

**University of Niš
Faculty of Mechanical Engineering**



**THE INTERNATIONAL CONFERENCE
Mechanical Engineering
in XXI Century**

PROCEEDINGS

Niš, Serbia, 25 - 26 November 2010.



**UNIVERSITY OF NIŠ
FACULTY OF MECHANICAL ENGINEERING**



**THE INTERNATIONAL CONFERENCE
MECHANICAL ENGINEERING IN XXI CENTURY**

PROCEEDINGS

25 – 26 November 2010, Niš, Serbia

ORGANIZERS

UNIVERSITY OF NIŠ
FACULTY OF MECHANICAL ENGINEERING

WITH SUPPORT OF:

Ministry of Science and Technological Development

Chairman of the International conference

Prof. dr Vlastimir NIKOLIĆ, Dean
Faculty of Mechanical Engineering, Niš

SCIENTIFIC COMMITTEE

Dečan Ivanović, PhD, Faculty of Mechanical Engineering, University of Montenegro
Dragiša Nikodijević, PhD, Faculty of Mechanical Engineering, University of Niš, Serbia, president
Dušan Golubović, PhD, Faculty of Mechanical Engineering, University of East Sarajevo, Bosnia and Herzegovina
Emil Nikolov, PhD, Technical University of Sofia, Bulgaria
Goran Radenković, PhD, Faculty of Mechanical Engineering, University of Niš, Serbia
Karl Kuzman, PhD, Faculty of Mechanical Engineering, University of Ljubljana, Slovenia
Lena Zentner, PhD, Technical University Ilmenau, Germany
Ljiljana Petković, PhD, Faculty of Mechanical Engineering, University of Niš, Serbia
Miroslav Radovanović, PhD, Faculty of Mechanical Engineering, University of Niš, Serbia
Miroslav Trajanović, PhD, Faculty of Mechanical Engineering, University of Niš, Serbia
Mladen Stojiljković, PhD, Faculty of Mechanical Engineering, University of Niš, Serbia
Nenad Gubelj, PhD, Faculty of Mechanical Engineering, University of Maribor, Slovenija
Nenad D. Pavlović, PhD, Faculty of Mechanical Engineering, University of Niš, Serbia
Noam Lior, PhD, University of Pennsylvania, USA
Petar Stankov, PhD, Technical University of Sofia, Bulgaria
Predrag Kozić, PhD, Faculty of Mechanical Engineering, University of Niš, Serbia
Predrag Rajković, PhD, Faculty of Mechanical Engineering, University of Niš, Serbia
Sava Ianici, PhD, Faculty of Engineering, University "Eftimie Murgu" Resita, Romania
Slobodan Vukićević, PhD, Faculty of Philosophy, University of Montenegro
Valentin Nedeff, PhD, Rector of Faculty of Engineering, University of Bacău, Romania
Vojislav Miltenović, PhD, Faculty of Mechanical Engineering, University of Niš, Serbia
Zoran Marinković, PhD, Faculty of Mechanical Engineering, University of Niš, Serbia

ORGANIZING COMMITTEE

Dragan Milčić, PhD, associate professor, president
Dušan Stamenković, PhD, associate professor
Melanija Mitrović, PhD, associate professor
Žarko Čojbašić, PhD, associate professor
Ljiljana Radović, PhD, assistant professor
Miloš Jovanović, PhD, assistant professor
Mirjana Laković, PhD, teaching assistant
Goran Janevski, PhD, teaching assistant
Jelena Milovanović, MSc, teaching assistant
Dragan S. Jovanović, teaching assistant

Publisher:

Faculty of Mechanical Engineering
Prof. dr Vlastimir Nikolić, Dean

Editor:

Prof. dr Dragan Milčić

Technical preparation:

Jelena Milovanović, MSc, teaching assistant
Dragan S. Jovanović, teaching assistant

Design & Prepress:

Saša Đorđević, computer operator

Number of copies:

300

Printing:

"Unigraf"

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

621(082)
621:004(082)
531/534(082)
174:621(082)
007.52(082)

#The #INTERNATIONAL Conference Mechanical
Engineering in XXI Century (2010 ; Niš)
Proceedings / The International Conference
Mechanical Engineering in XXI Century, 25 -
26 November, Niš, SERBIA ; [organized by
University of Niš, Faculty of Mechanical
Engineering]. - Niš : Faculty of Mechanical
Engineering, 2010 (Niš : Unigraf). - VI, 328
str. : ilustr. ; 30 cm

Tiraž 300. - Napomene uz tekst. -
Bibliografija uz svaki rad. - Registar.

ISBN 978-86-6055-008-0
1. Faculty of Mechanical Engineering (Niš)
a) Машинство - Зборници b) Машинство -
Рачунарска технологија - Зборници c)
Инжењерска етика - Зборници d) Роботика -
Зборници
COBISS.SR-ID 179681036

TABLE OF CONTENTS

APPLIED MATHEMATICS

VARIOUS ALMOST ORTHOGONAL POLYNOMIAL SEQUENCES AND THEIR APPLICATIONS

Bratislav DANKOVIĆ, Predrag RAJKOVIĆ, Miomir STANKOVIĆ, Slađana MARINKOVIĆ3

ON SOME MULTI-STEP ITERATIVE METHODS FOR SOLVING NONLINEAR EQUATIONS

Ljiljana PETKOVIĆ7

THE TILING AND MATCHING INTERPRETATIONS OF CLASSICAL ORTHOGONAL POLYNOMIALS

Predrag RAJKOVIĆ, Slađana MARINKOVIĆ, Nataša SAVIĆ,11

THEORETICAL AND APPLIED MECHANICS

MODELS OF HYBRID MULTI-PLATE SYSTEMS DYNAMICS

Katica (STEVANOVIĆ) HEDRIH, Julijana SIMONOVIĆ17

STABILITY OF A PLATE WITH LONGITUDINAL CONSTRUCTIVE DISCONTINUITY WITH ONE FREE EDGE

Ratko PAVLOVIĆ, Snežana MITIĆ21

BUCKLING OF A SIMPLY SUPPORTED STEPPED PLATE

Snežana MITIĆ25

THE STOCHASTIC STABILITY OF A TIMOSHENKO BEAM UNDER REAL-NOISE EXCITATION

Goran JANEVSKI, Predrag KOZIĆ, Ratko PAVLOVIĆ29

INFLUENCE OF ROTARY INERTIA ON VIBRATION AND BUCKLING OF A DOUBLE BEAM SYSTEM UNDER COMPRESSIVE AXIAL LOADING

Vladimir STOJANOVIĆ, Predrag KOZIĆ, Goran JANEVSKI33

OPTIMAL RHEOLOGICAL MODEL PARAMETER SETTING FOR VISCOELASTICAL ELEMENTS

Ivan PAVLOVIĆ, Ivan ĆIRIĆ, Petar ĐEKIĆ37

ENERGETICS AND PROCESS ENGINEERING

POSSIBILITIES OF MATHEMATICAL MODELING OF HEAT BALANCE IN A SEQUENCING BATCH REACTOR BASIN USED FOR DOMESTIC WASTEWATER TREATMENT WITH LOW FLOW

Narcis BARSAN, Valentin NEDEFF, Gabriel LAZAR43

NUMERICAL AND EXPERIMENTAL STUDY ON AIR JET SYSTEMS APPLIED IN AIR SUPPLY DEVICES Peter STANKOV, Iskra SIMOVA	47
THERMAL TRANSMISSION THROUGH TEXTILE AND CLOTHING SYSTEMS Radostina A. ANGELOVA	51
HYPERBOLIC COOLING TOWER'S FILLINGS Dušan GOLUBOVIĆ, Dušica GOLUBOVIĆ	55
ANALYSIS OF ADDITIONAL CONDITIONS FOR PLACEMENT OF GAS APPLIANCE OF TYPE A Dušan UZELAC, Marko ĐURĐEVIĆ, Siniša BIKIĆ	59
APPLICATION OF MODEL ANALYSIS FOR STUDING Dragoljub ŽIVKOVIĆ	63
INFLUENCE OF GEOMETRY AND FLOW PARAMETERS ON CHARACTERISTICS OF AIR TO AIR HEAT RECOVERY UNITS Branislav STOJANOVIĆ, Jelena JANEVSKI, Mladen STOJILJKOVIĆ, Marko IGNJATOVIĆ	67
EFFECT OF BAFFLES ON HEAT TRANSFER INTENSITY IN SHELL AND TUBE HEAT EXCHANGER Mića VUKIĆ, Gradimir ILIĆ, Predrag ŽIVKOVIĆ, Goran VUČKOVIĆ, Ivan STOJANOVIĆ	71
WIND ENERGY IN SERBIA Predrag ŽIVKOVIĆ, Gradimir ILIĆ, Mladen TOMIĆ, Mića VUKIĆ	75
DEVELOPMENT TRENDS OF VEHICLES AND ENGINES FROM THE ASPECT OF ECONOMY, LEGAL RESTRICTIONS AND MARKET OPPORTUNITIES AS WELL AS CURRENT TRANSITION PROBLEMS Aleksandar STEFANOVIĆ, Boban NIKOLIĆ	79
APPROXIMATIONS IMPACT OF GENERALIZED SIMILARITY INCOMPRESSIBLE BOUNDARY LAYER EQUATION ON VELOCITY AND SHEAR STRESS DISTRIBUTIONS FOR UNSTEADY FLOW AROUND CIRCULAR CYLINDER Dečan IVANOVIĆ, Vladan IVANOVIĆ	83
AXISYMMETRICAL IONIZED GAS BOUNDARY LAYER IN THE CASE OF VARIABLE ELECTROCONDUCTIVITY Branko OBROVIĆ, Slobodan SAVIĆ	87
GENERALIZED SIMILARITY METHOD IN THEORY OF UNSTEADY MHD BOUNDARY LAYER WITH UNIVERSAL EQUATIONS IN DIFFERENTIAL FORM Zoran BORIČIĆ, Dragiša NIKODIJEVIĆ, Dragica MILENKOVIĆ, Živojin STAMENKOVIĆ	91
MULTIPARAMETRIC METHOD FOR THE CASE OF UNSTEADY TEMPERATURE MHD BOUNDARY LAYER OF INCOMPRESSIBLE FLUID WITH VARIABLE ELECTROCONDUCTIVITY Dragan ŽIVKOVIĆ, Miloš JOVANOVIĆ, Miloš KOCIĆ, Jelena NIKODIJEVIĆ	95
DESIGNING OF LOW PRESSURE AXIAL FLOW FANS WITH DIFFERENT SPECIFIC WORK OF ELEMENTARY STAGES Božidar BOGDANOVIĆ, Jasmina BOGDANOVIĆ-JOVANOVIĆ, Živan SPASIĆ	99
NUMERICAL AND EXPERIMENTAL RESULTS OF FLUID VELOCITY FIELD AROUND A SMOOTH SPHERE USING DIFFERENT TURBULENCE MODELS Jasmina BOGDANOVIĆ-JOVANOVIĆ, Živojin STAMENKOVIĆ, Božidar BOGDANOVIĆ	103
VORTICITY EVOLUTION IN PERTURBED POISEUILLE FLOW Miloš JOVANOVIĆ, Jelena NIKODIJEVIĆ	107

MACHINE CONSTRUCTIONS, DEVELOPMENT AND ENGINEERING

PRODUCT DESIGN AS THE KEY FACTOR FOR DEVELOPMENT IN MECHANICAL ENGINEERING

Siniša KUZMANOVIĆ, Miroslav VEREŠ, Milan RACKOV 113

VIRTUAL PRODUCT DEVELOPMENT ON VENTURI PUMP

Sava IANICI, Milan BANIĆ, Aleksandar MILTENOVIĆ 117

KNOWLEDGE TRANSFER – AN EXAMPLE OF STUDENT'S PRACTICE WORK

Biljana MARKOVIC 121

CONCEPTUAL SOLUTION FOR PURIFYING INDUSTRIAL WASTE WATER USING “TRIZ” METHODOLOGY

Vojislav MILTENOVIĆ, Miloš KOCIĆ, Milan ĐORĐEVIĆ, Jovana MILENKOVIĆ 125

AUTOMATISATION OF BELTED POWER TRANSMISSION'S DESIGN PROCESS

Dragan MILČIĆ, Marko NIKOLIĆ, Miroslav MIJALLOVIĆ 129

AN APPLICATION OF MULTICRITERIA OPTIMIZATION TO PLANETARY GEAR TRANSMISSIONS

Jelena STEFANOVIĆ-MARINOVIĆ, Miloš MILOVANČEVIĆ 133

STUDY OF THE GEOMETRY OF RACK TRAIN OF A SHEARER LOADER'S HAULAGE SYSTEM

Viktor IVANOV, Dimitar KARAIVANOV, Ivan CHUMACHENKO 137

ON THE DETERMINATION OF EXTERNAL LOAD DURING THE LOAD CAPACITY CALCULATIONS OF GEAR TRAINS

Dimitar KARAIVANOV, Ralitsa PAVLOVA 141

THE RESEARCH OF DYNAMIC BEHAVIOR OF ROLLING ELEMENT BEARING

Radoslav TOMOVIĆ 145

EHD LUBRICATION OF JOURNAL BEARINGS WITH ROUGH SURFACES

Juliana JAVOROVA 149

EMBEDDED SYSTEMS IN VIBRATION MONITORING

Miloš MILOVANČEVIĆ, Aleksandar VEG, Jelena STEFANOVIĆ-MARINOVIĆ 153

EXPERIMENTAL INVESTIGATION OF RAILWAY VEHICLES DYNAMIC CHARACTERISTICS

Dušan STAMENKOVIĆ, Miloš MILOŠEVIĆ, Slobodan JOVANOVIĆ,
Milan BANIĆ, Dragan JOVANOVIĆ 157

INFORMATION PRODUCTION TECHNOLOGIES AND INDUSTRIAL MANAGEMENT

ANALYSIS OF INTERACTION BETWEEN RESIDUAL STRESSES AND SPRINGBACK IN THE CASE OF IN PLANE COLD FORMING OF STEEL SHEETS

Gheorghe BRABIE, Neculai NANU 163

ELASTIC DEFLECTION OF THE CYLINDRICAL WORKPIECES DURING TURNING

Laurențiu SLĂTINEANU, Margareta COTEAȚĂ, Oana DODUN, Irina GRIGORAȘ 167

GRAPHICAL-ANALYTICAL METHOD FOR DETERMINING THE OPTIMAL CUTTING PARAMETERS

Miroslav RADOVANOVIĆ, Velibor MARINKOVIĆ 171

DIGITAL MANUFACTURING – STATE OF THE ART AND FUTURE DEVELOPMENT Vidosav D. MAJSTOROVIĆ	175
SEMANTIC FEATURES IN COMPUTER AIDED MANUFACTURING SYSTEMS Miodrag MANIĆ, Miloš STOJKOVIĆ, Milan TRIFUNOVIĆ	179
MODELLING OF MANUFACTURING PROCESSES USING COLOURED PETRI NETS Milorad RANČIĆ, Miodrag STOJILJKOVIĆ, Vladislav BLAGOJEVIĆ	183
THE ABILITY TO PROCESS MODERN MATERIALS BY ABRASIVE WATER JET CUTTING Predrag JANKOVIĆ, Miroslav RADOVANOVIĆ, Goran RADENKOVIĆ	187
WELDING SIMULATION MODELS Miomir VUKIĆEVIĆ, Mišo BJELIĆ	191
TRIBOLOGICAL ANALYSIS OF CONTACT BETWEEN WELDING TOOL AND BASE METAL AS FUNCTION OF HEAT GENERATION WITHIN FSW PROCESS Miroslav MIJAJLOVIĆ, Miroslav ĐURĐANOVIĆ, Dragan MILČIĆ,	195
ANALYSIS OF MEASURING DEVICES AND MEASUREMENT SYSTEMS Iliya ZHELEZAROV	199
THE PARAMETRIC MODELING OF HUMAN VERTEBRA GEOMETRY Janko D. JOVANOVIĆ, Miomir Lj. JOVANOVIĆ	201
BONE MODELLING FOR STRUCTURAL ANALYSIS USING FEM Nikola KORUNOVIĆ, Miroslav TRAJANOVIĆ, Jelena MILOVANOVIĆ, Miloš STOJKOVIĆ, Nikola VITKOVIĆ	205
THE ADAPTIVE FEM METHOD TO STRESS AND STRAIN FOLLOWING AT FORWARD EXTRUSION HOLLOW ELEMENTS Dejan LAZAREVIĆ, Milan LAZAREVIĆ, Saša RANDJELOVIĆ	209
POSSIBILYTY OF APPLICATIO OF RUBBER POWDER AT NR/SBR MIXTURE Dragan TEMELJKOVSKI, Petar ĐEKIĆ, Bojan RANČIĆ, Stojanče NUSEV	213
FEM ANALYSIS OF INFLUENCE DAMAGE’S SHAPE OF SAMPLES FOR SCC TESTS TO STRESS STATION OF THE SAMPLES Dusan Lj. PETKOVIĆ, Goran M. RADENKOVIĆ	217
STRESS ANALYSIS OF THE HIGH-STRENGTH LOW-ALLOYED STEEL SUBMITTED TO VARIABLE LOAD Ivica ČAMAGIĆ, Slavica CVETKOVIĆ, Zijah BURZIĆ, Predrag ŽIVKOVIĆ	221
IMPROVEMENT OF PLASTIC COATING AND SHEET METAL TREATMENT PROCESS IN THE COMPANY „INTERLEMIND“A.D. LESKOVAC Peđa MILOSAVLJEVIĆ, Andrija MILOJEVIĆ, Dijana KRSTIĆ	225
 MECHATRONICS AND CONTROL	
DAS ERSTE JAHRZEHNT DER PARALLELROBOTERTECNIK AM IGM IN AACHEN Ivan IVANOV, Martin RIEDEL, Martin WAHLE, Burkhard CORVES	231
A NEW SOLUTION OF THE MULTIFUNCTIONAL HOSPITAL BED Nenad D. PAVLOVIĆ, Tomislav PETROVIĆ, Nenad T. PAVLOVIĆ, Miloš MILOŠEVIĆ, Slobodan JOVANOVIĆ, Dragan JOVANOVIĆ, Biljana ĐORDJEVIĆ	235

NEWLY DEVELOPED PRINCIPLES AND MECHANISMS FOR MOTION TRANSFORMATION Tomislav PETROVIĆ, Ivan IVANOV, Dušan MIHAJLOVIĆ.....	239
AN APPROACH TO COMPLIANT MECHANISMS WITH PARTICULAR EFFECTS Lena ZENTNER, Valter BÖHM.....	243
OPTIMAL SELECTION OF THE COMPLIANT MECHANISM SYNTHESIS METHOD Nenad D. PAVLOVIĆ, Dalibor PETKOVIĆ, Nenad T. PAVLOVIĆ.....	247
ARTIFICIAL IMMUNE SYSTEMS ENGINEERING IN MANUFACTURING Dragan DJURDJANOVIC.....	251
INTELLIGENT DECISION MAKING IN THE SYSTEM OF REMOTE CONTROL AND MONITORING OF THE WASTEWATER TREATMENT PLANT Vlastimir NIKOLIĆ, Žarko ČOJBAŠIĆ, Ivan ĆIRIĆ, Emina PETROVIĆ.....	255
APPLICATION OF AUTOMATIC MEASURING SYSTEM FOR ONLINE ANALYSIS OF PHYSICAL AND CHEMICAL CHARACTERISTICS OF DRINKING WATER Vlastimir NIKOLIĆ, Žarko ČOJBAŠIĆ, Ivan RANĐELOVIĆ, Emina PETROVIĆ.....	259
RELIABLE MODEL DEVELOPMENT FOR CONTROLLER DESIGN OF SMART STRUCTURES AND SYSTEMS Tamara NESTOROVIC, Miroslav TRAJKOV.....	263
FRICITION AND LUBRICATION AT THE ATOMIC LEVEL Jelena MANOJLOVIĆ.....	267
 TRAFFIC ENGINEERING, TRANSPORT AND LOGISTICS	
ADVANCES IN FEM-FORMULATIONS FOR EFFECTIVE COMPUTATION OF GEOMETRICALLY NONLINEAR DEFORMATIONS Dragan MARINKOVIĆ, Zoran MARINKOVIĆ, Goran PETROVIĆ.....	273
SEISMIC ANALYSIS AT TOWER CRANES Miomir JOVANOVIĆ, Goran RADOIČIĆ, Predrag MILIĆ.....	277
ANALYSIS OF THE ENERGY PARAMETERS OF HYDRAULIC EXCAVATOR METHOD OF DYNAMIC SIMULATION Dragoslav JANOŠEVIĆ, Boban ANĐELKOVIĆ, Nikola PETROVIĆ, Vesna NIKOLIĆ.....	281
VARIANT STORAGE DESIGN Zoran MARINKOVIĆ, Dragan MARINKOVIĆ, Danijel MARKOVIĆ, Predrag MILIĆ, Vojislav TOMIĆ.....	285
 PROFESSIONAL ENGINEERING ETHICS	
ENGINEERING ETHICS Jovan BABIĆ.....	291
THREE TRADITIONS OF NORMATIVE ETHICS: THE IMPORTANCE TO BUSINESS AND ENGINEERING ETHICS Milovan VUKOVIĆ.....	293
PROFESSIONAL ETHICS OF ENGINEERING IN CONTEMPORARY BUSINESS Jelena MANIĆ.....	297

THE SKILL OF TECHNIQUES AND THE PROFESSIONAL ETHICS OF ENGINEER Božo MILOŠEVIĆ	301
WORKPLACE AND PROFESSIONAL ETHICS OF ENGINEERS Slobodan VUKIĆEVIĆ	305
PROFESSIONAL ETHICS AND THE SPIRIT OF GLOBALIZATION Bogdan ĐUROVIĆ.....	309
PROFESSIONAL ETHICS AS BASIS FOR THE INTEGRATION OF KNOWLEDGE SOCIETY Danijela GAVRILOVIC	313
ETHICAL DIMENSIONS OF TECHNICAL KNOWLEDGE Radoš RADIVOJEVIĆ, Alpar LOŠONC	315
ENGINEERING ETHICS AND ECOLOGICAL SAFETY Vesna MILTOJEVIĆ.....	319
THE AMERICAN AND SERBIAN CODES OF ETHICS FOR ENGINEERS: A COMPARISON Dragoljub B. ĐORĐEVIĆ, Miloš TASIĆ	321
PROFESSIONAL ETHICS OF DOCTORS Dragan TODOROVIĆ	325
INDEX OF AUTHORS	327

Machine constructions, development and engineering

Information-production technologies and industrial management



TRIBOLOGICAL ANALYSIS OF CONTACT BETWEEN WELDING TOOL AND BASE METAL AS FUNCTION OF HEAT GENERATION WITHIN FSW PROCESS

Miroslav MIJAJLOVIĆ, Miroslav ĐURĐANOVIĆ, Dragan MILČIĆ,

Đorđe STAMENKOVIĆ, Bojan ANĐELKOVIĆ

Faculty of Mechanical Engineering, University of Nis, Aleksandra Medvedeva 14, Nis, Serbia

miroslav_mijajlovic@masfak.ni.ac.rs, djurdjan@junis.ni.ac.rs, milcic@masfak.ni.ac.rs, dusans@masfak.ni.ac.rs, bandjel@masfak.ni.ac.rs

Abstract: Friction Stir Welding – FSW is relatively new and still not completely theoretically described welding process. Parameters involved in weld creation during FSW are numerous. Quality of the weld, beside other parameters, directly is dependable from the amount of the generated heat and stirring of the base metal. Developed mathematical models describe plain FSW process with significant precision, but they include numerous approximations and assumptions in order to overcome lack of understanding of tribological aspects of FSW – friction coefficient on the contact of welding tool and base metal, adhesion, cohesion, contact pressure, wearing etc.

Key words: tribology, friction stir welding, heat generation

1. INTRODUCTION

Friction Stir Welding (FSW) is exclusively used for welding sheet parts and represents the typical example of indirect friction heat generation usage. FSW is patented in 1991 and during 1992 the industrial application of the process has started. Basic principle and scheme of the process is given in the Fig. 1. Welding pieces (1) and (2) are fixed above the backing plate (3) and positioned one to another along the joint line (7). Heat generation and welding is achieved with special cylindrical welding tool that consists of a shoulder (4) and a threaded probe (5). Shoulder has greater diameter than a probe and probe is mostly left threaded. Contact surface between shoulder and a probe is flat or cone surface called shoulder tip (6).

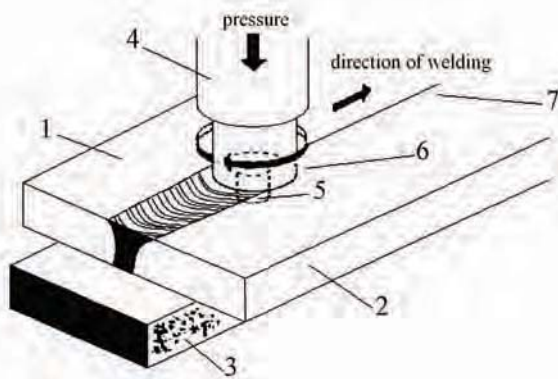


Fig. 1: Principle of the FSW: 1 and 2-weld pieces 3-postolja 4-shoulder 5-probe 6-shoulder tip 7-weld joint line

At the beginning of the welding process, welding tool is mounted above the backing plate and welding pieces and its main axis is perpendicular with the joint line (7). In

that position welding tool starts to rotate and translator movement down. Weld probe (5) plunges into both of the welding plates in a start point on the joint line, friction between probe and the welding plates initiates heat generation, welding plates soften and thread on a probe stirs the material of the welding plates constantly. When shoulder tip (6) touches the welding plates, and probe tip is very close to the backing plate, translator movement of the tool down stops and tool starts transversal (horizontal) movement along the joint line. Moving along the joint line, weld tool's probe heats new layers of the welding pieces, stirs them, and creates a layer of mixed and plasticized metal which softens and creates monolith connection between welding pieces – weld. Shoulder tip (6) confines upper surface of the weld and backing plate (3) does the same to the lower surface of the weld. Welding process is finished with end of translation of the welding tool and pulling out from the weld pieces.

Very important kinematical characteristic of the FSW is that welding tool always has main rotational movement and in most of the cases it has both translator auxiliary movements. Analyzing the kinematics, in order to analyze the process easily, complete technological cycle of the FSW can be separated into five basic phases (Fig. 2).

Heat generated during FSW is a product of two mutually dependable physical processes:

- Active surfaces of the welding tool slide over base metal
- Base metal around the welding tool is deformed.

During all phases of the FSW, welding tool and base metal have mutual contact over at least one active surface of the welding tool [4]. Active surface of the welding tool is area on welding tool directly involved in welding process.

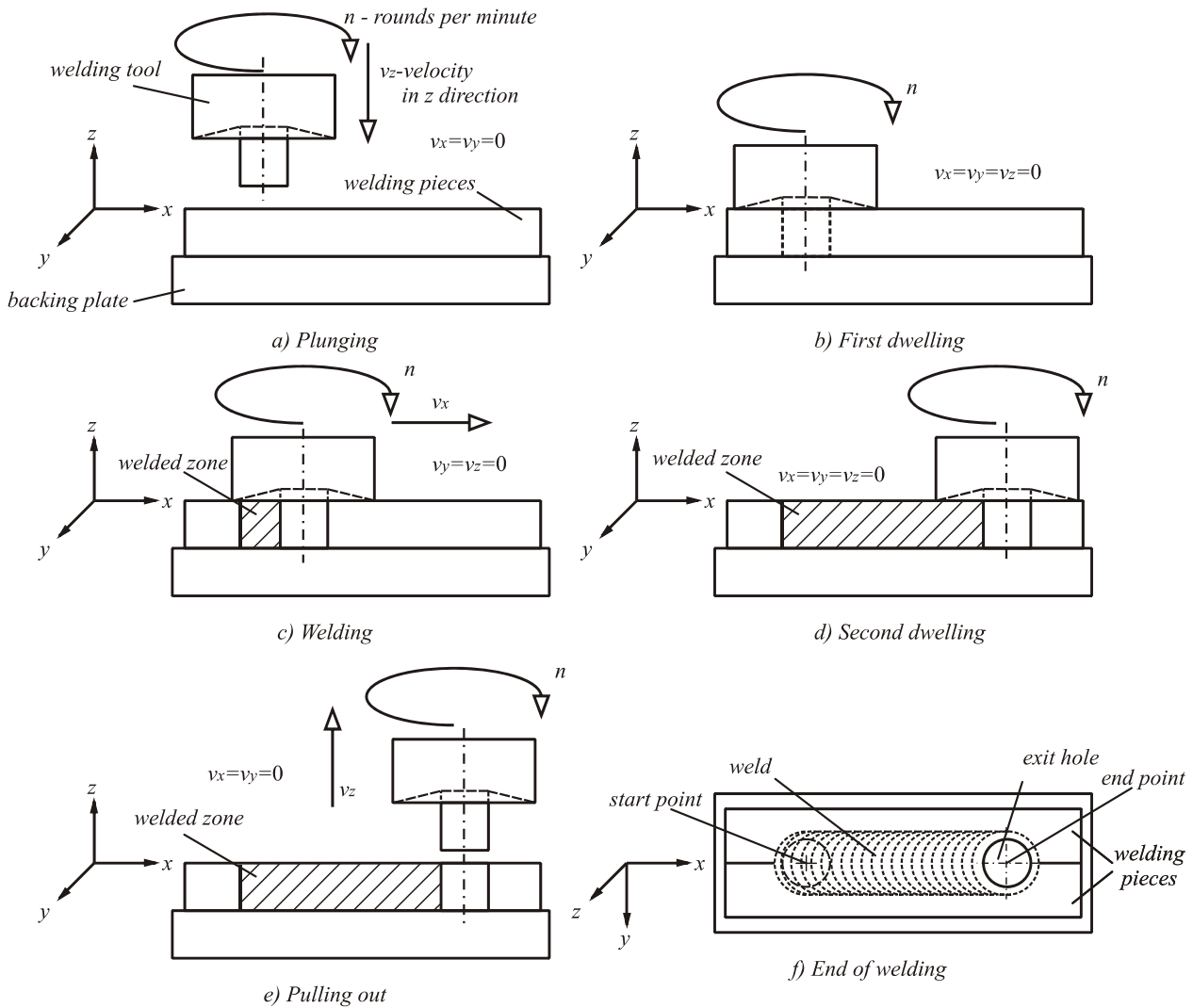


Fig. 2 Phases of the FSW

It influences the base metal on several different ways and makes welding possible. All used welding tools have at least 3 active surfaces: probe tip, probe side and shoulder tip (Fig. 3).

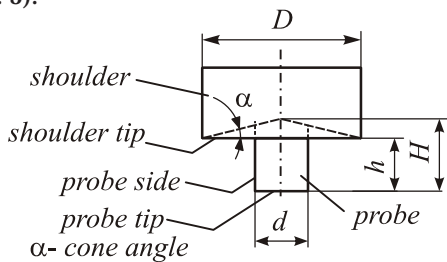


Fig. 3: Basic shape of the friction stir welding tool and basic active surfaces 4 .

Variations and complexity of welding tools make possible to have more than mentioned 3 active surfaces on the welding tool or these surfaces can be slightly greater.

2. SLIDING CONDITION

Active surfaces of the welding tool are significantly harder than any surface of the base metal and material of the welding tool is stronger than base metal. Since contact between any two moving solid bodies inflicts appearance

of new physical (tribological) processes – friction, wear, adhesion etc., [2], rotating and translating welding tool and base metal are in dynamical relationship. Constant sliding among surfaces can be explained over change of energetic status of the welding tool. One part of mechanical energy of the welding tool is transformed into heat on the sliding contacts between active surfaces and base metal. This heat increases the temperature of welding tool and base metal, they soften and change their mechanical properties and contact pressure between them, as well. Contact conditions between welding tool and base metal change and FSW process reaches some other pseudo – steady state.

3. DEFORMATION CONDITION

Besides pure sliding, constantly present physical process in FSW process is deformation. Since welding tool is harder and more wear resistant than base metals, contact between active surfaces and base metal results in constant transition of base metal's particles. Adhesion forces, which appear on contact, chop softened particles of base metal, stir them and move along the path of the welding tool's rotation or translation. This transition of material is called deformation.

Chopped, deformed and moved particles of base metal travel with the tool until they return to the relatively stable state, stick to the base metal again and stop further movement. While being deformed particles transform mechanical energy of the welding tool into the heat and changes mechanical properties of base metal and welding tool, too.

4. REAL TRIBOLOGICAL CONTACT CONDITION




Sliding and deformation appear constantly during tribo – contact between welding tool and base metal. They appear one at a time, both at the same time, one by one etc. It is almost impossible to isolate just one of the processes and explain it partially. Real tribological contact assumes that there is pure sliding contact

condition, pure sticking (deformation) condition and combination of both [3][4].

Active surfaces of the welding tool are not involved in welding all at once or fully during complete welding process. For example, probe tip is involved in welding process only during plunging phase. During all other phases probe tip is minimally or completely not involved in welding process. Probe side is successive involving in welding process during plunging phase and actively is involved in welding during all phases until the end of the pulling out phase. The largest active surface – shoulder tip is involving in welding process at the end of the first plunging phase or at the beginning of the dwelling phase. Shoulder tip has no active contact with the base metal from the end of the welding phase.

Table 1 show (descriptively) when and for how long active surfaces are involved in welding process (during phases of welding).

Table 1 Active surfaces involving in welding and heat generation during phases of FSW

Phase of FSW →	Plunging	First Dwelling	Welding	Second Dwelling	Pulling Out
Active surface ↓					
Probe Tip		...→			
Probe Side	→				
Shoulder Tip		→			

. AMOUNT OF GENERATED HEAT

Generated heat during FSW is a product of physical intercourse between active surfaces and base metal. At the same time generated heat softens base metal and eases the welding process – welding tool easier stirs the base metal and creates weld.

Analyzing contact surfaces, applying the tribological momentum of friction equations [2][3][4], it is easy to get equations capable to calculate heat generated on basic active surfaces – probe tip (Equation 1), probe side (Equation 2) and shoulder tip (Equation 3).

Probe tip:

$$p_t = \frac{2}{3} \cdot \pi \cdot \omega \cdot \tau_{cont} \cdot \left(\frac{d}{2}\right)^3 \quad (1)$$

Probe side:

$$p_s = 2 \cdot \pi \cdot \omega \cdot \tau_{cont} \cdot \left(\frac{d}{2}\right)^2 \cdot h \quad (2)$$

Shoulder tip:

$$p_{st} = \frac{2}{3} \cdot \pi \cdot \omega \cdot \tau_{cont} \cdot \left[\left(\frac{D}{2}\right)^3 - \left(\frac{d}{2}\right)^3 \right] \cdot (1 + \tan \alpha) \quad (3)$$

where:

ω – angular rate of the welding tool $\left[\frac{\text{rad}}{\text{s}} \right]$,

d – diameter of the probe [mm],

D – diameter of the shoulder [mm],

h – height of the welding plates [mm],

α – cone angle [$^\circ$],

τ_{cont} – contact tangent shear stress $\left[\frac{\text{N}}{\text{mm}^2} \right]$.

When analyzing pure sliding, contact tangent shear stress is:

$$\tau_{cont} = \mu \cdot p \quad (4)$$

where:

μ – friction coefficient between welding tool and welding metal [-],

p – contact pressure (normal stress at the contact of welding tool and welding pieces) $\left[\frac{\text{N}}{\text{mm}^2} \right]$.

When analyzing pure sticking, contact tangent shear stress is:

$$\tau_{cont} = \tau \quad (5)$$

where:

τ – tangent shear stress of the softer material (in this case: base metal) $\left[\frac{\text{N}}{\text{mm}^2} \right]$.

. TRIBOLOGICAL PARAMETERS OF THE FSW

Analyzing Equations 1, 2 and 3, it is obvious that tribological parameters involved in heat generation are: friction coefficient (μ), contact pressure (p), tangent shear stress (τ). Analyzing the fact that heat is generated during sliding and sticking, it can be said that other tribological parameters are: adhesion, cohesion, wear, lubrication etc. It is clear that generated heat () is:

$$= f \left(\begin{array}{l} \mu, p, \tau, \text{adhesion, cohesion,} \\ \text{wear, lubrication, ...} \end{array} \right). \quad (6)$$

All of these parameters are present during every phase of FSW, but difficulty is that all of them are in relationship with other parameters:

$$= f \left(\begin{array}{l} \mu(p, \tau, \dots), p(\mu, \tau, \dots), \\ \tau(\mu, p, \dots), \text{adhesion}(\mu, p, \tau, \dots), \\ \text{cohesion}(\mu, p, \tau, \dots), \text{wear}(\mu, p, \tau, \dots), \\ \text{lubrication}(\mu, p, \tau, \dots), \dots \end{array} \right). \quad (7)$$

It is difficult to superpose influence of any tribological parameter and to explain complete process after such a superposition. For example, friction coefficient is having static nature, at the beginning of the FSW, but the moment after, some particles of the base metal are heated, softened, stirred from the matrix and act as lubricant for the welding tool – base metal contact. Friction coefficient becomes kinetic. Fact that friction coefficient changes its nature, deliver different distribution of the contact pressure, what results in stability of the wearing process. Wear of the base metal becomes more intense and stirring (deformation) becomes dominant process. Welding tool increases its temperature as well and cohesive/adhesive forces increase. Softened particles of base metal stick to active surface of welding tool and travel along the joint line.

Example is more than enough to explain how difficult is analysis of the FSW with ambiguity of tribological parameters of the process.

. CONCLUSION

FSW is process relying on heat generating for weld joint creation. Parameters involving proper welded joint creation are just the same parameters involved in heat generation and this amount is directly dependable from the geometrical parameters of the tool, speed – rotational and traversal, pressure, shear stress and friction coefficient.

Determination of precise amount of heat generated during friction stir welding process is complicated since there are various uncertainties, assumptions and simplifications of mathematical model that describes welding process. Various experiments, from the very beginning of the FSW method's application gave dispersive results about the

generated heat. The analytical heat generation estimate correlates with the experimental heat generation, by assuming either a sliding or a sticking condition. For the sliding condition, a friction coefficient that lies in the reasonable range of known metal to metal contact values is used in order to estimate the experimental heat generation. Assuming the sticking condition yield shear stress, which is descriptive for the weld piece material at elevated temperatures, is used to correlate the values.

Main uncertainties about process are when welding condition is mixture of sliding and sticking. In this situation ambiguity of the value of the friction coefficient in every moment of the welding process, contact pressure between weld tool and weld pieces and shear stress are main reasons for difference between analytical and experimental results. Recognizing the nature and changes of these tribological parameters, some might theoretically describe FSW in precise and unique way.

REFERENCES

- [1] T OMAS, WM., NIC OLAS, ED., NEED AM, JC., MURC , MG., TEMPLE-SMIT , P., DAWES, CJ. Friction-stir butt welding, GB Patent No. (1991) 9125978.8, International patent application No. PCT/GB92/02203,
- [2] BOWDEN, F.P., TABOR, D., *Friction – An Introduction to Tribology*, Anchor Press / Doubleday, Reprinted 1982, Krieger Publishing Co., Malabar 1973,
- [3] Schmidt, ., attel, J., Wert, J. (2004) *An analytical model for the heat generation in Friction Stir Welding*, Modeling Simul. Mater. Sci. Eng. 12 No. 1 pp 143-157, PII: S0965-0393(04)69225-4, <http://iopscience.iop.org/0965-0393/12/1/013/>,
- [4] ĐURĐANOVIĆ, M., MIJALLOVIĆ, M., MILČIĆ, D., STAMENKOVIĆ, D. (2009) *eat Generation During Friction Stir Welding Process*, Tribology in Industry 2009, Serbia, Kragujevac, Faculty of Mechanical Engineering Kragujevac, Journal, Vol. 31, No. 1-2, pp 8-14, ISSN 0354-8996, <http://scindeks.nb.rs/article.aspx artid 0351-16420902008D>
- [5] SONG, M., KOVAČEVIĆ, R. *Numerical and e perimental study of the heat transfer process in friction stir welding*, Journal Engineering Manufacture, Vol. 217 Part B.
- [6] SONG, M., KOVAČEVIĆ, R. (2003) Thermal modeling of friction stir welding in a moving coordinate system and its validation. *International ournal of machine Tools Manufacture*, 43, pp 605-615.
- [7] ULYSSE, P. (2002) Three-dimensional modeling of the friction stir-welding process. *International ournal of Machine Tools Manufacture*, Vol. 42, pp 1549-1557
- [8] ARBEGAST, J.W. (2006) Friction stir welding after a decade of development. *Welding ournal*
- [9] STAMENKOVIĆ D, ĐURĐANOVIĆ M, MITIĆ D.: Zavarivanje postupkom FSW (2006) *Zavarivanje i zavarene konstrukcije*, godina LI, No. 2, pp 59–66.

INDE OF AUTHORS

A

Aleksandar MILTENOVIĆ	117
Aleksandar STEFANOVIĆ	79
Aleksandar VEG.....	153
Alpar LOŠONC.....	315
Andrija MILOJEVIĆ.....	225

B

Biljana ĐORDJEVIĆ	235
Biljana MARKOVIĆ.....	121
Boban ANĐELKOVIĆ	195, 281
Boban NIKOLIĆ	79
Bogdan ĐUROVIĆ	309
Bojan RANČIĆ	213
Božidar BOGDANOVIĆ.....	99, 103
Božo MILOŠEVIĆ.....	301
Branislav STOJANOVIĆ	67
Branko OBROVIĆ	87
Bratislav DANKOVIĆ	3
Burkhard CORVES.....	231

D

Dalibor PETKOVIĆ	247
Danijel MARKOVIĆ.....	285
Danijela GAVRILOVIĆ.....	313
Dečan IVANOVIĆ	83
Dejan LAZAREVIĆ.....	209
Dijana KRSTIĆ	225
Dimitar KARAIVANOV.....	137, 141
Dragan DJURDJANOVIĆ	251
Dragan JOVANOVIĆ	157, 235
Dragan MARINKOVIĆ	273, 285
Dragan MILČIĆ	129, 195
Dragan TEMELJKOVSKI	213
Dragan TODOROVIĆ.....	325
Dragan ŽIVKOVIĆ.....	95
Dragica MILENKOVIĆ	91
Dragiša NIKODIJEVIĆ.....	91
Dragoljub B. ĐORĐEVIĆ.....	321
Dragoljub ŽIVKOVIĆ.....	63
Dragoslav JANOŠEVIĆ	281
Dušan GOLUBOVIĆ	55
Dusan Lj. PETKOVIC.....	217
Dušan MI AJLOVIĆ	239
Dušan STAMENKOVIĆ.....	157, 195
Dušan UZELAC	59
Dušica GOLUBOVIĆ	55

E

Emina PETROVIĆ	255, 259
----------------------	----------

G

Gabriel LAZAR.....	43
Gheorghe BRABIE.....	163
Goran JANEVSKI	29, 33
Goran M. RADENKOVIC	217
Goran PETROVIĆ.....	273
Goran RADENKOVIĆ.....	187
Goran RADOIČIĆ.....	277
Goran VUČKOVIĆ	71
Gradimir ILIĆ.....	71, 75

I

Iliya Z ELEZAROV.....	199
Irina GRIGORAŞ	167
Iskra SIMOVA	47
Ivan C UMAC ENKO.....	137
Ivan ĆIRIĆ	37, 255
Ivan IVANOV	231, 239
Ivan PAVLOVIĆ.....	37
Ivan RANĐELOVIĆ	259
Ivan STOJANOVIĆ.....	71
Ivica ČAMAGIĆ	221

J

Janko D. JOVANOVIĆ	201
Jasmina BOGDANOVIĆ-JOVANOVIĆ.....	99, 103
Jelena JANEVSKI	67
Jelena MANIĆ	297
Jelena MANOJLOVIĆ	267
Jelena MILOVANOVIĆ.....	205
Jelena NIKODIJEVIĆ	95, 107
Jelena STEFANOVIĆ-MARINOVIĆ	133, 153
Jovan BABIĆ.....	291
Jovana MILENKOVIĆ	125
Juliana JAVOROVA	149
Julijana SIMONOVIĆ	17

K

Katica (STEVANOVIĆ) EDRI	17
--------------------------------	----

L

Laurențiu SLĂTINEANU.....	167
Lena ZENTNER.....	243
Ljiljana PETKOVIĆ	7

M

Margareta COTEAȚĂ	167
Marko ĐURĐEVIĆ.....	59
Marko IGNJATOVIĆ.....	67
Marko NIKOLIĆ	129
Martin RIEDEL	231

Martin WA LE.....	231
Mića VUKIĆ.....	71, 75
Milan BANIĆ.....	117, 157
Milan ĐORĐEVIĆ.....	125
Milan LAZAREVIĆ.....	209
Milan RACKOV.....	113
Milan TRIFUNOVIĆ.....	179
Milorad RANČIĆ.....	183
Miloš JOVANOVIĆ.....	95, 107
Miloš KOCIĆ.....	95, 125
Miloš MILOŠEVIĆ.....	157, 235
Miloš MILOVANČEVIĆ.....	133, 153
Miloš STOJKOVIĆ.....	179, 205
Miloš TASIĆ.....	321
Milovan VUKOVIĆ.....	293
Miodrag MANIĆ.....	179
Miodrag STOJILJKOVIĆ.....	183
Miomir JOVANOVIĆ.....	277
Miomir Lj. JOVANOVIĆ.....	201
Miomir STANKOVIĆ.....	3
Miomir VUKIČEVIĆ.....	191
Miroslav ĐURĐANOVIĆ.....	195
Miroslav MIJAJLOVIĆ.....	129, 195
Miroslav RADOVANOVIĆ.....	171, 187
Miroslav TRAJANOVIĆ.....	205
Miroslav TRAJKOV.....	263
Miroslav VEREŠ.....	113
Mišo BJELIĆ.....	191
Mladen STOJILJKOVIĆ.....	67
Mladen TOMIĆ.....	75

N

Narcis BARSAN.....	43
Nataša SAVIĆ.....	11
Neculai NANU.....	163
Nenad D. PAVLOVIĆ.....	235, 247
Nenad T. PAVLOVIĆ.....	235, 247
Nikola KORUNOVIĆ.....	205
Nikola PETROVIĆ.....	281
Nikola VITKOVIĆ.....	205

O

Oana DODUN.....	167
-----------------	-----

P

Peđa MILOSAVLJEVIĆ.....	225
Petar ĐEKIĆ.....	37, 213
Peter STANKOV.....	47
Predrag RAJKOVIĆ.....	3, 11
Predrag JANKOVIĆ.....	187
Predrag KOZIĆ.....	29, 33
Predrag MILIĆ.....	277, 285
Predrag ŽIVKOVIĆ.....	71, 75, 221

R

Radoš RADIVOJEVIĆ.....	315
Radoslav TOMOVIĆ.....	145
Radostina A. ANGELOVA.....	51
Ralitsa PAVLOVA.....	141
Ratko PAVLOVIĆ.....	21, 29

S

Saša RANDJELOVIĆ.....	209
Sava IANICI.....	117
Siniša BIKIĆ.....	59
Siniša KUZMANOVIĆ.....	113
Slađana MARINKOVIĆ.....	3, 11
Slavica CVETKOVIĆ.....	221
Slobodan JOVANOVIĆ.....	157, 235
Slobodan SAVIĆ.....	87
Slobodan VUKIČEVIĆ.....	305
Snežana MITIĆ.....	21, 25
Stojanče NUSEV.....	213

T

Tamara NESTOROVIĆ.....	263
Tomislav PETROVIĆ.....	235, 239

V

Valentin NEDEFF.....	43
Valter B M.....	243
Velibor MARINKOVIĆ.....	171
Vesna MILTOJEVIĆ.....	319
Vesna NIKOLIĆ.....	281
Vidosav D. MAJSTOROVIĆ.....	175
Viktor IVANOV.....	137
Vladan IVANOVIĆ.....	83
Vladimir STOJANOVIĆ.....	33
Vladislav BLAGOJEVIĆ.....	183
Vlastimir NIKOLIĆ.....	255, 259
Vojislav MILTENNOVIĆ.....	125
Vojislav TOMIĆ.....	285

Žana STEVANOVIĆ.....	75
Žarko ČOJBAŠIĆ.....	255, 259
Žarko STEVANOVIĆ.....	75
Zijah BURZIĆ.....	221
Živan SPASIĆ.....	99
Živojin STAMENKOVIĆ.....	91, 103
Zoran BORIČIĆ.....	91
Zoran MARINKOVIĆ.....	273, 285

ISBN 978-86-6055-008-0



9 788660 550080