

UNIVERSITY OF NIŠ
FACULTY OF MECHANICAL ENGINEERING IN NIŠ



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PREFACE

More than half a century of tradition, high standards in education of generations of students, modernly equipped classrooms, professional teaching and associate staff, their references and recognisability, position the Faculty of Mechanical Engineering, University of Niš, as the leader in the field of engineering sciences and technological sciences, not only on the territory of the Republic of Serbia, but also in the wider region of the Western Balkans.

The proceedings of the 4th International Conference **MECHANICAL ENGINEERING IN XXI CENTURY** appear in the year when the Faculty of Mechanical Engineering, University of Niš, celebrates its fifty eighth anniversary. The Department of Mechanical Engineering of the Faculty of Engineering in Niš was founded on May 18, 1960, and it developed into the Faculty of Mechanical Engineering of the University of Niš in 1971. The Faculty of Mechanical Engineering grew intensely, thus becoming one of the most renowned scientific and educational institutions in the country.

The mission of the Faculty is to organize and conduct academic study programmes and to develop and perform scientific and professional work in the field of engineering sciences and technology. Its vision is to be recognisable in the European and global academic environment in the areas of mechanical engineering and engineering management.

More than 100 teachers and associates, around 45 members of non-teaching staff, as well as numerous teachers and associates from other faculties and from the industry, are working hard every day to accomplish the mission and vision of the Faculty.

The Faculty of Mechanical Engineering, University of Niš, is accredited in compliance with the Law on Higher Education within the scientific and educational field of engineering sciences and technology. It conducts the academic studies of the first degree – undergraduate studies, the second degree – master academic studies, and the third degree – doctoral studies, within the scientific area of mechanical engineering and engineering management.

The Faculty of Mechanical Engineering is a scientific research institution, in addition to being an educational one. There are 11 international scientific research projects within the framework of FP7, TEMPUS, CEEPUS, DAAD, bilateral and cross-border programmes, as well as 24 national scientific research projects, being implemented at the Faculty this year. The participation of teachers and associates from the Faculty in these projects is of utmost importance for their educational and research work and their further career.

The 4th International Conference **MECHANICAL ENGINEERING IN XXI CENTURY** represents a forum for the presentation of latest results, basic and developmental research and application within the topics of:

- Energetics, Energy Efficiency and Process Engineering,
- Mechanical Design, Development and Engineering,
- Mechatronics and Control,
- Production and Information Technologies,
- Traffic Engineering, Transport and Logistics,
- Theoretical and Applied Mechanics and Mathematics,
- Engineering Management,
- Future of work, engineering and professional ethics in the era of globalization.

The Conference will also host the assembly meeting of Serbian Association for the Promotion of Mechanism and Machine Science (SATO-MM), as well as the meeting of the National Science Board for Mechanical Engineering and Industry Software, will be held.

One hundred and eight papers, whose authors come from 10 countries, are published in these Proceedings. The papers present the research results of numerous projects financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia, as well as the research results within international projects.

The main goal of the Conference is to bring together researchers from scientific and industrial institutions so that they can present and communicate their newest results, create personal contacts, promote research within the area of mechanical engineering, and stimulate the exchange of results and ideas within the fields encompassed by the Conference.

As Dean of the Faculty of Mechanical Engineering in Niš, I am honoured to greet all participants of the Conference and wish them very successful work.

Dean of the Faculty of Mechanical Engineering,
University of Niš

Prof. Dr Nenad T. Pavlović

Niš, April 2018

Table of Contents

PLENARY SESSION

René THESKA, Lena ZENTNER, Thomas FRÖHLICH, Christian WEBER, Eberhard MANSKE, Sebastian LINß, Philipp GRÄSER, Felix HARFENSTELLER, Maximilian DARNIEDER, Michael KÜHNEL State of the Art Precision Motion Systems Based on Compliant Mechanisms	3
Lauri LUOSTARINEN, Heikki HANDROOS Improving Human-Machine-Interface of Remote-Operated Mobile Machinery Using Haptic Feedback.....	9
Tihomir MARSENIĆ, Ivan SAMARDŽIĆ, Dejan MARIĆ, Božo DESPOTOVIĆ Overlay Welding in Production of Corrosion Resistant Waste Incineration Boilers	13
Dalibor PETROVIĆ The Ethics of Employees' Surveillance in the Context of Rapid ICT Development	19

ENERGETICS, ENERGY EFFICIENCY AND PROCESS ENGINEERING

Saša MILANOVIĆ, Miloš JOVANOVIĆ, Vladislav BLAGOJEVIĆ, Boban NIKOLIĆ The Influence of Vertical Forces at Pneumatic Transport of Granular Material in Horizontal Channels of Noncircular Cross Sections Mechanisms	27
Dragoljub ŽIVKOVIĆ, Milena RAJIĆ, Milan BANIĆ, Marko MANČIĆ, Branislav POPOVIĆ The Analysis of Thermo-Mechanical State of Steam Turbine Rotor in Non-Stationary Modes of Operation	33
Marko MANČIĆ, Dragoljub ŽIVKOVIĆ, Milan ĐORĐEVIĆ Optimisation of Polygeneration Systems with Utilization of Renewable Energy Sources	37
Milan ĐORĐEVIĆ, Marko MANČIĆ, Velimir STEFANOVIĆ A Parametric Study on Correlations for Heat Transfer in Helically Coiled Pipes	41
Miloš JOVANOVIĆ, Saša MILANOVIĆ, Boban NIKOLIĆ Spatially Periodic Temperature Modulation of Incompressible Flow in Oberbeck-Bousinesq Approximation	45
Jelena PETROVIĆ, Živojin STAMENKOVIĆ, Miloš KOCIĆ, Jasmina BOGDANOVIĆ-JOVANOVIĆ, Milica NIKODIJEVIĆ MHD Flow and Heat Transfer in the Porous Medium Between Stationary and Moving Plate	51
Živojin STAMENKOVIĆ, Jasmina BOGDANOVIĆ-JOVANOVIĆ, Živan SPASIĆ, Jelena PETROVIĆ, Miloš KOCIĆ Optimization of Axial Pico Hydro Turbine	55
Dečan IVANOVIĆ Injection-Ejection Fluid Influence Through Different Accelerating Porous Surfaces on Unsteady 2D Incompressible Boundary Layer Characteristics	61
Rade KARAMARKOVIĆ, Vladan KARAMARKOVIĆ, Đorđe NOVČIĆ, Nenad STOJIĆ, Miloš NIKOLIĆ Energetic and Exergetic Analysis for Reconstruction of a Direct District Heating Substation	67
Milena N. RAJIĆ, Dragan B. JOVANOVIĆ, Dragoljub S. ŽIVKOVIĆ Transversal Deformations in Tube Plate of Reversal Chamber of the Hot Water Boiler	73
Milica LJUBENOVIĆ, Branislav STOJANOVIĆ, Jelena JANEVSKI, Marko IGNJATOVIĆ Effect of Thermal Mass on Dynamic Heat-Transfer Characteristics of Insulated Building Walls	77
Jelena JANEVSKI, Branislav STOJANOVIĆ, Mladen STOJILJKOVIĆ, Dejan MITROVIĆ, Aleksandar DEDIĆ The Influence of the Outside Air Temperature on the Energy Efficiency of Wood Dryers with Heat Recovery	81
Miloš KOCIĆ, Živojin STAMENKOVIĆ, Jelena PETROVIĆ, Milica NIKODIJEVIĆ EMHD Micropolar Fluid Flow and Heat Transfer in a Channel	85
Bojan OŽEGOVIĆ, Siniša SREMAC, Miloš KOPIĆ, Jelena HODAK Analysis of Infectious Medical Waste in Serbia	91
Milica JOVIĆ, Mirjana LAKOVIĆ, Miloš BANJAC, Saša KALINOVIĆ, Ivan PAVLOVIĆ Comparative Advantages of Wood Biomass Compared to Other Fuels for Heating Households in Western Balkan ...	95
Dragana DIMITRIJEVIĆ JOVANOVIĆ, Predrag ŽIVKOVIĆ, Mladen TOMIĆ, Mića VUKIĆ, Petar MITKOVIĆ Influences of the Soil Layer on Extensive Green Roof Thermal Behavior	99

Predrag ŽIVKOVIĆ, Mladen TOMIĆ, Dragana DIMITRIJEVIĆ JOVANOVIĆ, Mića VUKIĆ Experimental Study of Rayleigh–Bénard Convection in a Rectangular Tank with Diesel	103
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MECHANICAL DESIGN, DEVELOPMENT AND ENGINEERING

Biljana MARKOVIĆ, Dejan SAMARDŽIJA, Aleksija ĐURIĆ Influence Determination of Scanning Parameters on the Scanning Time Using Analysis of Variance on 3D Scanner Nextengine	109
Lidija JELIĆ, Vladimir MILOVANOVIĆ, Nikola JOVANOVIĆ, Miroslav ŽIVKOVIĆ Parametric Optimization of the Structures Using Finite Element Method	113
Stefan OGNJANOVIĆ, Vladimir MILOVANOVIĆ, Miroslav ŽIVKOVIĆ FEM Analysis of Welded Joints	117
Branislav DIMITRIJEVIĆ, Milan BANIĆ, Aleksandar MILTENOVIĆ, Milan TICA Simulation of Structural Damping	121
Milutin ŽIVKOVIĆ, Nikola KORUNOVIĆ Stress Analysis of Mining Chain Link Using Finite Element Method	125
Miroslav MIJAJLOVIĆ, Dušan ĆIRIĆ Two Way Coupled Fluid-Structure Interaction Analysis of the Grasshopper Fishing Lure’s Movement in the Water Stream	129
Mile SAVKOVIĆ, Goran PAVLOVIĆ, Jelena STANOJKOVIĆ, Nebojša ZDRAVKOVIĆ, Goran MARKOVIĆ Comparative Analysis and Optimization of Different Cross-sections of Crane Hook Subject to Stresses According to Winkler-Bach Theory	135
Nebojša ZDRAVKOVIĆ, Milimir GAŠIĆ, Mile SAVKOVIĆ, Goran MARKOVIĆ, Goran PAVLOVIĆ Eigenvalue Analysis for Transverse Vibration of Stepped Column with Lumped Mass at the Top by Finite Difference Approach	141
Goran PAVLOVIĆ, Mile SAVKOVIĆ, Nebojša ZDRAVKOVIĆ, Radovan BULATOVIĆ, Goran MARKOVIĆ Analysis and Optimization Design of Welded I-girder of the Single-beam Bridge Crane	145
Dragan MILČIĆ, Nikola LAZIĆ, Miodrag MILČIĆ, Vojkan NOJNER Software for V-Belt Drives Calculations	151
Milan RACKOV, Ivan KNEŽEVIĆ, Siniša KUZMANOVIĆ, Vojislav MILTENOVIĆ, Dragan MILČIĆ, Maja ČAVIĆ, Marko PENČIĆ, Josip TEMUNOVIĆ Comparison of Shaft Calculation Methods of Output Shafts in Universal Gear Units	155
Oliver SLIVOSKI, Stojance NUSEV, Dragan TEMELJKOVSKI, Igor ANDREEVSKI Increasing Lifetime of the Die for Straw Pellets by Changing Existing Design	161
Dimitar KARAIVANOV, Magdalena VELYANOVA, Ventsislav BAKOV Kinematic and Power Analysis of Multi-Stage Planetary Change-Gears through the Torque Method	167
Jelena STEFANOVIĆ-MARINOVIĆ, Sanjin TROHA, Boban ANĐELKOVIĆ, Miloš MILOVANČEVIĆ, Branimir RONČEVIĆ Selection of the Appropriate Reversible Two-Carrier Planetary Gear Train	173
Amir ALSAMMARRAIE, Dragan MILČIĆ, Milan BANIĆ, Miodrag MILČIĆ Predictions of Wear in Hydrodynamic Journal Bearing Using Artificial Neural Networks	179
Adel M. BASH, Amir ALSAMMARRAIE, Sulaiman E. AL-BASAQR, Sabah M. SALIH Study the Effect of Load, Sliding Speed and Sliding time on Dry Sliding Wear Rate and Wear Resistance of Carburized Mild Steels	183
Dušan STAMENKOVIĆ, Milan NIKOLIĆ, Ljubislav VASIN Tribological Aspect of Road Traffic Safety	187
Miodrag ARSIĆ, Srđan BOŠNJAK, Vencislav GRABULOV, Mladen MLADENOVIĆ, Bojan MEDO, Zoran SAVIĆ Mechanical Properties of Steel API X60 Used for Welded Joints Created by Arc Welding	193
Miodrag MILČIĆ, Tomaž VUHERER, Igor RADISAVLJEVIĆ, Janez KRAMBERGER, Nataša ZDRAVKOVIĆ Influence of Kinematic Factors of Friction Stir Welding on the Characteristics of Welded Joints of Plates Made of EN AW-2024 T351 A Aluminium Alloy	197

Nataša ZDRAVKOVIĆ, Boban ANĐELKOVIĆ, Vukašin PAVLOVIĆ, Miodrag MILČIĆ, Biljana ĐORĐEVIĆ, Milan PAVLOVIĆ	
Testing of Adhesive Bonds: a Review	203
Milan BIŽIĆ, Dragan PETROVIĆ, Vladimir SINĐELIĆ	
Application of Strain Gauges in Experimental Testing of Mechanical Structures	207
Erdinč RAKIPOVSKI, Borche RISTOVSKI, Tasko SMILESKI	
Improving Functional Parameters of Distributor Valve Type MH3F HBG 310	211

MECHATRONICS AND CONTROL

Branislav POPKONSTANTINOVIĆ, Zorana JELI, Miša STOJICEVIĆ, Ivana CVETKOVIĆ, Boris KOSIĆ	
The Event Based Motion Study of the Mechanical Model of the Human Heart	217
Miša STOJICEVIĆ, Branislav POPKONSTANTINOVIĆ, Ljubomir MILADINOVIĆ, Ivana CVETKOVIĆ	
History of Escapement Mechanisms	221
Zorana JELI, Miša STOJICEVIĆ, Boris KOSIĆ, Dragan PETROVIĆ	
Analysis of the 3D Model of the Pendulum of Clock Mechanism under the Influence of Temperature Change	225
Danijela RISTIĆ-DURRANT, Muhammad Abdul HASEEB, Damon EMAMI, Axel GRÄSER	
Multimodal Sensor Fusion for Reliable Detection of Obstacles on Railway Tracks	231
Milica PETROVIĆ, Radiša JOVANOVIĆ, Zoran MILJKOVIĆ	
Fuzzy Particle Swarm Optimization Algorithm for Manufacturing Resource Scheduling	237
Andrija MILOJEVIĆ, Sebastian LINß, Lena ZENTNER, Heikki HANDROOS	
A New Prismatic Crossed Leaf-Type Flexure Hinge Based on Topology Optimization with Discrete Beam Elements	243
Maja ČAVIĆ, Marko PENČIĆ, Milan RACKOV, Milan KOSTIĆ	
Structural Synthesis of the Plastic Cup Stacking Machine Mechanism – Application of the Intermittent Motion Mechanisms	247
Nenad T. PAVLOVIĆ, Nenad D. PAVLOVIĆ	
Design of Compliant Cognate Mechanisms	253
Dalibor PETKOVIĆ, Miloš MILOVANČEVIĆ	
Prediction of the Surface Roughness in Machining by Adaptive Neuro-Fuzzy Technique	259
Aca MICIĆ, Biljana ĐORĐEVIĆ	
Image Fusion in Mechatronic Applications	263
Stefan HENNING, Sebastian LINß, Lena ZENTNER	
Numerical Calculation of Compliant Four-bar Mechanisms with Flexure Hinges	267
Dušan MILOŠEVIĆ, Mimica MILOŠEVIĆ, Ana STANOJEVIĆ, Violeta DIMIĆ, Aleksandra MILOŠEVIĆ	
Application of FAHP Method in the Process of Building Construction from the Aspect of Energy Efficiency	271
Jelena MANOJLOVIĆ	
Nanotechnology and Molecular Manufacturing	277
Marko MARKOV, Stevan STANKOVSKI, Gordana OSTOJIĆ, Igor BARANOVSKI, Sabolč HORVAT	
Application of Firebase Cloud Service for Storing and Analysing Data from IoT Mobile Devices	283
Miša TOMIĆ, Andrija MILOJEVIĆ, Heikki HANDROOS, Miloš MILOŠEVIĆ	
Development of the Conductive Graphite Foam Displacement Sensor Model by using Artificial Neural Network ..	287
Milan PAVLOVIĆ, Vlastimir NIKOLIĆ, Ivan ĆIRIĆ, Miloš SIMONOVIĆ	
Advanced Edge Detection Techniques for Rail Track Detection Using Thermal Camera	291
Žarko ČOJBAŠIĆ, Milan RISTANOVIĆ, Stefan SAVIĆ, Nemanja MARKOVIĆ, Marina STOJILJKOVIĆ	
Metaheuristic Tuning of Building Heating Controller	295
Nevena TOMIĆ, Miloš MILOŠEVIĆ, Nenad D. PAVLOVIĆ	
Optimal Synthesis of the Wippkran Mechanism using Genetic Algorithm	299

PRODUCTION AND INFORMATION TECHNOLOGIES

Nikola VITKOVIĆ, Miloš STOJKOVIĆ, Miroslav TRAJANOVIĆ, Jelena MILOVANOVIĆ, Milan TRIFUNOVIĆ, Miodrag MANIĆ, Jelena MITIĆ, Stojanka ARSIĆ, Karim HUSAIN Personalized 3D Model of Bone Scaffold Created by Application of Method of Anatomical Features	305
Petar S. ĐEKIĆ, Goran RADENKOVIĆ, Biljana MILUTINOVIĆ, Gordana STEFANOVIĆ Cost-Benefit Analysis of Modification of Recycling Rubber Powder	309
Jelena STANOJKOVIĆ, Miroslav RADOVANOVIĆ Selection of Indexable Milling Cutters Using Entropy and TOPSIS Multi Criteria Decision Method	313
Karim N. HUSAIN, Miloš STOJKOVIĆ, Mohammed M. RASHID, Nikola VITKOVIĆ, Miodrag MANIĆ, Jelena MILOVANOVIĆ, Nikola KORUNOVIĆ Digital Reconstruction of Large Missing Part of Mandible by Anatomically Shaped Scaffold	317
Jelena BARALIĆ, Bogdan NEDIĆ, Borivoje NEDELJKOVIĆ, Predrag JANKOVIĆ Wear of the Focusing Tube in Abrasive Water Jet Machining	321
Miloš MILOVANČEVIĆ, Dalibor PETKOVIĆ Prediction of the Power Consumption in Machining by Adaptive Neuro-Fuzzy Technique	325
Andelija MITROVIĆ, Pavel KOVAČ, Jelena BARALIĆ, Nenad KULUNDŽIĆ Analysis of Influence of Depth of Cut on Cutting Temperature in Milling in Software AdvantEdge	329
Vladislav BLAGOJEVIĆ, Saša RANDELOVIĆ, Saša MILANOVIĆ Experimental Model for Pneumatic Actuators Synchronization	335
Miloš MADIĆ, Miroslav RADOVANOVIĆ, Predrag JANKOVIĆ Mathematical Model for Laser Cutting Time Estimation	339
Saša RANDELOVIĆ, Mladimir MILUTINOVIĆ, Vladislav BLAGOJEVIĆ, Dejan TANIKIĆ Nonlinear FEM Simulation of Extrusion Process	343
Mladimir MILUTINOVIĆ, Tomaž PEPELNJAK, Dragiša VILOTIĆ, Plavka SKAKUN, Dejan MOVRIN, Saša RANDELOVIĆ Influence of Blank Shape to Material Formability in Stretch Forming	347
Dušan PETKOVIĆ, Miloš MADIĆ, Goran RADENKOVIĆ Application of Extended TOPSIS Method for Biomaterial Selection	353
Jovan ARANDELOVIĆ, Pavle DRAŠKOVIĆ, Rajko TURUDIJA, Marko DIMITROV, Nikola BOŽIĆ, Nikola KORUNOVIĆ, Miroslav TRAJANOVIĆ Towards a Methodology for CAD program Efficiency Assessment	357

TRAFFIC ENGINEERING, TRANSPORT AND LOGISTICS

Nadica STOJANOVIĆ, Jasna GLIŠOVIĆ, Ivan GRUJIĆ, Aleksandar DAVINIĆ Thermal Loads of the Ventilated Brake Disc and Pads	365
Ivan GRUJIĆ, Jasna GLIŠOVIĆ, Nadica STOJANOVIĆ, Aleksandar DAVINIĆ, Miroslav PETROVIĆ Engine Vibration Analysis During the Combustion Process	369
Jovan PAVLOVIĆ, Dragoslav JANOŠEVIĆ, Boban ANĐELKOVIĆ, Vesna JOVANOVIĆ Models for Determination of the Loaders Digging Resistance Forces	373
Muhamed HERIĆ, Edin CERJAKOVIĆ, Alan TOPČIĆ, Slađan LOVRIĆ Modeling and Simulation of Warehouse Operation within Production System	377
Nikola PETROVIĆ, Jelena PETROVIĆ, Saša MARKOVIĆ, Vesna JOVANOVIĆ Performance Analysis of Bus Alternative Drive Technologies	383
Saša MILOJEVIĆ, Radivoje PEŠIĆ Challenges in City Transport - Alternative Fuels and Door to Door Model	387
Aleksandar G. STANKOVIĆ, Predrag M. RAJKOVIĆ, Goran S. PETROVIĆ Usage of Multicriteria Analysis for Selecting the Appropriate Host University to Study	393
Miomir JOVANOVIĆ, Jovan VLADIĆ, Radomir ĐOKIĆ, Goran RADOIČIĆ Modern Examination of Export Mining Machines	397

Vedran VUKŠIĆ, Sreten SIMOVIĆ, Tijana IVANIŠEVIĆ The Role and Importance of Information Technologies in Transport Logistics	403
Slavko VESKOVIĆ, Života ĐORĐEVIĆ, Marko VASILJEVIĆ, Sanjin MILINKOVIĆ, Željko STEVIĆ Monitoring of Malfunction of Railway Rolling Stock Regarding Wagon Usability and Traffic Safety Alloy	409
Slavko VESKOVIĆ, Gordana STOJIC, Snježana RAJLIĆ, Sanjin MILINKOVIĆ, Marko VASILJEVIĆ Identification and Quantification of Criteria for Establishing the Business Balance of Railway Operators	415

THEORETICAL AND APPLIED MECHANICS AND MATHEMATICS

Nikola NEŠIĆ, Predrag KOZIĆ, Goran JANEVSKI Vibration of Damped Nonhomogeneous Cantilever Beam on Winkler Layer	423
Ljiljana PETKOVIĆ Computers in Mathematical Theory and Proofs	427
Nikola JOVIĆ, Dragan RAKIĆ, Miroslav ŽIVKOVIĆ Development and Implementation of Drucker-Prager Constitutive Model for Plane Strain Condition	431
Nikola NEŠIĆ, Dragan B. JOVANOVIĆ, Goran JANEVSKI Analysis of Natural Frequency in Beam with Multiple Cracks and General Boundary Conditions	437
Predrag RAJKOVIĆ, Miodir STANKOVIĆ, Slađana MARINKOVIĆ Problems in the Generalizations of the Laplace Transform	441
Melanija MITROVIĆ, Siniša CRVENKOVIĆ, Branislav M. RANĐELOVIĆ Constructive Semigroups with Apartness: Foundations of the Order Theory - II	445
Dragan MARINKOVIC, Manfred ZEHN, Gil RAMA Interactive Simulations of Shell Structures	447
Carsten STRZALKA, Manfred ZEHN, Dragan MARINKOVIĆ Selective Model Order Reduction for Finite Element Based Fatigue Analyses	451
Biljana RADOVANOVIĆ DINIĆ, Predrag RAJKOVIĆ, Snežana TEŠIĆ RAJKOVIĆ How to Separate Inseparable Convex Hulls and Applications	455
Predrag MILIĆ, Dragan MARINKOVIĆ, Goran PETROVIĆ, Žarko ČOJBAŠIĆ Modal Isogeometric Analysis of Thin Plates	461

FUTURE OF WORK, ENGINEERING AND PROFESSIONAL ETHICS IN THE ERA OF GLOBALIZATION

Ljubiša MITROVIĆ The Treatment of Human Labour and the Problem of Motivation for Work in Countries in Transition	467
Bogdan ĐUROVIĆ, Dragoljub B. ĐORĐEVIĆ Globalization, Neoliberalism and the Growing Disparity Between the Wealthy and the Poor	471
Vesna STANKOVIĆ PEJNOVIĆ Higher Education Reforms Under Globalisation	475
Božo MILOŠEVIĆ “Creative Industries” as a Strategic Necessity for the Accumulation of Capital in the New Liberal Key	479
Radoš RADIVOJEVIĆ, Sonja PEJIĆ Scientific and Technical Potential, Digitalization, and Social Change	483
Sonja PEJIĆ, Radoš RADIVOJEVIĆ Sociological View of Engineering Profession in Modern Society	489
Alpar LOŠONC, Andrea IVANIŠEVIĆ Professional Ethics in Confrontation with the Dynamics of Work	493
Nidal SHABAN, Vladan PEŠIĆ, Eman KADHUM University Leadership Role in Effective Education for Sustainable Development	497
Dimitrije BUKVIĆ Globalization as an Opportunity for Old Crafts: the Case of a Sweet Shop in Belgrade	501

ENGINEERING MANAGEMENT

Dragan TEMELJKOVSKI, Vladan NIKOLIĆ, Stojanče NUSEV, Dragana TEMELJKOVSKI Knitting Plant Reengineering in the Textile Industry	507
Marjan LEBER, Pedja M. MILOSAVLJEVIC, Bisera KAJMAKOSKA, Robert OJSTERSEK Integrating the Business Excellence Model into Enterprise Innovation Processes	511
Milan KOLAREVIĆ, Vladan GRKOVIĆ, Aleksandra PETROVIĆ, Branko RADIČEVIĆ Statistical Control of the Assembly Process of Gun Cabinet	515
Miroslav FERENČAK, Mladen RADIŠIĆ, Dušan DOBROMIROV, Peđa MILOSAVLJEVIĆ Decision-making Under Ambiguity: The Case of Investment Process	519
Pedja MILOSAVLJEVIĆ, Milena RAJIĆ, Rado MAKSIMOVIĆ, Dragan PAVLOVIĆ, Miroslav FERENČAK, Marjan LEBER Material and Energy Flow in Industrial Environment	523
Dragan PAVLOVIĆ, Srđan MLADENOVIĆ Differences between the Implementation of Lean Principles in SMEs and Large Companies	527
Index of Authors	531

Two Way Coupled Fluid-Structure Interaction Analysis of the Grasshopper Fishing Lure's Movement in the Water Stream

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Abstract— The special group of the fishing lures are insect shaped lures that are dragged in the water stream and while dragged they imitate the injured insect swimming in the water stream. The lure is moving both laterally and longitudinally; it is vibrating, making noise and shining in the water – this tricks the fish to attack it and get hooked. The movement, vibration and noise produced by the lure depend on the topology of the lure and the relative speed of the lure in water stream. The modeling and simulation of such a physical process requires an analysis that simultaneously runs structural and fluid-based analysis. The paper is presenting preparation and results of a two-way coupled fluid-structural interaction Ansys analysis applied on a grasshopper lure. The goal is to investigate the deflections of the fishing lure in the water stream.

Keywords— Grasshopper Fishing Lure, Ansys Workbench, Two Way Fluid-Structure Interaction, Displacement

I. INTRODUCTION

During the last two centuries, line fishing has become more than a pure need for the food resources harvesting – the modern fishing has a goal to use a bait, outfox the fish, enjoy the catch, make a photo of the fish and return it unharmed to the water.

A massive group of recreational fisherman use artificial baits for the fish – fishing lures, which imitate the behavior of the natural food of the fish (they imitate insects, amphibians, small mammals or small fish). The lure fishing is quite simple: the lure is cast to the water and dragged by the fishing line. While dragged, the fishing lure spins (partially or fully), dives, vibrates and makes for the fish irritating noise. There are numerous types and shapes of the lures [1-3], with different designs and textures, but this is simply not enough: the trophy fish is too cautious to get caught so easily. Therefore the fishing lure has to be optimized for the fish, water and season of the year, weather and the fisherman.

II. DESIGN OF THE FISHING LURE

There is no universal fishing lure that can be used for all fish and all fishing circumstances; the fishing lure used for the analysis is a small grasshopper (max. 50 mm long, fig. 1, position 6), the primary target fish is a chub (predatory fish), and the fishing is planned in the shallow and clear river waters during spring and summer [2]. The lure is light – floating or shallow diving, maneuverable,

balanced, with a detailed surface texture and with a limited vibration and noise creation. It has the ability to define the intensity of the lateral and longitudinal movement of the lure while fishing by pure adaptation of the fishing lure's dragging speed.

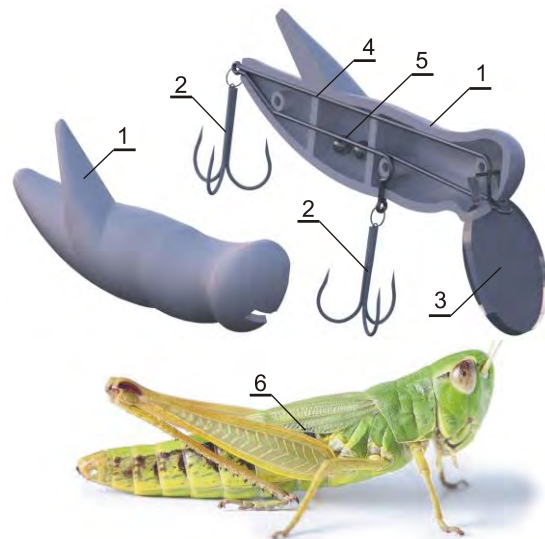


Fig. 1 The Grasshopper: 1) grasshopper lure's body, 2) fishing hooks, 3) diving lip, 4) steel frame of the lure, 5) steel balls inside the vibration chamber, 6) the grasshopper

The shape, size and position of the diving lip in the fishing lure (fig 1, position 3) define the diving depth of the lure, enforce stabile/unstable and controlled/uncontrolled movement of the lure while steel balls inside the vibration chamber (fig. 1, position 5) generate noise and vibration of the lure. Steel balls inside the lure improve/degrade the gyro-stability of the lure, but they always restrain the lure's spin around the longitudinal axis – fishing line [1].

The diving lip on the fishing lure is elliptical (axis: 10 mm×5,6 mm) and it is mounted to the lure at the front side of the grasshopper's head at the angle of $\alpha=60^\circ$ between the horizontal (represented with the fishing line, Fig. 2, position 3) and the diving lip. The diving lip cannot be rotated or translated along the mounting position (what is possible to be done at some state of the art fishing lures [1]).

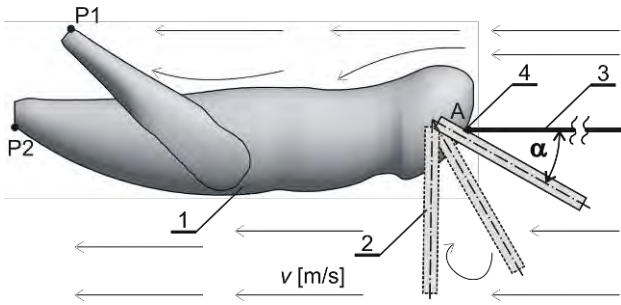


Fig. 2 Location of the diving dip in the fishing lure: 1) fishing lure, 2) diving dip, 3) fishing line, 4) anchor point – A

The fishing line (Fig. 2, position 3) is connected to the lure over only one constraining point located in the middle of the diving dip/ front side of the fishing lure (Fig. 2, position 4)

III. NUMERICAL SIMULATION OF THE FISHING LURE TRAVELLING THROUGH THE WATER STREAM

In reality, the fishing lure is dragged by the fishing line through the water, that is either unmovable or has a positive or negative stream. Regarding on the relative speed of the lure's travel through the water, the pseudo oscillatory movement of the lure appears in the regimes defined with the lure's topography and the travel/dragging speed. In order to simplify the simulation, it is considered that the lure is restrained in the water flow. Therefore, the simulation is considering the change of the water stream v [m/s] to receive the translational response of the fishing lure. The simulation is performed in Ansys Workbench 18.1 environment [4].

A. Numerical Model

The numerical model consists of 3 discretized parts: the fishing lure, fishing line and enclosure (Fig. 3).

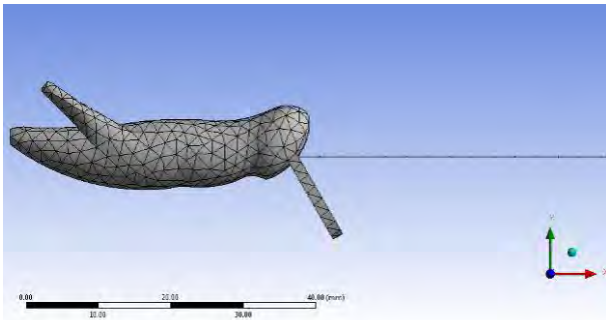


Fig. 3 Discretized fishing lure and fishing line

The lure is modeled/discretized with the 3D-high order Tet10 (SOLID187 [5]) elements while the fishing line was modeled with the beam elements (BEAM188 [6]) and the mesh is stationary. The fishing line has a rounded cross section of 0,25 mm diameter and it is 200 mm long. The fishing lure and the fishing line are connected over a fixed joint (point on curve) while the other side of the fishing line is fully constrained (fixed). The materials used for analysis are PA 6.6 (plastic/nylon with the density of $\rho=1150$ kg/m³, Young's Modulus $E=3500$ MPa, Poisson's Ratio $\nu=0,4$ and Tensile Yield Strength $\sigma_{yield}=85$ MPa) used for the fishing lure and FL (steel with the density of $\rho=7850$ kg/m³, Young's Modulus $E=200000$ MPa, Poisson's Ratio $\nu=0,3$ and Tensile Yield Strength

$\sigma_{yield}=25$ MPa [7]) for the fishing line. The both materials are considered to be ideally elastic.

The enclosure – water is modeled as the non-uniform cube surrounding the fishing lure and the fishing line. Since water has only a minor influence on the fishing line, the enclosure is limited only to the fishing lure (Fig. 4), with the boundary surfaces set 5 mm to 25 mm away from the fishing lure model. The enclosure cube's boundaries (named selections) are set as: inlet (+x plane), outlet (-x plane), walls (+y, -y, +z, -z) and as fluid-solid-interface (the set of surfaces that are in contact with the fishing lure).

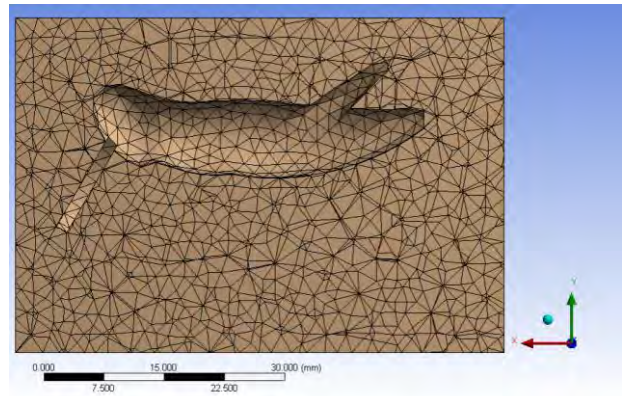


Fig. 4 Discretized enclosure – water (lateral section view)

The water is discretized with the linear 3D Tet4 [8] elements. The mesh is set to be dynamical – the enclosure is being re-meshed after each iteration cycle. The main properties of the water are: density $\rho=998,2$ kg/m³ and viscosity $\eta=0,001003$ Pas.

B. Two-Way Coupled Fluid-Structure Interaction Analysis

Preparation of the model, simulation and analysis of the lure's movement in the water requires understanding the realistic physical process. The lure is attached to the fishing line and it always resists to the water stream. The water stream runs around the fishing lure and due the topology of the lure, the uniform water stream deforms locally (the velocity and pressure). The local changes of the water stream enforce displacement of the lure – it tensions the fishing line and translates/rotates in all 3 directions to reach the meta-stabile or stabile mechanical equilibrium. Such a displacement changes the water stream again, what results in new movement of the fishing lure. Therefore, the process continues and lasts until the water stream runs around the fishing lure or until the stabile mechanical equilibrium is reached.

In such a case, the fluid is interfacing with the solid and the solid is influencing the fluid. Such a case is recognized by the Ansys Workbench as the coupled two-way coupled fluid-structure interaction (FSI) analysis [4]. It is coupling the Transient Structural Analysis – TSA (stress, deformation) of the solids (the fishing lure and fishing line) and the Fluid Flow Analysis – FFA (Fluent) of the fluid – water (Fig. 5) [9].

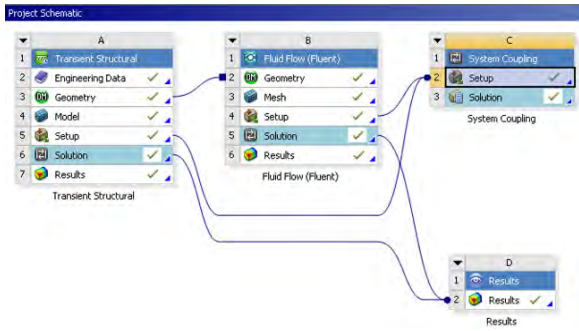


Fig. 5 The Ansys Workbench Coupled FSI Analysis – the project schematic

Both the TSA and FFA share the same geometry consisting of the fishing lure, fishing line and water around the fishing line and fishing lure. The TSA Model uses the geometry of the fishing line and fishing lure while the water is suppressed. On the other hand, the FFA Model uses only the water geometry and the fishing lure and the fishing line are suppressed.

The TSA Setup, beside common structural settings, requires use of the Fluid Solid Interface loading (set to all surfaces/faces of the fishing lure, fig. 6) and the use of the APDL Command to activate initial stress-deformation of the solids (e.g. elastic strain defined over the INISTATE command). This APDL is required to stabilize the numerical model at the first time step of analysis.

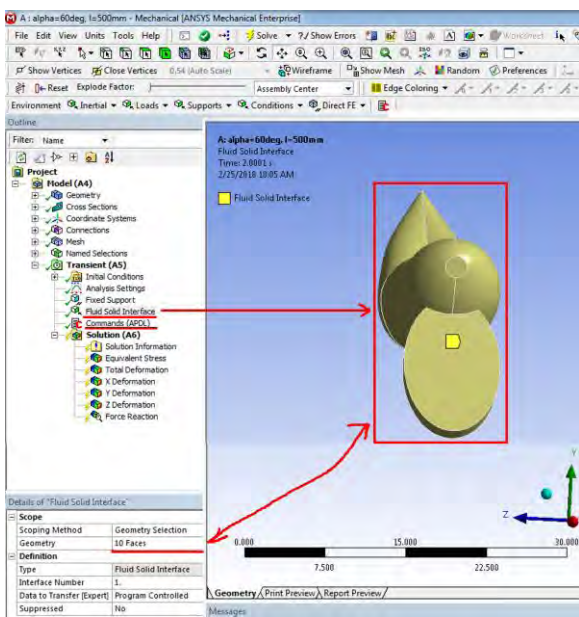


Fig. 6 The TSA – Fluid-Structure Interaction loads and APDL Command

It is necessary to set only 1 calculation step in the settings (otherwise the coupling analysis will not work). All other analysis settings concerning time/time step are unimportant because the coupling settings overrides them all [10, 11].

The FFA Setup is slightly more complex than the TSA Setup. It is mandatory to set:

General→Transient Analysis; Models→Viscous→k-epsilon (2 eqn)→Realizable→Scalable Wall Functions; Materials→Fluid→Water-Liquid; Cell Zone Conditions→Select Water Liquid; Boundary Conditions→it is necessary to set Inlet (Fig. 7), Outlet, Walls and Fluid Interior. The boundary layer of water

flowing around the fishing lure, that is necessary for more precise capture of local pressure drops, has been neglected.

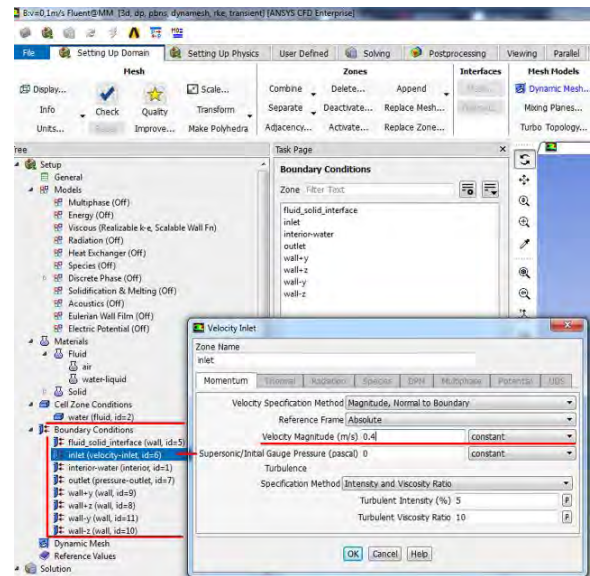


Fig. 7 The FFA – Boundary Conditions, Inlet Settings, water stream $v=0,4$ m/s

Dynamic Mesh→Smoothing→Settings→Diffusion→Diffusion Parameter→2; Dynamic Mesh→Dynamic Mesh Zones→Walls, Inlet, Outlet (Stationary), Fluid Solid Interface (coupled), Interior (dynamic), shown in Fig. 8.

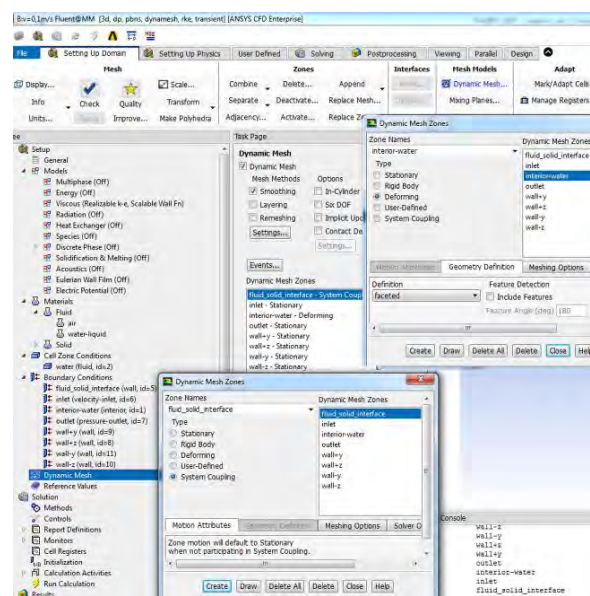


Fig. 8 The FFA – Dynamic Mesh

Method→Solution Methods→Scheme→Coupled; Initialization→Initialize.

All other settings are optional or semi-optional since coupling overrides almost all of them.

The Coupling Setup (Fig. 9) requires connecting the TSA and FFA: it is necessary to make the data transfer from TSA to SA and vice versa. It is done over the Fluid Structure Interface: the TSA delivers incremental displacement to the FFA while FFA delivers forces to the TSA. After setting the time step (due to the convergence issues it is necessary, in many cases, to set very small values, e.g. $\Delta t=0,0001$ s), end time (smaller than one

given in TSA) and min/max iterations the coupling setup is done.

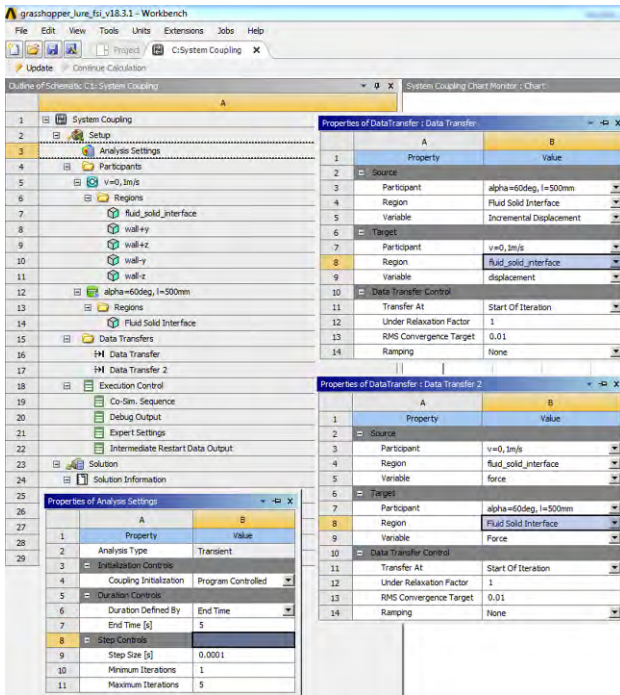


Fig. 9 The Coupling Setup – Settings

Unfortunately, solving the coupling system, even for relatively small numerical models (e.g. less than 100000 elements and less than 200000 nodes) is extremely slow – TSA and FFA have to converge, and afterwards data transfer from TSA to FFA and data transfer from FFA to TSA, as well.

IV. RESULTS AND DISCUSSION

The coupled analysis has been ran for five different water streams (0,3; 0,35; 0,37; 0,4 and 0,5 m/s), analysing the first 5 seconds of water flow. The results have been showed only for three characteristic points on the fishing lure (A, P1 and P2, shown in figure 2), with absolute coordinates in mm: A (36,817; 3,3084; 0), P1 (4,0915; 15,549; 0), P2 (-0,95601; 6,8278; 0). The results are presented considering global coordinate system (given in figures 2, 4, 6 and 10) where: $-x$ direction is the direction of the water stream (flow) – longitudinal direction, $-y$ is the (vertical lateral) direction of the gravity (the gravity has been neglected) and the z direction is (horizontal) lateral.

There are some notations that have to be taken into consideration while checking the results:

1. The results show intensive oscillatory behaviour of the fishing lure in the water stream.
2. The TSA model has received initial (before the first iteration) artificial pre-loading defined as the constant elastic strain of 10^{-8} mm/m for all the elements in the model. This was a necessity for the proper numerical constraining and numerical stability of the coupled model. Therefore, after achieved convergence at the first time step, the model is „resting” from the initial loading. Also, the TSA model is being calculated first without concern on FFA model what gives non realistic results. Considering both reasons, the first 0,5 s of the analysis should be neglected.

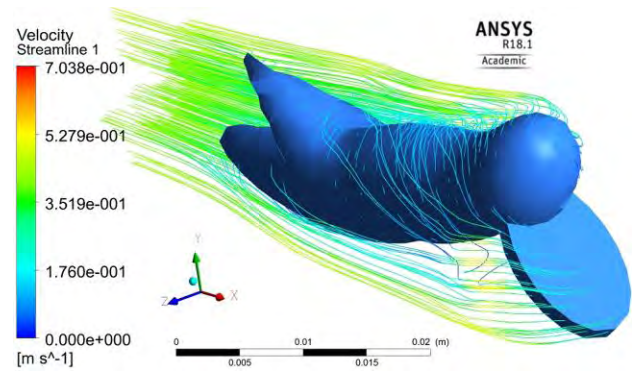


Fig. 10 The velocity/streamline for $v=0,5$ m/s

The fishing lure and the fishing line are initially set to have collinear (horizontal) axes. However, the water stream is forcing the lure to dive (in $-y$ direction) to reach natural fluid-mechanic equilibrium position, regardless on speed of the water flow. The „equilibrium” position is reached after 0,5 s to 1,5 s for all water streams and afterwards (in time interval 1,0 s to 5,0 s) the fishing lure is in the stable dynamic influence of the water stream.

The relative diving depth of the selected points (A, P1 and P2) for the case when water stream is $v=0,3$ m/s is given in figure 11.

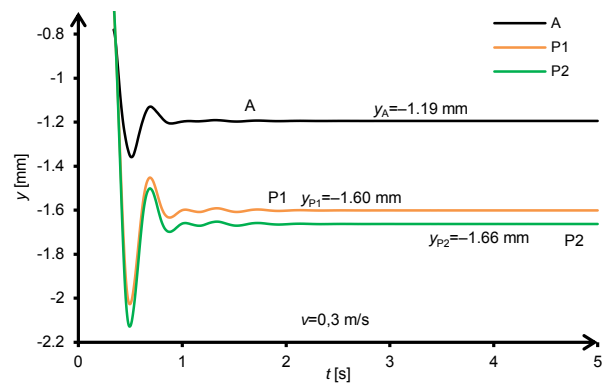


Fig. 11 The relative displacements of points A, P1 and P2 in the y -direction for the water stream of $v=0,3$ m/s

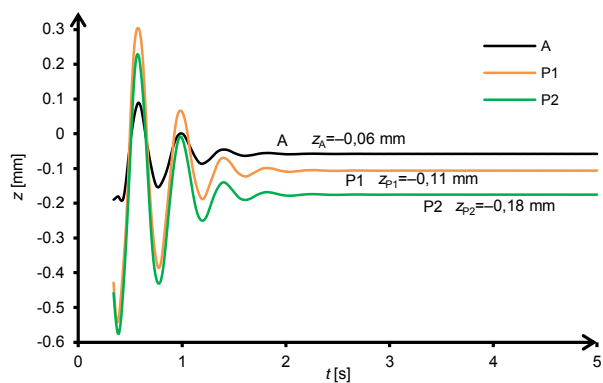


Fig. 12 The relative displacements of points A, P1 and P2 in the z -direction for the water stream of $v=0,3$ m/s

Comparing the initial y coordinates of points A, P1, and P2 and appropriate relative displacements of points in y -direction in steady water stream (y_A, y_{P1}, y_{P2}), it can be observed that the lure as is diving, but the points P1 and P2 (the back side of the lure) dive app. 0,5 mm more than the point A (the front side of the lure). The water stream is too slow to initiate oscillatory movement of the fishing

lure what results in constant relative displacement of the points in z -direction (Fig. 12). The existence of the lures deflection in $-z$ -direction is (z_A , z_{P1} , z_{P2} different from 0, Fig. 11) is induced by ununiformed distribution of the lure's mass, what is the product of the solid discretization-meshing and numerical calculus.

The water stream of $v=0,35$ m/s induces a bit deeper diving of the fishing lure (Fig. 13) than with water stream of 0,30 m/s. The backside of the fishing lure goes deeper than the front side, as well. The diving depth is not constant anymore but slightly oscillatory.

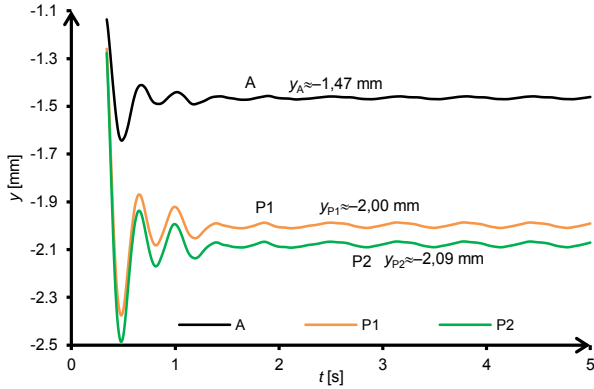


Fig. 13 The relative displacements of points A, P1 and P2 in the y -direction for the water stream of $v=0,35$ m/s

The lure deflects in $\pm z$ direction with a frequency of $f_z \approx 2\text{Hz}$ (Fig. 14) and the deflection of the points is: z_A ($z_{A\min} = -0,08$ mm; $z_{A\max} = 0,05$ mm), z_{P1} ($z_{P1\min} = -0,04$ mm; $z_{P1\max} = 0,41$ mm) and z_{P2} ($z_{P2\min} = -0,08$ mm; $z_{P2\max} = 0,32$ mm).

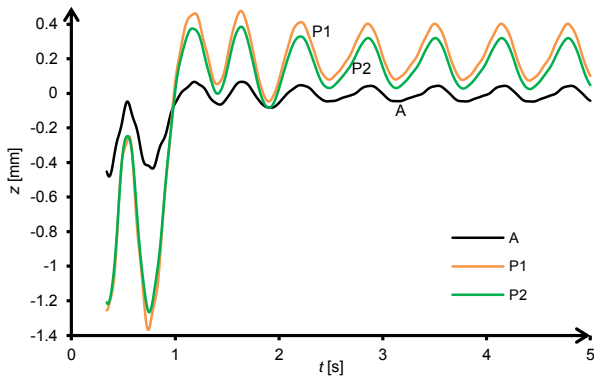


Fig. 14 The relative displacements of points A, P1 and P2 in the z -direction for the water stream of $v=0,35$ m/s

The water stream of $v=0,4$ m/s enforces oscillatory and more deeper diving of the lure (Fig. 15). The diving depth of the points varies between y_A ($y_{A\min} = -2,51$ mm; $y_{A\max} = -1,76$ mm), y_{P1} ($y_{P1\min} = -3,52$ mm; $y_{P1\max} = -2,42$ mm) and y_{P2} ($y_{P2\min} = -3,60$ mm; $y_{P2\max} = -2,47$ mm) and frequency of $f_y \approx 10\text{Hz}$. The lure deflects in $\pm z$ direction with a frequency of $f_z \approx 10\text{Hz}$ (Fig. 16) and the deflection of the points is: z_A ($z_{A\min} = -1,47$ mm; $z_{A\max} = 1,67$ mm), z_{P1} ($z_{P1\min} = -3,34$ mm; $z_{P1\max} = 3,48$ mm) and z_{P2} ($z_{P2\min} = -1,60$ mm; $z_{P2\max} = 1,70$ mm).

The water stream of $v=0,5$ m/s enforces highly oscillatory and more deeper diving of the lure (Fig. 17). The frequency of oscillations is $f_y \approx 11\text{Hz}$ while the diving amplitude varies between 1mm to 2,5 mm.

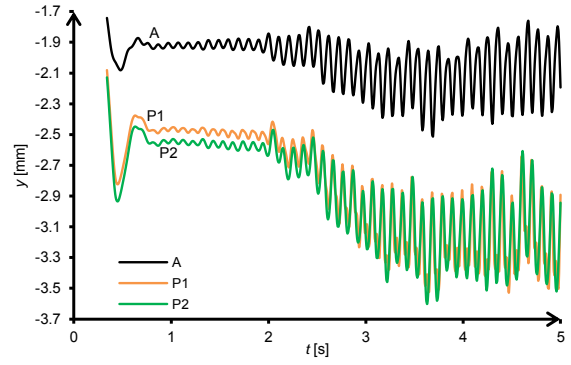


Fig. 15 The relative displacements of points A, P1 and P2 in the y -direction for the water stream of $v=0,4$ m/s

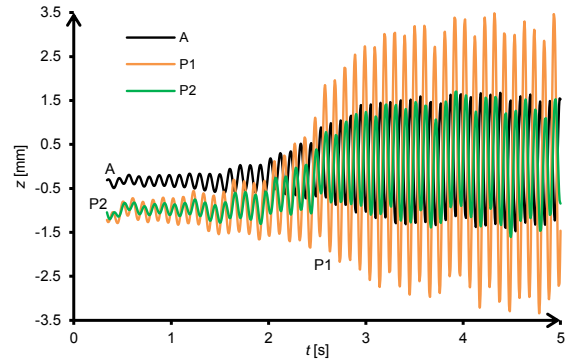


Fig. 16 The relative displacements of points A, P1 and P2 in the z -direction for the water stream of $v=0,4$ m/s

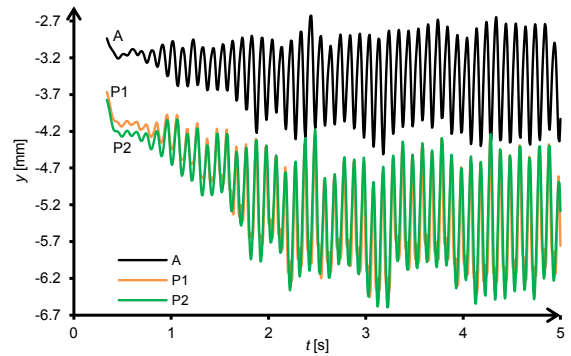


Fig. 17 The relative displacements of points A, P1 and P2 in the y -direction for the water stream of $v=0,5$ m/s

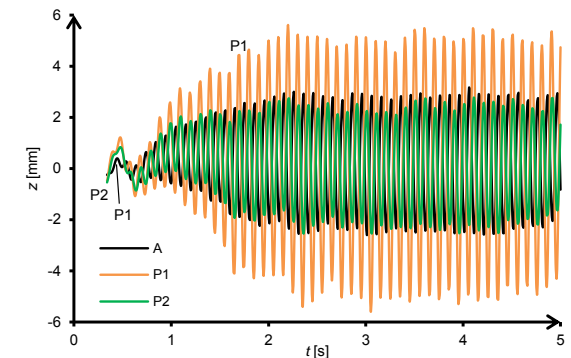


Fig. 18 The relative displacements of points A, P1 and P2 in the z -direction for the water stream of $v=0,5$ m/s

The deflection in $\pm z$ direction is more intensive than for the lower water streams: the frequency is $f_z \approx 11\text{Hz}$ (comparing to 10 Hz for 0,4 m/s), but the amplitudes of point deflections are much higher (from 1 mm to 10 mm, Fig. 18).

The force delivered by the water stream to the fishing lure (over the Fluid Solid Interface) is rather small (Fig. 19). The reasons are that the lure is connected to the elastic fishing line that captures the resistance force and the lure is free to move in the water so the water stream does not deform the lure or stresses it intensively (Fig. 20).

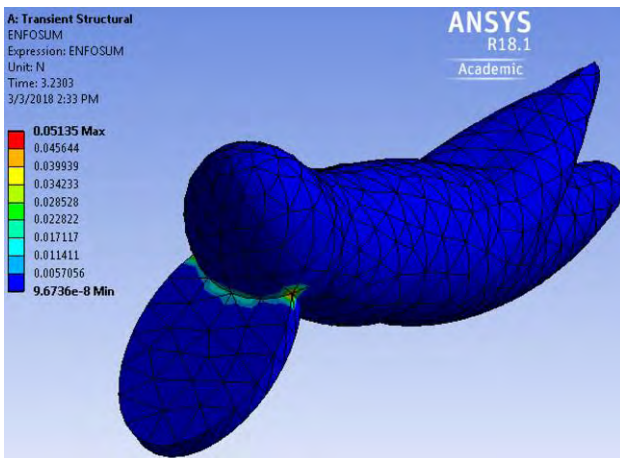


Fig. 19 The intensity of the forces delivered to the fishing lure by the water stream of $v=0,5$ m/s

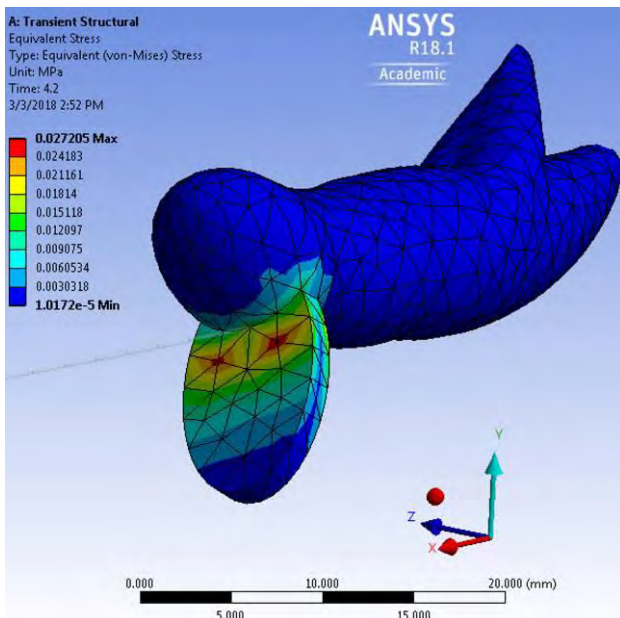


Fig. 20 The equivalent stress in the fishing lure enforced by the water stream of $v=0,5$ m/s

The fishing line does not receive loading from the water stream but only from the fishing lure while restrains it. Therefore, the fishing line is always under pure tension.

V. CONCLUSIONS

The coupled FSI analysis of the proposed grasshopper lure shows that the model starts to oscillate in the water flow faster than 0,3 m/s. It is not investigated what is the critical water stream where oscillatory movement of the lure appears but at the 0,37 m/s grasshopper lure oscillates both in lateral horizontal and vertical directions with 2 Hz.

With the rise of the water flow, the frequency rises, as well, and at water stream of 0,5 m/s it reaches 11 Hz.

The rise of the water stream's intensity induces diving of the fishing lure and the greatest diving has been recorded for the 0,5 m/s. However, the diving is not uniform – the back side of the lure is diving deeper than the front side of the lure. The maximal diving depth of the complete lure is app. 10 mm what classifies the fishing lure as shallow diving.

Deflection of the fishing lure in lateral direction (z-axis) is intensive if the water stream is 0,35 m/s or higher. The fishing lure deflects maximally 10 mm for the water stream of 0,5 m/s what is the maximal expected water stream in the river. Higher water streams might induce larger deflections and higher oscillation frequencies what might lead to unstable travel of the fishing lure. As a result of such a travel the fish might not be intrigued to attack the lure – it might get scared and swim away from the lure.

Further research will be focused on boundary water streams, improvement of the fluid-flow model and diving lip – the size, shape and position in the fishing lure.

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