrangian for both x and λ are zero. This method treats the contact forces as independent variables (Lagrange multipliers), ensuring that contact non-penetration conditions are exactly satisfied.

The penalty method addresses constrained optimization by adding a penalty term to the objective function. This term imposes a cost for violating the constraints, converting the problem into an unconstrained one. The modified objective function becomes:

$$P(x) = f(x) + \frac{1}{2} r \cdot g(x)^2 \quad (1)$$

Where r is the penalty parameter, which penalizes constraint violations. In the context of contact problems, the penalty method approximately satisfies contact conditions by introducing a penalty parameter that controls the severity of constraint violations. As $r \rightarrow \infty$ the solution better adheres to the constraints, but too high a penalty parameter can lead to numerical instability.

3 FE MODELS

Two finite element models were developed to study the contact between cylindrical convex surfaces, which are tangent to each other and form a 90° angle. The finite element models were developed to simulate the stress and pressure distribution in the contact region under a 50 kN pressure load. Both plates are made of steel and have identical material properties: 2.1×10^5 MPa as Young Modulus, 7.85×10^6 kg/mm³ as density, and 0.3 as Poisson ratio. The numerical analysis was performed in the Nastran software, while the pre and post-processing were carried out in Femap software [8]. The FE model – left (Figure 1), consists of 216 3D hexahedral finite elements and 1728 nodes, and the FE model – right (Figure 1), consists of 216 shell elements and 864 nodes.

The first finite element model employs 3D hexahedral elements, which can accurately capture complex geometries and stress variations within the contact area. This finite element model, as shown in Figure 1 – left, provides a solid representation of the volume and material behavior of the cylindrical surfaces. By utilizing 3D hexahedral elements, the finite element model achieves a high degree of accuracy in representing the physical interaction between the contacting surfaces, particularly in areas with high-stress gradients.

The second finite element model, shown in Figure 1 – right, is developed using shell elements, which are computationally more efficient due to their lower dimensionality compared to 3D hexahedral elements. In this study, the shell element model is employed to evaluate whether this simpler representation can still capture the essential contact behavior between the cylindrical surfaces while offering faster computational times compared to the 3D hexahedral finite element model. Figure 1 illustrates the problem setup, including the corresponding loads (50 kN pressure force)

and constraints.

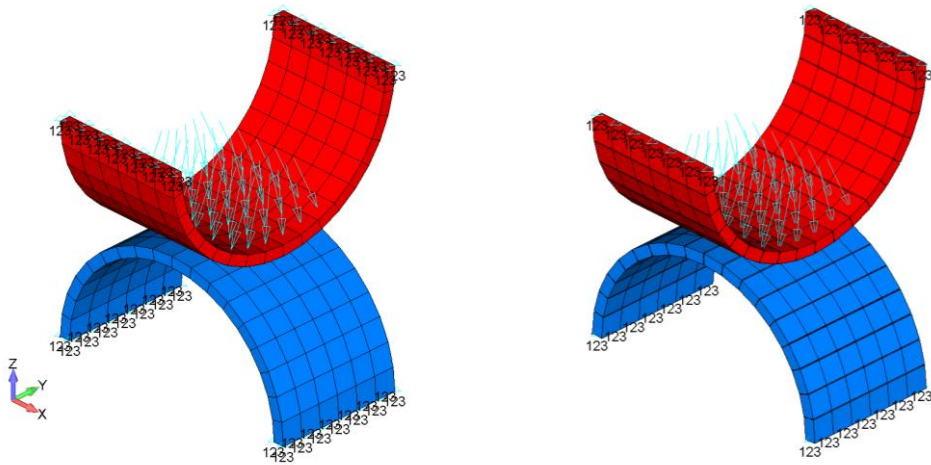


Figure 1 *Finite element model for contact examination between two cylindrical convex surfaces; 3D – hexahedral finite elements – left; b) shell elements – right [9]*

For each finite element model, three different finite element sizes were used: 5 mm x 5 mm x 5 mm, 10 mm x 10 mm x 5 mm, and 20 mm x 20 mm x 5 mm.

3.1 Results and Discussion

Figure 2 shows diagrams that represent stress and pressure values in the contact region depending on mesh density.

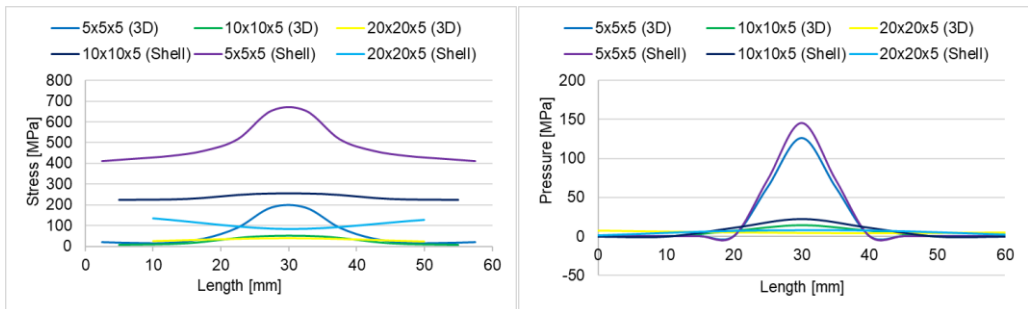


Figure 2 *Changes in stress and pressure values in the contact region depending on mesh density; left – stress values, right – pressure values*

As shown in the diagrams in Figure 2 – left, the stress value in the contact region increases with the increase in mesh density, and vice versa. Finer meshes, such as the 5 mm x 5 mm x 5 mm mesh, capture localized stress concentrations more accurately due to their ability to better resolve the complex geometry and stress gradients at the contact interface. In contrast, as the mesh density decreases FE model may underrepresent the peak stress values, leading to less accurate predictions. The stress value is observed to be significantly higher when the mesh density is 5 mm x 5 mm x 5 mm, indicating that a finer mesh provides a more precise

and detailed representation of the stress distribution in regions of high contact stress.

A similar trend is observed for the contact pressure value, as illustrated in Figure 2 – right. As the mesh density increases, the contact pressure value rises, reflecting a more accurate computation of the pressure distribution across the contact surfaces. A finer mesh, such as the 5 mm x 5 mm x 5 mm mesh, by offering a higher resolution in the contact region, is better suited to model the localized pressure peaks that occur due to the applied load. A coarser mesh, such as the 20 mm x 20 mm x 5 mm mesh, smoothing out these peaks, underestimating the true contact pressure values. This increase in pressure values with finer mesh density demonstrates the necessity of using a sufficiently refined mesh to capture the details of contact mechanics accurately.

4 CONCLUSION

As observed from the diagrams, the results obtained from the numerical analysis using 3D hexahedral finite elements and shell elements exhibit notable variations. These differences underscore the impact of element type on the accuracy and reliability of contact simulations. To enhance the precision of the analysis and ensure more reliable results, several key recommendations should be followed:

- Optimal analysis results are achieved when the mesh density is uniform across both the master and slave segments of the contact interface. This uniformity ensures that the contact conditions are consistently represented across the entire interface, minimizing potential discrepancies caused by varying mesh resolutions. Discrepancies in mesh density between the contact segments can lead to inaccurate stress and pressure predictions, affecting the overall quality of the analysis.
- When modeling contact regions using shell elements, it is crucial to pay careful attention to the front and back sides of the shell. Shell elements are often used to represent thin structures and may not capture the full three-dimensional behavior of contact interactions if not properly configured. Ensuring that the shell elements are correctly oriented and adequately represent the contact surfaces is essential for accurate simulations.
- It is essential to avoid merging nodes at the contact interface. Merging nodes can inadvertently simplify the contact representation and may lead to unrealistic results, particularly in terms of stress concentrations and contact pressures. Maintaining separate nodes at the interface ensures that the contact conditions are modeled correctly, preserving the accuracy of the simulation.

The analysis indicates that more reliable and accurate results in contact mechanics are generally obtained when the contact regions are defined using 3D hexahedral finite elements. This element type provides a more detailed and precise representation of the contact geometry and interactions compared to shell elements. The finer resolution offered by hexahedral elements allows for better capture of localized stresses and pressures, leading to more accurate predictions of contact behavior. While 3D hexahedral elements may require higher computational resources, their ability to provide detailed results justifies their use in scenarios where precision is critical.

By adhering to these recommendations and choosing the appropriate element type, researchers and engineers can enhance the accuracy and reliability of contact analysis, ultimately leading to better-informed design decisions and improved performance of engineering systems.

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