ESTIMATION OF COMBINED CYCLE POWER PLANT POWER OUTPUT USING MULTILAYER PERCEPTRON VARIATIONS

Ivan LORENCIN [1)], Zlatan CAR [1)], Jan KUDLÁČEK [2)], Vedran MRZLJAK [1)], Nikola ANĐELIĆ [1)], Sebastijan BLAŽEVIĆ [1)]

[1)] Faculty of Engineering, University of Rijeka, Vukovarska 58, 51000 Rijeka, Croatia

[2)] Department of manufacturing technology, Faculty of Mechanical Engineering, Czech Technical University in Prague, Technická 4, 166 07 Praha, Czech Republic

Abstract:

In this paper an artificial intelligence-based method for output electric power of combined cycle power plant (CCPP) is presented. Method is based on utilizing various designs of multilayer perceptron (MLP). Different MLPs are designed by varying activation functions, solvers and configurations of hidden layers. MLPs are trained and tested by using training dataset of 7500 samples and test dataset of 2068 samples. From obtained results it can be concluded that by using appropriate activation function and solver, low output errors are achieved, regardless of hidden layers. Furthermore, it can be concluded that minimal error is achieved if MLPs designed with Tanh activation function are used.

Keywords: Activation function, Combined cycle power plant, Gas turbine, Multilayer perceptron, Stem turbine

1. Introduction

Gas turbine (GT) power plants are today widely used in applications where heat production together with power production is acceptable [1], [2]. The conventional GT is characterized with higher grade heat that is exhausted to the atmosphere. This heat can be used for steam generating with aim for additional electric power producing [3]. Generated stem is than used for power generating by using a steam turbine (ST). ST is nowadays used in various applications in range from electric power producing to ship propulsion systems [4-9]. For modeling and control of complex systems as CCPP, artificial intelligence methods could be used. Artificial intelligence algorithms are used in wide spectrum of science such as: medicine [10] [11], robotics [12], etc. In this research an artificial intelligence-based system for electrical power production of CCPP is presented.

2. Power plant description

The combined cycle power plant (CCPP) used in this research is composed of two gas turbines (GT) and one steam turbine (ST). Motion energy of forementioned turbines is thought shaft transmitted to electric power generators where electric power is generated. Gas turbines, together with motion energy, are generating fairly hot exhaust that is used for steam generation in heat recovery steam generators (HRSG) [13]. Each of two GT produces exhaust that is used for generating steam in one HRSG. Scheme of CCPP used for these research is shown in Figure 1.

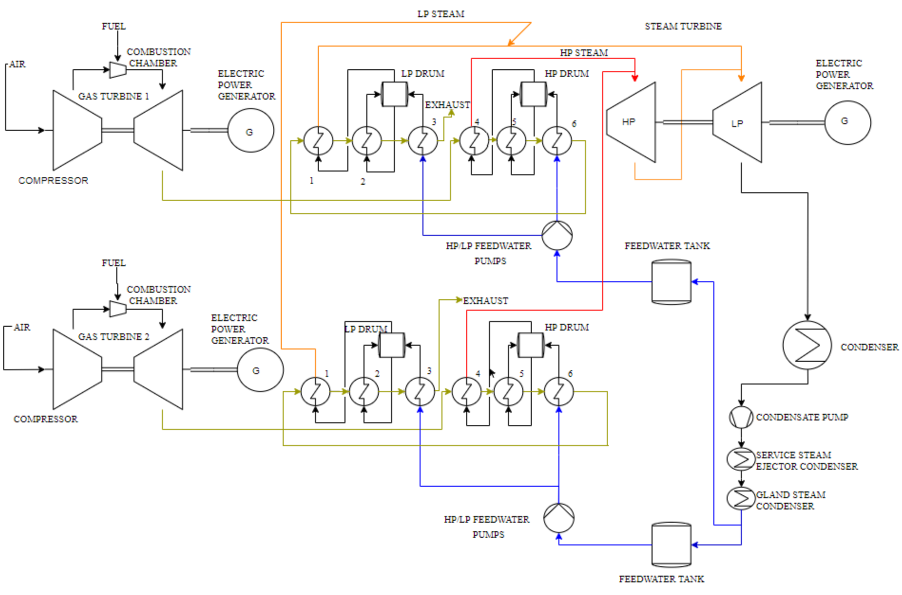

Figure 1. *– Scheme of the combined cycle power plant used in this research*

Steam system utilized in this CCPP consists of the high pressure (HP) and the low pressure (LP) ST.

In Figure 1. components of HRSG are enumerated as follows:

1. LP super heater,
2. LP evaporator,
3. LP economizer,
4. HP super heater,
5. HP evatorator and
6. HP economizer.

Dataset used for this research is obtained in power plant with a nominal generating capacity of 480 MW. This system is made by using two 160 MW ABB 13E2 GTs and one 160 MW ABB ST. Dataset is constructed of 7500 samples used for training and 2068 samples used for testing.

3. Dataset description

Dataset used in this research consists of four input parameters and one output parameter, as shown in Table 1.

Table 1. *– Paramaters used for MLP training and testing*

Input/Output	***Parameter***	***Range***
Input	Temperature (T)	1.81°C – 37.11°C
Input	Ambient Pressure (AP)	992.89 mB - 1033.30 mB
Input	Relative Humidity (RH)	25.56% - 100.16%
Input	Exhaust Vacuum (V)	25.36 cm Hg - 81.56 cm Hg
Output	Net hourly electrical energy output (EP)	420.26 MW - 495.76 MW

First three input parameters are obtained by measuring GT air intake parameters and fourth is obtained by measuring ST exhaust vacuum. Net hourly electrical energy output is obtained by measuring electrical power generators output power. Described parameters are used for training and testing the Multy-layer perceptron (MLP) for net hourly electrical energy output prediction.

4. Multilayer perceptron

Multilayer perceptron (MLP) is a type of artificial neural network (ANN) wich consists of three types of layers: Input layer, hidden layer(s) and output layer [14]. Multilayer perceptron (MLP) is a type of artificial neural network (ANN) wich consists of three types of layers: Input layer, hidden layer(s) and output layer. ANN is designed by using artificial neurons (ANs), mathematical models of the biological neuron [15]. Output value of each AN can be defined as

$$\boldsymbol{y} = \boldsymbol{f}(\boldsymbol{u}), \tag{1}$$

where u represents a sum of all weights multiplied with all AN input values

$$\boldsymbol{u} = \sum_{\boldsymbol{n}=\boldsymbol{1}}^{\boldsymbol{N}} \boldsymbol{w}_{\boldsymbol{n}} \boldsymbol{x}_{\boldsymbol{n}} \tag{2}$$

and *f* represents activation function, mathematical equivalent to action potential in the biological neuron [15].

Activation functions used for designing MLPs used in this research are [16]:

- Logistic sigmoid,
- Tanh and
- ReLU.

Logistic sigmoid is an activation function that maps values from $\langle -\infty, +\infty \rangle$ domain interval into $[\boldsymbol{0}, \boldsymbol{1}]$ codomain interval This activation function can be defined as

$$\boldsymbol{f}(\boldsymbol{u}) = \frac{\boldsymbol{1}}{\boldsymbol{1} + \boldsymbol{e}^{-\boldsymbol{u}}}. \tag{3}$$

Tanh is an activation function that maps values from $\langle -\infty, +\infty \rangle$ domain interval into $[-\boldsymbol{1}, \boldsymbol{1}]$ codomain interval This activation function can be defined as

$$f(u) = tanh(u) = \frac{e^{u} - e^{-u}}{e^{-u} + e^{u}}. \quad (4)$$

In the case of ReLU activation function, the domain interval will be mapped into the codomain interval by using rectified linear function

$$f(u) = \begin{cases} 0, x < 0 \\ u, x \geq 0 \end{cases}. \quad (5)$$

MLPs are trained by using three different solvers. These solvers are:

- Adam is an adaptive learning rate method (Adam)
- Stochastic gradient descent (SGD) and
- Limited-memory Broyden–Fletcher–Goldfarb–Shanno (L-BFGS)

5. Research methodology

For purposes of this research, 102 different MLPs are designed. These MLPs are designed by varying designs of hidden layers, activation functions and solvers used for MLP training. All MLPs that are designed are trained and tested by using training and test dataset. By using test dataset, output data errors are determined as

$$error = \frac{100 \cdot (y_{real} - y_{output})}{y_{output}}, \quad (6)$$

where y_{real} represents real output value and y_{output} represents value predicted with MLP. Minimal errors achieved with each of activation functions, number of hidden layers and solver are obtained.

6. Results and discussion

When minimal errors versus number of hidden layers performances are evaluated for MLPs designed with Logistic sigmoid activation function, it can be seen that minimal errors are achieved if MLPs are trained by using L-BFGS solver. MLPs are performing with higher errors if are trained by using Adam or SGD solver, as it is shown in Figure 2.

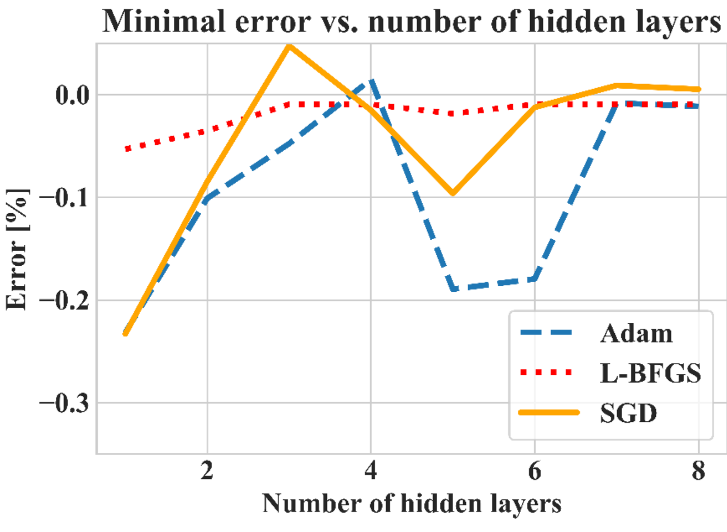

Figure 2. *– Minimal error versus number of hidden layers performances for MLPs designed with Logistic sigmoid activation function*

For the case of MLPs designed with Tanh activation function, it can be seen that lowest errors are achieved if SGD solver is used. For MLPs with two or more hidden layers, similar errors are achieved if L-BFGS is used. Higher errors are present if Adam solver is used, as shown in Figure 3.

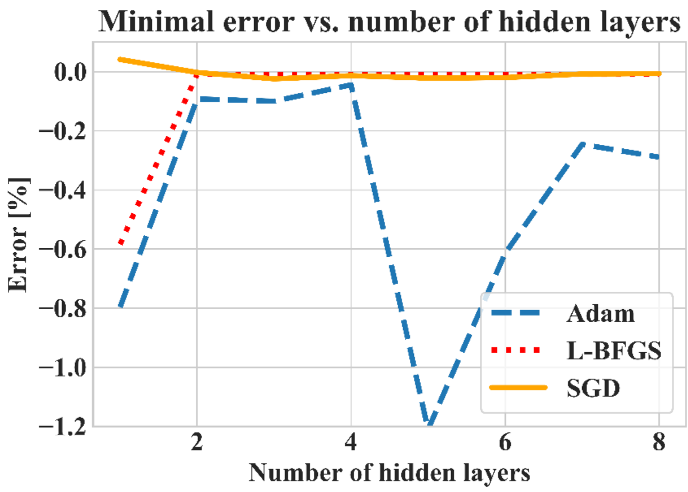

Figure 3. *– Minimal error versus number of hidden layers performances for MLPs designed with Tanh activation function*

When minimal error versus number of hidden layers is observed, it can be seen that minimal errors are achieved if L-BFGS solver is used. Slightly higher errors are achieved by using Adam solver, as it can be seen in Figure 4. By using SGD errors higher than 20 % are achieved. These errors are not included into graph into Fgiure 4.

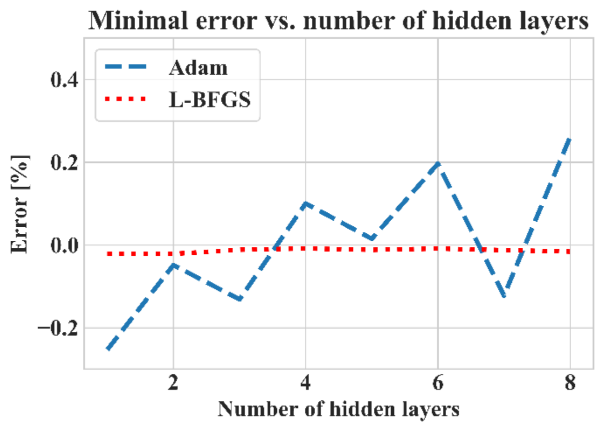

Figure 4. *– Minimal error versus number of hidden layers performances for MLPs designed with ReLU activation function*

When minimal errors are observed for each of activation functions, it can be seen that the lowest errors are achieved if Tanh activation function is used. MLPs designed with ReLU activation function are achieving the highest minimal error, as it is shown in Figure 5.

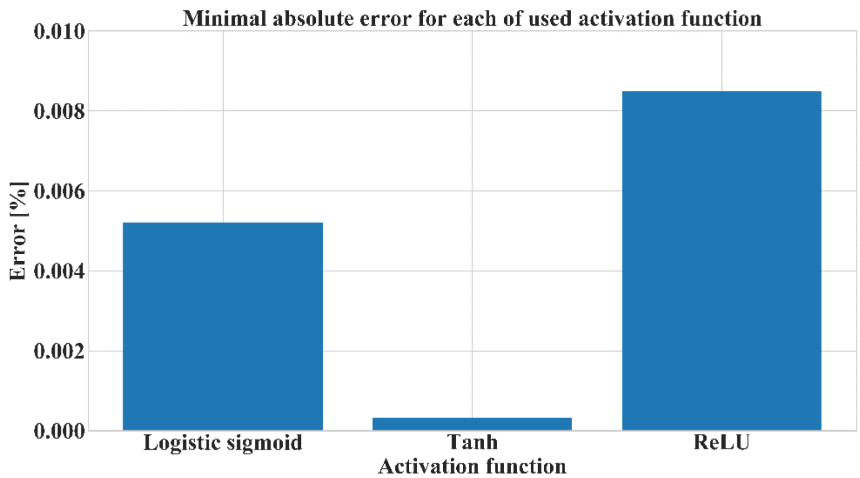

Figure 5. *– Minimal absolute errors achieved with MLPs designed with Logistic sigmoid, Tanh and ReLU activation function*

7. Conclusion

In this paper a MLP-based method for CCPP electric power output estimation is presented. From presented results it can be concluded that is possible do utilize more than one MLP for electric power output estimation. This is achieved by varying MLP designs. From presented results it can be seen that estimation with the highest accuracy will be achieved if MLPs designed with Tanh activation function are used. It can also be seen that similar results are achieved regardless of MLP hidden layers design, if right solver is used.

Anknowledgment

This research has been (partly) supported by the CEEPUS network CIII-HR-0108, European Regional Development Fund under the grant KK.01.1.1.01.0009 (DATACROSS) and University of Rijeka scientific grant uniri-tehnic-18-275-1447.

Bibliography

[1] Mrzljak, V., Poljak, I., Orović, J., & Prpić-Oršić, J. (2019, January). Numerical analysis of real open cycle gas turbine. In INTERNATIONAL SCIENTIFIC CONFERENCE HIGH TECHNOLOGIES. BUSINESS. SOCIETY 2019.

[2] Mrzljak, V., Perčić, G., & Prpić-Oršić, J. (2018, January). GAS TURBINE UPGRADE WITH HEAT REGENERATOR-NUMERICAL ANALYSIS OF ADVANTAGES AND DISADVANTAGES. In Third International Scientific Conference-Winter Session-" Industry 4.0 2018".

[3] Polyzakis, A. L., Koroneos, C., & Xydis, G. (2008). Optimum gas turbine cycle for combined cycle power plant. Energy conversion and management, 49(4), 551-563.

[4] Blažević, S., Mrzljak, V., Anđelić, N., & Car, Z. (2019). Comparison of energy flow stream and isentropic method for steam turbine energy analysis. Acta Polytechnica, 59(2), 109-125. (doi:10.14311/AP.2019.59.0109)

[5] Mrzljak, V., Poljak, I., & Prpić-Oršić, J. (2019, January). Numerical analysis of turbo-generator steam turbine energy efficiency and energy power losses change during the variation in developed power. In INTERNATIONAL SCIENTIFIC CONFERENCE MACHINES. TECHNOLOGIES. MATERIALS 2019-winter session.

[6] Orović, J., Mrzljak, V., & Poljak, I. (2018). Efficiency and Losses Analysis of Steam Air Heater from Marine Steam Propulsion Plant. Energies, 11(11), 3019. (doi:10.3390/en11113019)

[7] Mrzljak, V., Prpić-Oršić, J., & Poljak, I. (2018). Energy Power Losses and Efficiency of Low Power Steam Turbine for the Main Feed Water Pump Drive in the Marine Steam Propulsion System. Pomorski zbornik, 54(1), 37-51. (doi :10.18048/2018.54.03)

[8] Mrzljak, V., Poljak, I., & Mrakovčić, T. (2017). Energy and exergy analysis of the turbo-generators and steam turbine for the main feed water pump drive on LNG carrier. Energy conversion and management, 140, 307-323. (doi: 10.1016/j.enconman.2017.03.007)

[9] Mrzljak, V., Poljak, I., & Medica-Viola, V. (2017). Dual fuel consumption and efficiency of marine steam generators for the propulsion of LNG carrier. Applied Thermal Engineering, 119, 331-346. (doi:10.1016/j.applthermaleng.2017.03.078)

[10] Brnić, M., Čondrić, E., Blažević, S., Anđelić, N., Borović, E., & Car, Z. (2018, January). SEPSIS PREDICTION USING ARTIFICIAL INTELLIGENCE ALGORITHMS. In International Conference on Innovative Technologies, IN-TECH 2018.

[11] Bogović, K., Lorencin, I., Anđelić, N., Blažević, S., Smolčić, K., Španjol, J., & Car, Z. (2018, January). ARTIFICIAL INTELLIGENCE-BASED METHOD FOR URINARY BLADDER CANCER DIAGNOSTIC. In International Conference on Innovative Technologies, IN-TECH 2018.

[12] Anđelić, N., Blažević, S., & Car, Z. (2018, January). TRAJECTROY PLANNING USING GENETIC ALGORITHM FOR THREE JOINTS ROBOT MANIPULATOR. In International Conference on Innovative Technologies, IN-TECH 2018.

[13] Tüfekci, P. (2014). Prediction of full load electrical power output of a base load operated combined cycle power plant using machine learning methods. International Journal of Electrical Power & Energy Systems, 60, 126-140. (doi: 10.1016/j.ijepes.2014.02.027)

[14] Tang, J., Deng, C., & Huang, G. B. (2015). Extreme learning machine for multilayer perceptron. IEEE transactions on neural networks and learning systems, 27(4), 809-821. (doi: 10.1109/tnnls.2015.2424995)

[15] Schmidhuber, J. (2015). Deep learning in neural networks: An overview. Neural networks, 61, 85-117., (doi: 10.1016/j.neunet.2014.09.003)

[16] Karlik, B., & Olgac, A. V. (2011). Performance analysis of various activation functions in generalized MLP architectures of neural networks. International Journal of Artificial Intelligence and Expert Systems, 1(4), 111-122.

CZECH TECHNICAL UNIVERSITY IN PRAGUE
FACULTY OF MECHANICAL ENGINEERING
DEPARTMENT OF MANUFACTURING TECHNOLOGY

10th INTERNATIONAL TECHNICAL CONFERENCE

TECHNOLOGICAL FORUM 2019

IMMANUEL konferenční centrum – VESELÝ KOPEC
CZECH REPUBLIC

18. – 20. 6. 2019
ITCTF.CZ

Publisher:

Ing. Jan Kudláček
Na Studánkách 782
551 01 Jaroměř

Tisk:

TISK AS, s.r.o., Jaroměř

Pages:

Quantity:	100 copies
Year:	2019
Publication:	first

ISBN 978-80-87583-30-2

Dear colleagues,

the tenth year of the “Technological Forum” and “Technological Forum Junior”, based on your suggestions and contributions, aims to contribute to the objectives of sustainable development of mechanical technologies.

This conference has become a place of traditional meetings of the teachers and the students from technological departments of technical universities and debating the results of their yearly work.

The organization of expert and social meetings has also a long tradition. Also the gathering of technological departments has its own tradition. The proof of the meaningfulness is the high quality of the presentations and the papers, increase in the attendance of the participants from the individual departments and the presentation of the new technological research and knowledge.

The production with high value-added ideas and responsibilities is the necessary for the sustainable development of our countries in accordance with all of the current and future restrictions and requirements. For this goal the high standard of the education, the skills and the discipline is vital. These attributes are still accepted by the majority of the population in our countries. Let us not give a space to the rest of the population, the minority of indifference.

All of the published articles of this year's Technological Forum show rapid development in technologies and requirements for new information. The most important is the mutual cooperation in every field and in every form of education. Topics include up-to-date engineering technologies, materials and other related issues.

On Behalf of all organizers I would like to welcome you at the 10th scientific conference “Technological forum 2019”. I would like to thank you for your contribution, cooperation and participation

Ing. Jan Kudláček, Ph.D.
Department of manufacturing technologies,
Faculty of Mechanical Engineering,
CTU in Prague

CONTENTS

COMPARISON OF MECHANICAL PROPERTIES OF PRECIPITATION HARDENING TOOL STEEL 1.2709 - PRINTED X CONVENTIONALLY PRODUCED 1
Vladislav ANDRONOV, Zdeněk PITRMUC, Lukáš PELIKÁN, Libor BERÁNEK

THE ISSUE OF REGENERATION OF METAL POWDER DLMS 3D PRINTING 8
Karla BÜRGEROVÁ, Aleš HERMAN

THE CALCULATED EXPERIMENT IN THE THEORY OF FIBER FOAM CONCRETE 15
Kseniia DOMNINA, Valentin REPKO

COMPARISON OF CHANGES IN EMISSIVITY AND ROUGHNESS OF THE ELECTRODES FOR RESISTENCE SPOT WELDING DUE TO THEIR WEAR 18
Lucie FOREJTOVÁ, Tomáš ZAVADIL, Ladislav KOLAŘÍK, Marie KOLAŘÍKOVÁ, Vlastimil KRÁLÍK

APPLICATIONS OF REVERSE ENGINEERING USING FARO ARM WITH LINE LASER SCANNER 24
Miklós GÁBRIEL, Miklós CZAMPA, Tibor SZALAY

WAAM OPTIMIZED BY TROUGH ARC SEAM TRACKING 29
Tomáš GURČÍK, Karel KOVANDA, Ladislav KOLAŘÍK

HYDROGEN DIFFUSION INTO STEEL DUE TO SURFACE TREATMENTS 33
Hana HRDINOVÁ, Viktor KREIBICH

DEVELOPMENT OF LABORATORY EQUIPMENT FOR PLASMA ELECTROLYTIC OXIDATION (PEO) 38
Martin CHVOJKA, Viktor KREIBICH, Jan KUDLÁČEK

WELDING SIMULATION RESULTS IN COMPARISON WITH REAL WELDING PROCESS 45
Štěpán JEŽEK, Ladislav KOLAŘÍK, Jaroslav BRABEC, Libor BENEŠ

LOCATION OF VEHICLE REGISTRATION PLATES USING ADAPTIVE THRESHOLDING 51
Ladislav KARRACH, Elena PIVARČIOVÁ

OPTIMIZATION OF CASTINGS IN INVESTMENT CASTING FOUNDRY KDYNIUM A.S 60
Tomas KMENT

COMPARISON OF DIFFERENT TYPES OF TEMPERATURE SENSORS FOR SURFACE TEMPERATURE MEASUREMENT OF HEAT SINK 71
Pavol KOLEDA, Zuzana BRODNIANSKÁ

MAINTENANCE OF INTERNAL SURFACES AND LIQUID WASTE DISPOSAL 78
Jiří KUCHAŘ, Viktor KREIBICH

DESIGN OPTIMIZATION OF MOULDS FOR VIBROCASTED REFRACTORY 83
Jiří KYNCL, Tomáš KELLNER, Martin KYNCL, Michal SLANÝ, Libor BERÁNEK

MANUFACTURING OF COMPRESSOR IMPELLERS 88
Martin LAMRICH

ESTIMATION OF COMBINED CYCLE POWER PLANT POWER OUTPUT USING MULTILAYER PERCEPTRON VARIATIONS . 94
Ivan LORENCIN, Zlatan CAR, Jan KUDLÁČEK, Vedran MRZLJAK, Nikola ANĐELIĆ, Sebastijan BLAŽEVIĆ

AUTOMATED SYSTEM OF SUPPORT OF DECISION-MAKING STRUCTURES 99
Yury MIKHAYLOV, Pavol BOŽEK

ANALYSIS OF TWO METHODS FOR STEAM TURBINE DEVELOPED POWER CALCULATION IN INDUSTRY 4.0................ 103
Vedran MRZLJAK, Zlatan CAR, Jan KUDLÁČEK, Nikola ANĐELIĆ, Ivan LORENCIN, Sebastijan BLAŽEVIĆ

THE EFFECT OF PUNCH SPEED ON POSITION OF FORMING LIMIT CURVE 111
Vít NOVÁK, Michal VALEŠ, František TATÍČEK, Jan ŠANOVEC, Lukáš CHRÁŠŤANSKÝ

FE ANALYSIS OF MECHANICAL STRESS DISTRIBUTION IN SPUR GEAR DUE TO THE ASSEMBLY ERRORS..................... 115
Adam PATALAS, Pawel ZAWADZKI, Natalia WIERZBICKA, Dominika SZADKOWSKA, Lukasz FURMANSKI, Stanislaw LEGUTKO, Rafał TALAR

PRECISION AND DIMENSIONAL LIMITS ANALYSIS OF ALUMINIUM ALLOY ARTIFACTS PRODUCED ON DMLS MACHINE CONCEPT LASER M2 CUSING 121
Lukáš PELIKÁN, Vladislav ANDRONOV, Libor BERÁNEK, Jan ŠIMOTA, Zdeněk PITRMUC

EDGE TRIMMING OF UNIDIRECTIONAL CARBON FIBRE REINFORCED POLYMER COMPOSITES 128
Csongor PERESZLAI, Norbert GEIER

INCREASING THE EFFICIENCY OF PRODUCTION PLANNING 133
Vanessa PRAJOVÁ

THE METHOD OF PRODUCT CLASSIFICATION IN PRODUCTION LEVELLING 138
Paulina REWERS

THE POLY CONTACT CONNECTION WITH INTERFERENCE 142
Alexey SCHENYATSKIY, Ella SOSNOVICH, Olga ZUYKOVA

CREEP FEED GRINDING OPTIMIZATION 150
Jan ŠIMOTA, Zdeněk PITRMUC, Lubomír ŠTAJNOCHR, Libor BERÁNEK

THE INFLUENCE OF MG PARTICLES IN THE MATRIX OF ORGANIC PAINTS ON THE ABRASION RESISTANCE OF COATINGS.. 155
Miroslav SLOVINEC, Michal ZOUBEK, Jan KUDLÁČEK

NEW CHROME-FREE PASSIVATIONS OF HOT-DIP GALVANIZED SURFACE 160
Jakub SVOBODA, Jan KUDLÁČEK, Viktor KREIBICH, Eva M. SEDLÁČKOVÁ

ANALYSIS OF MANUFACTURING PROCESS - CASE STUDY 165
Marta SZCZEPANIAK

INTERACTIVE THERMOSENSITIVE PAINTINGS.. 172
Zuzana TATÍČKOVÁ, Viktor KREIBICH, Dana BENEŠOVÁ, Jan KUDLÁČEK

JOINING OF NITINOL WITH STAINLESS STEEL IN MEDICAL CATHETERS... 177
Jan TAUER, Tomáš KRAMÁR, Petr VONDROUŠ

INFLUENCE OF SETTING UP OF SCANNING SPEED OF TACTILE PROBING CMM SYSTEMS ON THE FINAL MEASUREMENT PROCESS CAPABILITY 182
Jan URBAN, Libor BERÁNEK, Ondřej KOŠŤÁK, Jan ŠIMOTA, Rudolf DVOŘÁK

FEASIBILITY OF DP500 STEEL OUTER CAR BODY PARTS 187
Michal VALEŠ, Vít NOVÁK, František TATÍČEK, Jan ŠANOVEC, Lukáš CHRÁŠŤANSKÝ

DEVELOPMENT OF ELECTROPLATING TECHNOLOGY CHROMIUM-DIAMOND COATINGS BY IMPROVING METHODS FOR STABILIZING NANODIAMONDS 194
Svetlana VARFALAMEEVA, Anastasia BUTORINA, Sergey SHUKLIN

BULK COATING HIGH STRENGTH SCREWS BY CATAFORETIC PROCESS 198
Václav VEVERKA, Kamil HYLÁK, Petr DRAŠNAR, Jan KUDLÁČEK, Martin JINDŘIŠEK

THERMAL FIELD ANALYSIS IN HIGH PRESSURE DIE CASTING TECHNOLOGY 201
Tomáš VÍTEK, Aleš HERMAN

COMPARISON OF DEFORMATION OF WAX PATTERNS WITH APPROPRIATE CASTINGS FOR BLADES MS3002-2 206
Ondřej VRÁTNÝ, Aleš HERMAN, Irena KUBELKOVÁ

THE MODEL OF TECHNICAL SYSTEM OPERATION 219
Ivan ABRAMOV, Ella SOSNOVICH, Yuri TURYGIN

DESIGN AND DEVELOPMENT OF AN IN-LINE INSPECTION IN THE PRODUCTION OF CERAMIC CHIMNEY PIPES 224
Libor BERÁNEK, Lubomír ŠTAJNOCHR, Jiří KYNCL, Jiří SOMMER, Tomáš KELLNER, Martin KYNCL

THE NEW POSSIBILITIES OF UTILIZING THE INERTIAL NAVIGATION SYSTEM IN ROBOTOTECHNICS 231
Pavol BOŽEK, Yuri NIKITIN, Yuri TURYGIN

INTEGRATION OF MODERN CAD SYSTEMS IN PRODUCTION ENGINEERING SYSTEMS 237
Miroslav CÍSAR, Zuzana SÁGOVÁ, Olga ZHUYKOVA

CREATIVE USE OF THE INTERNET TO DISSEMINATE MESSAGES 241
Svetlana FIRSOVA

INTENSIVE AGRICULTURE PRODUCTION IN LOW CONSUMPTION ENERGY ENVIRONMENT.......................................246
J. GALVÃO, A. NABAIS, H. CORREIA, P. AMARO, A. NEGRÃO, V. RIBEIRO

MTBF, MTTR – KEY INDICES IN THE TPM SYSTEM 253
Pawel GROBELNY, Lukasz FURMANSKI, Stanislaw LEGUTKO, Pawel ZAWADZKI, Natalia WIERZBICKA, Dominika SZADKOWSKA, Adam PATALAS

THE PRODUCTION OPTIMIZATION OF STEEL IMPELLERS BY USING OF THE ELECTRON BEAM WELDING METHOD......257
Petr HAVLÍK, Jan KOUŘIL, Libor VÁLKA, Ivo DLOUHÝ, Petr ChALUPNÍK

NEW METHODS TO ENSURE A PREDICT THE DEFORMATION BEHAVIOUR OF WAX PATTERN BLADE SEGMENT 264
Aleš HERMAN, Irena KUBELKOVÁ, Ondřej VRÁTNÝ

DEVELOPMENT AND TESTING OF SELF-LUBRICATING COMPOSITE FOIL FOR BEARINGS 272
Martin CHVOJKA, Vratislav HLAVÁČEK, Jakub MELICHAR, Michal MÉSZÁROS, Barbora KYSELÁ

INFLUENCE OF WELDING PROCESS CONTROL ON RESISTANCE SPOT WELDS QUALITY 276
Marie KOLAŘÍKOVÁ, Ondřej BALIHAR

IMPLEMENTING INFORMATION SUPPORT PRODUCTION ACTIVITIES 282
Alexander KORSHUNOV, Voyachek Igor IVANOVICH

ELIMINATION OF WASTE IN THE WORKPLACE THROUGH FIVE STEPS..286
Alexander KORSHUNOV, Vanessa PRAJOVÁ

MANAGEMENT OF UNIVERSAL SHELF STACKER...290
Voyachek Igor IVANOVICH, Alexander KORSHUNOV

FORGING A DRAW ROD FOR A STEAM LOCOMOTIVE NO. 464 053 295
Břetislav MACHKA, Vít NOVÁK, Michal VALEŠ, František TATÍČEK, Ondřej STEJSKAL

INNOVATIVE ALGORITHM FOR SOLVING SIMULTANEOUS LOCATION AND MAPPING PROBLEM 301
Ivan ABRAMOV, Timur MAZITOV, Pavol BOŽEK, Yuri NIKITIN

SIMULATION OF PROCESS OF SOLIDIFICATION OF TEST PIECES FOR ASSESSMENT OF VALUES OF MECHANICAL PROPERTIES IN CASTING INTO SELF-HARDENING MIXTURES **309**
Antonín MORES, Ondřej VRÁTNÝ, Jaroslav PROVAZNÍK, Milan NĚMEC

ACCURACY IMPROVEMENT OF THE NUMERICAL SIMULATION RESULTS IN THE PROCESS OF SHEET METAL WORKING **322**
Tomáš PAČÁK, František TATÍČEK, Michal VALEŠ

INJECTION MOULDING FOR PROTOTYPING AND SMALL BATCH PRODUCTION **327**
Tomaž PEPELNJAK, Jure DEŽMAN

HEAT TRANSFER IN COUNTERCURRENT AND PARALLEL FLOW IN A PLATE HEAT EXCHANGER **334**
Mohammad Emal QAZIZADA

CALCULATE THE TRAJECTORIES OF MECHATRONIC SYSTEMS AND CAD/CAM **341**
Zuzana SÁGOVÁ, Aleksander LOZKIN, Ivana KLAČKOVÁ

MIRCRO/NANO MATERIAL PROCESSING **347**
Mladen ŠERCER, Tomislav BREŠKI, Pero RAOS

FOUNDRIES TECHNICAL PREPARATION OF PRODUCTION (TPP) IN THE CONTEXT OF INDUSTRY 4.0 .... **355**
František Václav ŠTOURAČ

LASER REMELTING PROCESS OF AL-ALLOYS **359**
Roman ŠTURM, Janez GRUM, Slavko BOŽIČ

ELECTRON BEAM WELDING **366**
Yuri TURYGIN, Yuliya ZUBKOVA

METHODOLOGY TS FOR REDUCE RISK **372**
Lukáš TURZA

SOLDERING OF NITINOL WIRES **375**
Petr VONDROUŠ, Jakub KŘIVÁNEK