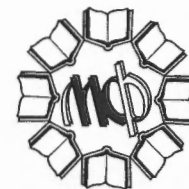




UNIVERSITY OF EAST SARAJEVO
FACULTY OF MECHANICAL
ENGINEERING



2nd INTERNATIONAL SCIENTIFIC CONFERENCE



COMETa2014

*"Conference on Mechanical Engineering Technologies
and Applications"*

PROCEEDINGS

2nd - 5th December 2014
East Sarajevo - Jahorina, B&H, RS

COMETa2014

2nd INTERNATIONAL SCIENTIFIC CONFERENCE

2nd - 5th December 2014
Jahorina, B&H, Republic of Srpska



University of East Sarajevo
Faculty of Mechanical Engineering
Conference on Mechanical Engineering Technologies and Applications

ZBORNIK RADOVA PROCEEDINGS

*Istočno Sarajevo – Jahorina, BiH, RS
2 - 5. Decembar 2014.*

*East Sarajevo – Jahorina, B&H, RS
2nd – 5th December 2014.*

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PREFACE

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

Faculty of Mechanical Engineering, University of East Sarajevo, organizes the Second international conference "COMETa2014 - Conference on Mechanical Engineering Technologies and Application", which has tasks: to increase economic competitiveness in the region and to give an contribution to creation of unique European Research Area.

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

COMETa2014 conference program structure is consisted of the following thematic areas: Production technologies and advanced materials, Energy and environment, Applied mechanics and mechatronics, Development of products and mechanical systems, Quality and management and Organization and maintenance.

Participation in international conference COMETa2014 was achieved by: 229 authors from 11 countries, with a total of 102 papers, including 3 plenary lectures.

Inside of conference COMETa2014 has been planned organization of three working meeting and one round table discussion based on actual topics of conference. During the conference, it will be presented some of technical solutions produced in companies from our region.

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

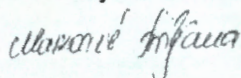
On the basis of previous exposure, a gathering of scientists and researchers at the international conference COMETa should be understood not only as an exchange of knowledge and achievements of the narrower set of scientists and researchers, but also as a constant and serious attempt to focus social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

On behalf of the Organizing Committee and Scientific Committee of the Conference COMETa2014, we want to express our gratefulness to all authors, reviewers, as well as institutions, companies and individuals who contributed to realization of the Conference.

East Sarajevo, November 19th, 2014.


President of the Scientific Committee

Prof. dr Biljana Marković



President of the Organizing Committee

Prof. dr Ranko Antunović



CONTENT

PLENARY LECTURES

1. **Milosav Ognjanović, Miloš Ristić, Sanja Vasin**
HYBRID TECHNICAL SYSTEMS AND THE NEW ALTERNATIVE
SOLUTIONS DESIGN 1
2. **Lubomir Dimitrov, Spas Spasov**
AUTOMATION IN SMALL SERIES BATCH PRODUCTION. A CASE
STUDY 9
3. **Predrag Ćosić**
MACHINE TOOLS SELECTION USING AHP METHOD AND
MULTIOBJECTIVE OPTIMIZATION 17

MANUFACTURING TECHNOLOGIES AND ADVANCED MATERIALS

Chairpersons: Darko Petković, Milan Zeljković, Milan Šljivić

4. **Mihajlo Popović, Ljubodrag Tanović**
TAPPING PROCESSES SIMULATION BASED ON ORTHOGONAL
CUTTING TESTS 25
5. **Saša Živanović, Goran Vasilic**
VARIANTS OF CONFIGURING THE 2-AXIS RECONFIGURABLE
PARALLEL MECHANISM – MOMA 33
6. **Vladimir Blanuša, Milan Zeljković**
COMPUTER MODELING OF STATIC BEHAVIOR MAIN SPINDLE
ASSEMBLY WITH THE DOUBLE ROW CYLINDRICAL ROLLER
BEARING 41
7. **Mirjana Bojanić, Goran Jovičić, Milan Zeljković**
DETERMINATION OF ACCURACY AND REPEATABILITY OF
POSITIONING OF CNC MACHINE TOOL 49
8. **Goran Jovicic, Mirjana Bojanic, Slobodan Tabakovic**
DEVELOPMENT GRAPHICAL USER INTERFACE-GUI FOR
CALCULATING ACCURACY OF NC MACHINE TOOLS 59
9. **Ibrahim Plančić, Darko Petković, Samir Lemeš, Hazim Bašić**
RESEARCH ON IMPACT FACTORS INFLUENCING ROUNDNESS OF
PRODUCTS MADE OF AL 99.5% FORMED BY COLD ROTARY
EXTRUDING TECHNOLOGY 69
10. **Igor Kacmarcik, Aljoša Ivanisevic, Dejan Movirn,
Miroslav Plancak, Dragisa Vilotic**
INVESTIGATION OF FORWARD EXTRUSION PROCESS OF
BIMETALLIC MATERIALS 75

11. Mirna Nožić, Himzo Đukić, Daut Denjo HEAT BALANCE OF IRONING PROCESS	81
12. Amra Talić-Čikmiš, Suad Hasanbegović, Nedeljko Vukojević, Fuad Hadžikadunić THE EXTRA STRESS BECAUSE OF THE BENDING IN THE PROCESS THE DEEP DAWING	89
13. Miroslav Rogić, Duško Lukač FUTURE OF INDUSTRIAL PRODUCTION	95
14. Milan Šljivić, Mićo Stanojević, Nenad Grujović, Igor Kuzmanović, Zorana Pašalić DEVELOPMENT OF INDUSTRIAL PRODUCTS BY ADDITIVE MANUFACTURING	103
15. Ivica Jovanović 3D PRINTING USING WOOD COMPOSITE MATERIALS	111
16. Mladen Knežević PRODUCTION OF COMPLEX MECHANICAL PARTS BY MIG/MAG WELDING ROBOT	121
17. Nikola Bajić, Slobodan Stojadinović, Jasmina Pekez THE RESULTS OF THE PRELIMINARY RESEARCH FOR PRODUCING AND APPLICATION OF SPECIAL COATED ELECTRODES	129
18. Ivan Palinkaš, Eleonora Desnica, Jasmina Pekez, Ljiljana Radovanović PLASMA CUTTING – APPLICATION OF CAD/CAM TOOLS AND ADVANTAGES OF ROBOTICS COMPARING TO CNC MACHINE	135
19. Luka Panić, Ekrem Nežirović, Atif Hodžić PROJECTING FURNITURE FROM 3D PLYWOOD PLATES	141
20. Nedeljko Dučić, Žarko Čojbašić, Radomir Slavković THE APPLICATION OF NEURAL NETWORK IN MANAGING WHITE CAST IRON PRODUCTION	149
21. Svetlana Pelemiš, Dragoljub Mirjanić, Igor Hut SOME OPPORTUNITIES OF NANOTECHNOLOGICAL MATERIALS IN MECHANICS	155
22. Milija Krašnik, Dragiša Vilotić, Leposava Šiđanin, Žarko Petrović, Milan Šljivić, Milentije Stefanović MORPHOLOGY OF STEEL C45E MICROSTRUCTURE DURING UPSETTING	161

ENERGY AND ENVIRONMENT

Chairpersons: Ejub Džaferović, Petar Gvero, Dragoljub Živković

23. Miodrag Grujić, Dejan Ivezić, Marija Živković CRITERIA FOR THE SELECTION OF OPTIMAL OPTION FOR CENTRALIZED HEAT SUPPLY SYSTEM DEVELOPMENT	169
24. Milena Todorović, Dragoljub Živković, Marko Mančić PROCESS OF STARTING UP HOT WATER BOILERS	175
25. Dragana Temeljkovski, Goran Vučković MECHANISM OF HEAT TRANSFER IN VENTILATED ROOF	183
26. Almin Halač, Ejub Džaferović CALCULATION OF THE VERTICAL AND INCLINED PNEUMATIC CONVEYING WITH VARIOUS DIAMETER	189

27.	Mitar Jocanović, Velibor Karanović, Milija Krašnik SOLID CONTAMINANTS IN HYDRAULIC OIL AND THEIR IMPACT ON THE INTENSITY OF WEAR AND TEAR OF WORKING ELEMENTS IN DIRECTIONAL VALVES	195
28.	Srđan Ćurić, Obrad Spaić CHOICE OF LOCATION FOR CONSTRUCTION THE SOLAR SYSTEM USING EXPERT SYSTEM	203
29.	Marko Mančić, Dragoljub Živković, Milena Todorović SIMULATION OF A SOLAR SYSTEM FOR DEMENDS OF AN INDOOR SWIMMING POOL	211
30.	Marko Ikić, Slobodan Lubura, Milomir Šoja, Srđan Lale, Srđan Vasković HYBRID POWER SUPPLY SYSTEM	219
31.	Jovan Nešović, Dragan Arsenijević ENERGY EFFICIENCY OF PUBLIC BUILDINGS – ONE OF THE POSSIBLE FACTORS OF DEVELOPMENT AND COMPETENCY INCREASE OF LOCAL GOVERNMENTS IN THE REPUBLIC OF SERBIA	227
32.	Merima Maslo, Mersida Manjgo APPLICATION OF THE F-CHART METHOD FOR DESIGNING SOLAR THERMAL SYSTEM FOR HEATING DOMESTIC HOT WATER	235
33.	Dragan Antunović, Milan Savić ENERGY EFFICIENCY OF THE HOSPITAL BUILDING	243
34.	Srđan Vasković, Petar Gvero, Vlado Medaković, Velid Halilović, Marko Ikić, Goran Ašonja ENERGY INDEX FOR PRODUCTION WOODEN CHIPS	251
35.	Srđan Vasković, Petar Gvero, Vlado Medaković, Velid Halilović, Davor Milić FEASIBILITY STUDY FOR REPLACEMENT HEATING SYSTEM ON NATURAL GAS WITH PELLET BOILERS AT PRIMARY SCHOOL "SVETI SAVA " IN LUKAVICA	259
36.	Alojz Tovarović, Veljko Mastilo HEAT RECOVERY IN HVAC SYSTEMS	267
37.	Alojz Tovarović, Veljko Mastilo STRATEGY AND STEPS OF THE EUROPEAN UNION TOWARDS MORE ENERGY EFFICIENT BUILDINGS	273
38.	Sanja Stijačić, Davor Milić, Dušan Golubović, Novica Stijačić, Stojan Simić, Mirko Dobrnjac HIDRAULIC CALCULATION OF WATER DISTRIBUTION SYSTEM IN WET COOLING TOWERS	281
39.	Mile Stojilković TRIBOLOGICAL PROPERTIES OF VEGETABLE OILS	289
40.	Jovan Sredojević, Maja Krajišnik WASTE TYRES PYROLYSIS PROCESS	297
41.	Stojan Simić, Novica Stijačić, Dušan Golubović, Sanja Stijačić, Davor Milić ENVIRONMENTAL EMISSIONS AS A RESULT OF OIL REFINING	307
42.	Stojan Simić, Novica Stijačić, Dušan Golubović, Davor Milić, Sanja Stijačić BASIC ASPECTS OF PREPARATION AND PROCESSING OF REFINERY WATER	313

43. Milan Blagojević, Jelena Erić, Ljubica Knežević, Miroslav Živković, Ljiljana Tihaček Šojić	
NUMERICAL MODELING OF THE EDENTULOUS MANDIBLE WITH A COMPLETE DENTURE USING MULTIBLOCK METHOD	321
44. Nebojša Radić, Dejan Jeremić, Lana Sekulić	
BUCKLING ANALYSIS OF ORTHOTROPIC DOUBLE- NANOPLATE- SYSTEMS BASED ON NONLOCAL TWO- VARIABLE REFINED PLATE THEORY	327
45. Dejan Jeremić, Nebojša Radić	
INFLUENCE OF CARBON FIBER ANGLE ORIENTATION ON BUCKLING PROPERTIES OF COMPOSITE PLATES	339
46. Nikola Vučetić, Nebojša Radić, Miroslav Milutinović, Spasoje Trifković, Aleksandar Košarac	
CARBON NANOTUBES NATURAL FREQUENCIES RESULTS COMPARISON USING FEM AND ANALYTICAL METHOD	347
47. Tale Geramitchioski, Ljupco Trajcevski	
DYNAMIC ANALYSIS OF THE SLOPING BRIDGE USING FEM	357
48. Miroslav Živković, Marko Topalović, Milan Blagojević, Aleksandar Nikolić, Vladimir Milovanović, Siniša Mesarović, Jagan Padbidri	
BOUNDARY IDENTIFICATION AND WEAK PERIODIC CONDITION APPLICATION IN DEM METHOD	365
49. Duško Tešanović, Nijaz Pužić, Marko Vasiljević, Relja Jovanović	
RECYCLING THE VITAL SETS OF THE RAILWAY VEHICLES AND TRACK GEOMETRY, AS AN ECONOMICAL WAY OF BUSINESS OF THE RAILWAY	371
50. Ranko Antunović, Amir Halep	
APPLICATION OF FUZZY LOGIC IN THE IDENTIFICATION OF DEFECTS JOURNAL BEARINGS	381
51. Radivoje Mitrović, Natasa Soldat, Ivana Atanasovska	
DYNAMIC BEHAVIOR OF RADIAL BALL BEARING DUE TO THE PERIODIC VARIABLE STIFFNESS	389
52. Darko Knežević, Saša Laloš	
THE EFFECT OF RADIAL CLEARANCE ECCENTRICITY ON FLUID FLOW RATE	397
53. Miljan Rutar, Remzo Dedić, Adisa Vučina, Haris Đindo	
MEASURING EQUIPMENT IN THE RESEARCH AND THE DEVELOPMENT OF HYDRAULIC ABOVE – KNEE PROSTHESIS	407
54. Dragoslav Janošević, Vesna Jovanović, Jovan Pavlović, Predrag Milić	
ANALYSIS OF A MOVEMENT RESISTANCE OF CRAWLER MOBILE MACHINES	415
55. Saša Prodanović, Novak Nedić	
NON-CONVENTIONAL CONTROL OF LEVEL AND TEMPERATURE IN THE FLOW TANK	421
56. Branislav Gavrilović, Zoran Bundalo, Savo Gavrilović	
SIMULATION OF LOCOMOTIVE TENT 443 MANEUVER WORK USING MATLAB - SIMULINK	429

DEVELOPMENT OF PRODUCTS AND MECHANICAL SYSTEMS

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- | | |
|---|-----|
| 57. Zorica Djordjević, Miloš Zuvić, Mirko Blagojević, Saša Jovanović, Miloš Matejić | |
| ANALYSIS OF THE VEHICLE DYNAMIC STABILITY | 437 |
| 58. Siniša Kuzmanović, Milan Rackov, Miroslav Vereš | |
| THE BASIC CHARACTERISTICS OF MODERN BACKLASH GEAR REDUCERS | 443 |
| 59. Predrag Živković | |
| FORMS AND CAUSES OF FATIGUE GEARS TOOTH FLANK FAILURE AND THEIR IDENTIFICATION | 451 |
| 60. Dragan Čukanović, Milan Blagojević, Snežana Vulović, Miroslav Živković | |
| ANALYSIS OF PRE-STRESSES CAUSED BY WIRE TENSION OF STONE CUTTING MACHINE | 459 |
| 61. Zoran Stamenić, Mileta Ristivojević, Marko Tasić | |
| INFLUENCE OF GEOMETRY ON CARDAN JOINT LOAD DISTRIBUTION | 463 |
| 62. Miroslav Milutinović, Aleksija Đurić, Spasoje Trifković, Nikola Vučetić | |
| MEASUREMENT OF TORQUE ON THE CARDAN SHAFT EMBEDDED IN THE FREIGHT VEHICLE | 471 |
| 63. Rade Grujičić, Dejan Bratić, Luka Grubiša, Ognjen Mijanović, Marina Mijanović Markuš, Radoslav Tomović, Zoran Mijanović | |
| APPLICATION OF METHODOLOGICAL PROCEDURE OF CONSTRUCTING IN DEVELOPING MECHATRONIC CONSTRUCTIONS | 481 |
| 64. Žarko Mišković, Zoran Stamenić, Jefto Terzović, Radivoje Mitrović | |
| MECHANICAL TESTING OF METAL BUILDING CONSTRUCTION IN EARTHQUAKE CONDITIONS | 491 |
| 65. Radivoje Mitrović, Žarko Mišković, Gradimir Ivanović, Milan Tasić, Zoran Stamenić | |
| DEVELOPMENT OF EXPERIMENTAL METHODOLOGY FOR CONVEYOR IDLER'S SEALING GROUP TESTING | 497 |
| 66. Miloš Matejić, Lozica Ivanović, Nenad Petrović | |
| ADOPTION OF OPTIMAL TEETH PARAMETERS OF GEROTOR PUMP | 505 |
| 67. Nenad Kostić, Nenad Petrović, Nenad Marjanović, Mirko Blagojević, Miloš Matejić | |
| PARAMETRIC MODELING OF GEAR TRANSMISSIONS IN CAD SOFTWARE WITH DEFINABLE SHAFT AXIS POSITIONS | 513 |
| 68. Vesna Jovanović, Dragoslav Janošević, Jovan Pavlović | |
| ANALYSIS AND SYNTHESIS DRIVE MOVEMENT OF HYDRAULIC EXCAVATORS | 521 |
| 69. Aleksandar Miltenović, Milan Banić, Vojislav Miltenović | |
| ROLE AND IMPORTANCE OF LIGHTWEIGHT DESIGN IN THE PRODUCT DEVELOPMENT | 529 |

70. Zdravko Božičković, Bogdan Marić, Dragoslav Dobraš, Gordana Lakić-Globočki, Đorđe Čiča	
VIRTUAL MODELING OF ASSEMBLY AND WORKING ELEMENTS OF HORIZONTAL HYDRAULIC PRESS	539
71. Radoslav Tomović, Rade Grujičić	
METHODOLOGICAL APPROACH TO RISK ASSESSMENT IN PRODUCT DEVELOPMENT PROCESS	547
72. Vojkan Nojner	
A MODULAR APPROACH IN GENERATING A FAMILY OF ACTUAL STANDARD GEARBOXES	555
73. Vladislav Krstić, Vojkan Nojner	
APPLICATION PERSPECTIVE OF A NEW GENERATION OF SPLIT SPHERICAL ROLLER BEARINGS	563
74. Srđan Pelkić, Aleksija Đurić, Biljana Marković, Radivojka Vučinić	
DEVELOPMENT OF NEW PRODUCTS IN INDUSTRY OF UPHOLSTERED FURNITURE	571
75. Aleksija Đurić, Biljana Marković, Srđan Pelkić	
BASIC PRINCIPLES AND RULES FOR IMPLEMENTATION OF THE LIGHTWEIGHT DESIGN IN MECHANICAL ENGINEERING	579

QUALITY AND MANAGEMENT

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76. Branko Vučijak, Snežana Mišić Mihajlović, Dino Delibašić, Emir Imamović	
MULTICRITERIA RANKING OF PRIORITY MEASURES FOR IMPROVED MANAGEMENT OF WATER SUPPLY IN RURAL AREA SCHOOLS	589
77. Smail Klarić, Senada Pobrić,	
PROCESS MANAGEMENT – IMPROVEMENT OF QUALITY PROCESS	597
78. Saša Čudić, Miloš Sorak	
A MODEL FOR THE IDENTIFICATION OF ESSENTIAL CHARACTERISTICS OF INSURANCE COMPANIES SERVICES USING TOOLS OF QUALITY	603
79. Biljana Marković	
THE NEXT VERSION OF ISO 9001:2015 - REFLECTION ON QMS OF AN AEROSPACE COMPANY	613
80. Slaviša Moljević, Ranka Gojković, Božo Vukoja, Dalibor Musa	
COMPARATIVE RELATIONS REQUIRES THE BOLOGNA PROCESS AND 9001: 2008 MODEL IN RESPECT OF INSURANCE AND QUALITY MANAGEMENT	621
81. Mirsada Oruč, Sulejman Muhamedagić, Jusuf Duraković, Dragana Agić	
QUALITY IN THE PRODUCTION	629
82. Neira Delić, Fahrudin Tarahija	
QUALITY CONTROL AS A KEY FACTOR IN THE FUNCTIONING OF THE PRODUCTION PROCESSES	633
83. Vlado Medaković, Milan Cvijić	
THE EFFECT OF SMALL ENTERPRISES IN THE REGIONAL DEVELOPMENT	639

84. Vlado Medaković, Savo Šehovac, Srđan Vasković, Davorin Đurović	
THE POSSIBILITY OF MORE EFFECTIVE KNOWLEDGE	645
MANAGEMENT IN THE AREA OF RENEWABLE ENERGY SOURCES	
85. Elvis Hozdić, Emine Hozdić	
THE FOUNDATIONS OF A NEW INDUSTRIAL REVOLUTION –	653
INDUSTRY 4.0	
86. Miljan Savić, Goran Tešanović	
BUSINESS CONTINUITY MANAGEMENT	663
87. Predrag Petrović, Marija Petrović, Ana Velimirović, Mina Petrović	
PHILOSOPHICAL APPROACH TO RISK AND PROJECT RISK	669
MANAGEMENT	

ORGANIZATION AND MAINTENANCE

Chairpersons: Ljubica Duđak, Zoran Stamenić, Vojin Vukotić

88. Radivoje Mitrović, Žarko Mišković, Zoran Stamenić	
REVIEW OF MACHINE ELEMENTS AND SYSTEMS TESTING	681
CAPACITIES OF FACULTY OF MECHANICAL ENGINEERING AT	
UNIVERSITY OF BELGRADE	
89. Žarko Mišković, Radivoje Mitrović	
ANALYSIS OF CURRENT STATE OF HIGHER EDUCATION IN THE	689
FIELD OF TECHNICAL LEGISLATION AND MACHINE DESIGN AT	
UNIVERSITY OF BELGRADE – FACULTY OF MECHANICAL	
ENGINEERING	
90. Mirko Blagojević, Nenad Petrović, Nenad Kostić, Miloš Matejić,	
Nenad Marjanović	
PRODUCT DEVELOPMENT AT THE FACULTY OF ENGINEERING	697
UNIVERSITY IN KRAGUJEVAC	
91. Azra Emić, Neira Delić	
EMPLOYEE MOTIVATION IN METALLURGICAL INSTITUTE "KEMAL	701
KAPETANOVIC" ZENICA AS DETERMINANTS OF ORGANIZATIONAL	
BEHAVIOR, THUS IMPROVING THE RESULTS OF THE WORK	
92. Ljubica Duđak, Tatjana Savic-Sikoparija, Sinisa Mitic	
CORPORATE RESPONSIBILITY IN CREATING COMPETITIVE	709
ADVANTAGE OF A COMPANY	
93. Biljana Marković, Dejan Jeremić	
PRODUCT DEVELOPMENT AT THE FACULTY OF MECHANICAL	717
ENGINEERING AT THE UNIVERSITY OF EAST SARAJEVO	
94. Olivera Janković	
M2M COMMUNICATION IN THE SERVICE OF PREDICTIVE	725
MAINTENANCE	
95. Olivera Janković	
CMMS: SELECTION AND REVIEW OF APPLICATIONS	729
96. Goran Orašanin, Branko Vučijak, Dragana Ristić	
DEVELOPMENT OF METHODOLOGY FOR EVALUATION AND REAL	737
WATER LOSS REDUCTION IN WATER SUPPLY SYSTEMS IN	
TRANSITION COUNTRIES - MEASUREMENT, MONITORING AND	
MAINTENANCE	
97. Vojin Vukotić, Rajko Tanasijević	
ANALYSIS OF THE EXISTING SITUATION AND FLOW	747
REVITALIZATION OF BUCKET WHEEL EXCAVATOR ER-1250 17/15	

STUDENT SESSION

Chairpersons: Saša Prodanović, Spasoje Trifković, Aleksija Đurić

98. **Mihailo Radojičić, Aleksija Đurić, Nikola Vučetić**
THE NOISE MEASUREMENT USING SOUND LEVEL METER IN CNC 757
LABORATORY OF FACULTY OF MECHANICAL ENGINEERING IN
EAST SARAJEVO
99. **Ratko Joksimović**
THE POSSIBILITY OF USING SOLAR ENERGY WITH 763
PHOTOVOLTAIC PANELS IN BOSNIA AND HERZEGOVINA
100. **Marko Šolaja**
TYPES, PURPOSE, AND REPORT OF MECHANICAL AND BRAKES 771
PROOF ON DETACHABLE CHAIRLIFT "OGORJELICA 1"
101. **Ranka Gojković, Marija Kunarac, Vladimir Gojković**
THE INFLUENCE OF REFRIGERANT TO ENERGY EFFICIENCY OF 777
THE SYSTEM

APPENDIX

102. **Vladimir Gojković, Ranka Gojković, Nedeljko Mijović**
PROCEDURES FOR IMPLEMENTATION OF SMALL HYDRO POWER 785
PLANTS AND EXTENT OF ITS SIMPLIFICATION

INDEX OF AUTORS

793

PRESENTATIONS OF PARTICIPANTS

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BOUNDARY IDENTIFICATION AND WEAK PERIODIC CONDITION APPLICATION IN DEM METHOD

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Vladimir Milovanović⁵, Siniša Mesarović⁶, Jagan Padbidri⁷

Abstract: Meshless character of the DEM method brings forth certain problems that must be solved in a computer implementation, such as the determination of the neighbouring particles, determining the boundaries of the model and the definition of boundary conditions. During large deformations of the model a particular internal particle may become boundary particle and the other way round so it is necessary to re-determine the boundary layer after a given number of steps in the analysis. In this paper, two approaches for defining the boundary layer are shown, whose effectiveness depends on the current positions of the particles, and imperfections in their arrangement. Due to the large computer requirements of the DEM method, only a small part of the real problem is modelled and continuity can be achieved by using periodic boundary conditions. Since the DEM particles have arbitrary radius and the boundary is often irregular, it is not possible to achieve the classic periodic boundary conditions in which the particle that leaves the model on one side enters the model on the other side, but it is possible to apply a soft periodic boundary conditions that transmit only the force from one to another end of the model. Previously mentioned routines are applied to the modelling of shear in the critical layer of granular material.

Key words: DEM method, boundary layer, periodic boundary conditions

1. INTRODUCTION

Granular materials are the second most manipulated material in engineering (water is first), so understanding their behavior is crucial in designing new machines for their transportation, manipulation and processing. Theoretical study of stress and strains in granular material gives great insight into grain interaction [1] while experimental testing shows behavior of whole granular material such as failure of

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overloaded material along narrow shear bands [2]. Within these shear bands vortexes are formed and dissolved and dilatation of material in shear band is observed [2]. To analyze these phenomena a numerical method called Discrete Element Method (DEM) is used [3]. DEM method is based on modeling inter-particle contact forces using non-linear elastic Hertz law which requires very small time step to achieve accurate results [4]. Loads in granular material are not transmitted equally over the whole volume of material, with most of the load transmitted over certain particles that form "force chains", while other particles only have supportive role [5]. During deformations of granular material some chains are broken while new ones are formed [5]. These deformations are sum of all translations and rotations of granular particles, where rotations are more likely to occur due to lower friction coefficient. Rotations also require smaller time step for the calculations [4]. Since this method is very computationally demanding, most of the problems that are analyzed are modeled in 2D using only a section of real-life problems. Determination of the boundary layer is important in the DEM analysis because through the particles of the boundary layer loads are imposed that simulate the interaction of the analyzed part of the granular material with the environment.

2. IDENTIFICATION OF THE BOUNDARY LAYER

In order to include entire model in analysis of boundary layer we must first find the most left particle, then we continued counter-clockwise searching for next boundary particle, until we reach the beginning of the boundary layer (most left particle). We used two methods to search for next boundary particle:

- The most right method
- Smallest deviation angle method

In both methods we have previous particle p_1 , current particle p_2 and we search all particles connected to particle p_2 for the best candidate for the next particle p_3 . Both methods compare angles in order to find proper next particle.

In the most right method, vector between current and previous particle is defined with $\vec{r}_1 = (x_2 - x_1, y_2 - y_1)$, while $\vec{r}_2 = (x_3 - x_2, y_3 - y_2)$ is calculated for every possible next particle, like it is illustrated in Figure 1.

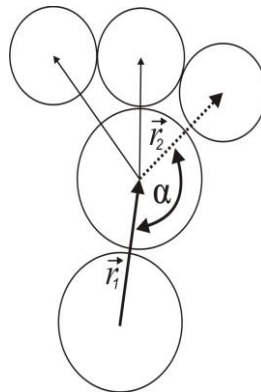


Figure 1. Identification of the next boundary particle using the most right method

Using dot product of vectors $\vec{r}_1 \cdot \vec{r}_2 = |\vec{r}_1| \cdot |\vec{r}_2| \cos \alpha$ we can calculate cosine of angle between vectors using equation (1)

$$\cos \alpha = \frac{(x_2 - x_1)(x_3 - x_2) + (y_2 - y_1)(y_3 - y_2)}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \cdot \sqrt{(x_3 - x_2)^2 + (y_3 - y_2)^2}} \quad (1)$$

From equation (1) we can obtain angle using arc cosine function and search all contacts for minimum angle (most right particle) but since arc cosine is very expensive mathematical operation, we can avoid using it and search for maximum cosine (which would yield minimum angle). In order to account all possible cases for positions of particles the following if condition is formulated, using equation (2)

$$\begin{aligned} \text{if } (((x_2 - x_1)(y_3 - y_2) - (y_2 - y_1)(x_3 - x_2)) > 0) \text{ then } \cos \alpha &= \cos \alpha - 2 \\ \text{else } \cos \alpha &= -\cos \alpha \end{aligned} \quad (2)$$

The smallest deviation angle method aims to keep boundary as straight as possible which could lead to some particles remain outside of the boundary, but the boundary has more regular particle arrangement. This method is illustrated in Figure 2.

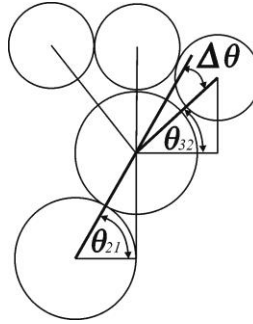


Figure 2. Identification of the next boundary particle using the smallest deviation method

Excluded particles can be moved by another routine to more appropriate position and are included in the next boundary search. Angles between vectors and x axis is defined by equations (3) and (4).

$$\theta_{21} = \arctan \frac{y_1 - y_2}{x_1 - x_2} \quad (3)$$

$$\theta_{32} = \arctan \frac{y_3 - y_2}{x_3 - x_2} \quad (4)$$

Difference between these angles is the value that we seek to minimize, as given in equation (5)

$$\Delta \theta = \theta_{23} - \theta_{21} \quad (5)$$

Efficiency of both methods depends on several factors such as distance tolerance for determination of neighboring particles. A situation that arises if this parameter is not defined appropriately is shown in Figure 3.

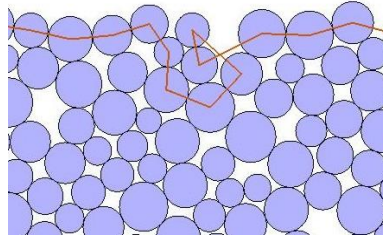


Figure 3. *Selection of wrong boundary particle due to large distance between particles*

Another problem that may occur due to large displacements of particles and that may cause failure of boundary routines is formation of groups of particles that dangle on the sides of the model, Figure 4.

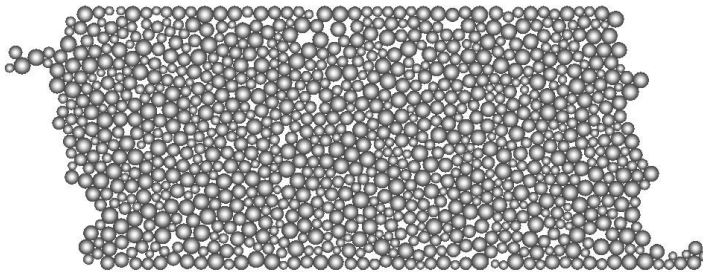


Figure 4. *Formation of groups of dangling particles*

3. APPLICATION OF WEAK PERIODIC CONDITION IN DEM

In order to reduce irregular arrangement of boundary particles which could cause failure of both methods for boundary identification, weak periodic boundary condition is implemented. Classical periodic boundary condition is not applicable to DEM method, because DEM particles have arbitrary radius so that moving certain particle from one side to another could lead to significant overlapping of particles if particular particle has greater radius than there is void space available on the other side. Weak boundary condition only transfers force from one boundary to the other, while particles remain part of their respective boundaries. Force that needs to be transferred to certain particle k can be calculated as partial derivate of work given by equation (6)

$$F_k = \frac{\partial W}{\partial v_k} \quad (6)$$

where v_k is horizontal velocity of particle k . If we observe certain boundary particle k we can see that it is connected to particles $k-1$ and $k+1$, while on the other side at the same height there is boundary line that connects particles m and $m+1$, as illustrated in Figure 5.



Figure 5. Particles in boundary layer

Considering all particles on the left and right side, work on the boundary is given with equation (7)

$$W = \sum_L \frac{1}{2} K (v^L - \tilde{v}^D)^2 + \sum_D \frac{1}{2} K (v^D - \tilde{v}^L)^2 \quad (7)$$

where L is the number of particles on the left side while D is the number of particles on the right side. K is the coefficient that depends on average particle mass. Velocity of the real particle on the left side is given with v^L while \tilde{v}^D represents interpolated velocity on the right boundary line. The same notation applies for velocities on the right boundary. Solving partial differential equation (6) for work calculated using equation (7) gives us the force that needs to be applied on particle k , which is calculated using equation (8).

$$F_k = \frac{\partial W}{\partial v_k} = K \left[\begin{aligned} &v_k^L - v_{m+1}^D \frac{y_k^L - y_m^D}{y_{m+1}^D - y_m^D} + v_m^D \frac{y_k^L - y_{m+1}^D}{y_{m+1}^D - y_m^D} - \\ &v_m^D \frac{y_m^D - y_{k+1}^L}{y_k^L - y_{k+1}^L} + v_k^L \left(\frac{y_m^D - y_{k+1}^L}{y_k^L - y_{k+1}^L} \right)^2 - v_{k+1}^L \frac{y_m^D - y_{k+1}^L}{y_k^L - y_{k+1}^L} \frac{y_m^D - y_k^L}{y_k^L - y_{k+1}^L} + \\ &v_{m+1}^D \frac{y_{m+1}^D - y_{k-1}^L}{y_{k-1}^L - y_k^L} + v_k^L \left(\frac{y_{m+1}^D - y_{k-1}^L}{y_{k-1}^L - y_k^L} \right)^2 - v_{k-1}^L \frac{y_{m+1}^D - y_k^L}{y_{k-1}^L - y_k^L} \frac{y_{m+1}^D - y_{k-1}^L}{y_{k-1}^L - y_k^L} \end{aligned} \right] \quad (8)$$

4. RESULTS

Two methods for boundary identification are implemented in DEM code and used in analysis of shear bands in granular material. In order to prevent large deformations of the boundary and irregular arrangement of particles weak periodic boundary condition is implemented. Figure 6a shows the model with boundary layer used to impose velocities on top and bottom particles, with weak periodic condition applied on left and right side. Figure 6b shows the formation of vortices in modeled problem.

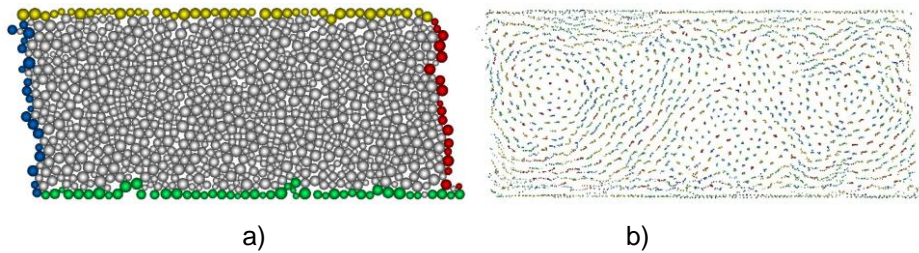


Figure 6. Analysis of granular material shear process a) model with boundary
b) vortex formation in model

5. CONCLUSION

Both analyzed methods are very accurate in identification of boundary particles, but also, they both have limitations which could be exceeded if deformation of model becomes too large and arrangement of particles too irregular. In some distorted particle configurations the first method was able to successfully identify whole boundary while the second method failed, but in some other configurations the first method failed and the second method succeeded. These methods could complement each other, with one method chosen to be primary and used by default, and if it fails to identify the whole boundary the other (secondary) method could be called in to attempt to complete the task. Weak periodic boundary condition virtually connects right and left boundary of the model creating impression of continuity. Using these routines, behavior of granular material in shear band can be successfully modeled and formation of vortices can be observed.

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