THE OPTIMIZATION OF OPERATING PARAMETERS FOR A MELTING FURNACE DURING MELTING OF ALUMINIUM ALLOY AlSi7Mg0.6

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One of the key requirements for almost every technical device is its reliable, safe and economical operation. All these requirements can only be fulfilled by the appropriate choice of the individual elements of a technical device and their appropriate constructional arrangement concept. The choice of the elements of a technical device and their constructional arrangement must be done as a matter of priority when designing it, and with respect to maximization of the operation reliability and safety. At the same time, its operation should also be economically efficient while preserving the required functions and operating parameters given by technical conditions for the given type of a technical device. Operating parameters of a technical device must be optimized due to its economical operation. The aim of this paper is therefore to describe the process of choosing a favourable operating mode of the melting furnace KOV 010/1998 for melting of Aluminium alloy AlSi7Mg0.6 based on the optimization of its operating parameters. The optimization was focused mainly on achieving as short time as possible for a single melting cycle with the lowest possible natural gas consumption.

KEYWORDS

optimization, technical device, melting furnace, operating parameters, economic efficiency.

1 INTRODUCTION

In general, the worse reliability of a technical device is, the worse is its safety and economic efficiency of its operation [Birolini 2014]. The criterion for operation reliability [Dhillon 2004] of a technical device is mainly the requirement to fulfil the required function during the set period while maintaining operating parameters given by technical conditions [Cacko 2014]. Technical conditions mean [Dubjak 2016] the sum of specifications of technical characteristics prescribed for the required function of a technical device, as well as its operation mode, storage, transport, maintenance [Famfulik 2007] and repair [Straka 2016]. Requirements for its operational parameters are mainly about productivity indicators [Murcinkova 2013], energy intensity, but also about economic efficiency. It is particularly necessary to optimize operating parameters [Turtelli 2006, Swiercz 2018] of a technical device [Yan 2017] in order to achieve favourable economic indicators. One of the key and indispensable basis for the expert selection of the most propitious operating mode is the optimization of operating parameters of a technical device [Straka 2017]. By optimizing operating parameters, it is possible to choose from a set of possible settings of operating parameters aimed at increasing the overall economy of the technical device operation [Jurko 2012] and a suitably chosen optimization criterion [Mohammed 2016] to choose a variant which subsequently ensures maximum productivity of a technical device at minimum operating costs.

2 THEORETICAL OVERVIEW IN THE FIELD OF THE OPTIMIZATION OF AL ALLOY MELTING PROCESS

Aluminium and its alloys have come to the fore in the last two decades [Michalik 2018] due to the intense development of the aerospace and automotive industry. Aluminium alloy castings are the second most commonly used non-ferrous metal material after iron castings. More than 15 million tons of Aluminium casting are produced annually, with annual demand estimated at 24 million tons [Miskufova 2013]. It is necessary to increase the production of available equipment [Zidek 2017] while maintaining low cost [Zhang 2017] and high-quality production conditions to meet the demand for Al castings. This can be achieved by optimizing the energy consumption and the total time required for the casting production. Apart from the pressure casting machine itself, the melting furnace is an important device in the production of Al castings. It needs a lot of thermal energy for its operation [Malega 2017]. Thermal energy is most often obtained by the conversion of electricity or natural gas combustion which is financially demanding. Therefore, there are extensive studies in the field of Al alloy melting process. Li attempted to create a modified model [Li 2005] that allows some theoretical guidance to optimization of Al alloy melting process in melting furnaces. Edward and Lazic. proposed a way to increase [Edward 2009] the performance of melting furnaces for Al alloys [Lazic 2005]. However, only few studies have been directed towards optimizing the heat consumption needed to melt Al alloys and towards time of one melting cycle. According to Zang, the current technical solutions of the Al alloy melting furnaces are characterized by relatively low energy efficiency, low productivity [Wanga 2012] and high levels of environmental pollution [Zhang 2017]. At the same time, the optimization of operating parameters in the Al alloy melting process is very important for achieving high thermal efficiency [Salcedo 2017], less polluting substances and high-quality products. However, the traditionally used methods of optimization which are based on calculations are inefficient and, in addition, can give a misleading result [Panda 2017]. It is therefore necessary to optimize operating parameters [Rimar 2018] of the melting furnace on the basis of experimental results in order to obtain credible results. The aim of the experiment was therefore to determine the favourable operating mode of the melting furnace KOV 010/1998 while melting of Al alloy EN AC-42200 (AlSi7Mg0.6) on the basis of measurements made in the form of the optimization of operating parameters [Straka 2011]. The optimization has been done with respect to maximizing the melt furnace productivity with as little natural gas consumption per one melting cycle as possible.

3 MATERIAL AND METHODS OF WORK

3.1 *Technical means used in the experiment*

The process of optimization was performed on the melting furnace KOV 010/1998. It is a melting furnace made of steel profiles and sheets, which is used mainly for Al alloy melting. Its design consists of a support frame that is anchored to the base plate. The furnace is mounted on two sliding bearings on the front while on the back it is mounted to a hydraulic cylinder that allows the furnace to tilt (lift) during emptying. The following Figure 1 shows the melting furnace KOV 010/1998 used in the experiment.

Figure 1: Melting furnace KOV 010/1998

The lining of the melting furnace KOV 010/1998 consists of refractory bricks containing 42% of Al. There is an insulating layer made of ceramic insulation boards on the steel furnace shell. This type of lining provides for the reduction of total heat losses through the steel furnace shell. This ensures that the temperature on the outside of given steel furnace shell is for the given melting furnace below 80°C. The spout and the exhaust gas opening are protected by refractory concrete. The melting furnace space at the burner place is covered with special refractory material that resists temperatures up to 1600°C. The movable door of the melting furnace is secured with refractory cast concrete. Tilting of the melting furnace during its emptying is performed by means of a hydraulic cylinder with a maximum stroke height of 1.8m. The opening of the movable door is solved by pulley transfer and hydraulic cylinders with a maximum stroke height of 0.7m. Hydraulic cylinders for opening the movable door are controlled by hydraulic fluid pressure with two pumps. The following Table 1 shows the basic technical parameters of the melting furnace KOV 010/1998 and natural gas used.

Table 1: Technical parameters of the melting furnace KOV 010/1998 and natural gas used

Parameter of the melting furnace	Range
Maximum melting power	0.7 up to 0.9 $t \cdot h^{-1}$
Essential dimensions of the furnace width/ length/height	4.93/3.20/3.08 m
Maximum furnace capacity	8.0 t
Method of heating	gas burners 2x0.7MW
Source of heat	natural gas
Standby weight of the melting furnace	35.0 t
Working pressure	5 – 10 kPa
Installed input of the hydraulic unit	7.7 kW
Installed el. Input of the fan	5.2 kW; 400 V
Parameter of natural gas	**Range**
Methane content	93 to 99 %
Density	0.71 to 0.72 $kg.m^{-3}$
Calorific value	9.5 to 9.8 $kWh.m^{-3}$
Emission factor CO_2	55 to 56 tCO_2/TJ

The melting of aluminium alloy AlSi7Mg0.6 in the melting furnace KOV 010/1998 was realized by using two gas burners with a total power of 2x0.7MW. These are monoblock burners with a built-in fan and an electric motor. The burners have a power control system that includes a programmable automatic flame ionisation fuse. The following Figure 2 shows the system of installed burners and the air supply to the melting furnace KOV 010/1998.

Figure 2: The system of burner no. 1 and no. 2 including the air supply to the melting furnace KOV 010/1998

The measurement of natural gas consumption in m^3 was performed by using the digital gas meter ELGAS miniElcor Volume Converter during each experimentally selected modes of the operation for the melting furnace KOV 010/1998 while melting aluminium alloy AlSi7Mg0.6. The following Figure 3 shows the way of installing the digital gas meter ELGAS miniElcor Volume Converter for experimental purposes.

Figure 3: Digital gas meter ELGAS miniElcor Volume Converter

The melting furnace KOV 010/1998 does not primarily have a device for direct measurement of the internal furnace temperature and molten metal. Therefore, the indirect method with the resistance temperature sensor Limatherm Sensors TTSC-22 and the Fluke 185 True RMS Multimeter was used to measure the temperature. The following Figure 4 represents the method of placing the resistance temperature sensor in the melting furnace and measuring its electrical resistance values by means of the multimeter.

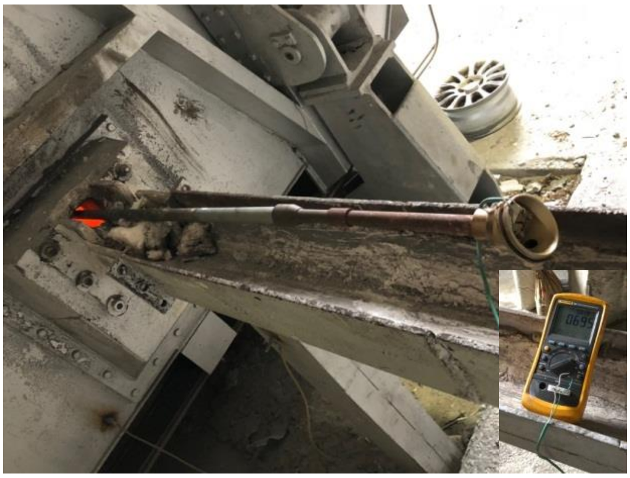

Figure 4: Indirect temperature measurement of aluminium alloy AlSi7Mg0.6 with the Limsetm Sensors TTSC-22 and Fluke 185 True RMS Multimeter

The following Table 2 sets out the basic technical specification of the temperature resistance sensor Limatherm Sensors TTSC-22, which was used in the experiment to measure the temperature of the molten Al alloy indirectly.

Table 2: Basic technical specification of the temperature resistance sensor Limatherm Sensors TTSC-22

Temperature range / sensing element
0 to 1600°C ; class 2
Sheath
– holding tube material: steel 1.4841, 22mm diameter – ceramic tube: corundum 799, 15mm diameter – length *L*: 0.3 – 2.0m
Thermocouple wire diameter
– 0.5mm diameter
Connection head
–A A, IP53, -40 to 100°C
Temperature transmitter
with standard 4-20mA output signals
Tolerance for thermocouple classe 2
from 0°C to +600°C is tolerance ±1,5°C from +600°C to +1600°C is tolerance ±|t| 0.0025°C |t| is the absolute value of temperature

Aluminium alloy AlSi7Mg0.6 which by its chemical composition corresponds to the EN AC-42200 standard was used in the experiment. This is Al alloy that is often used in the production of thin-walled castings with complex geometry of the shape. Its application is mainly found in the automotive, aerospace and space industries. It has relatively high electrical conductivity of 40% IACS, medium thermal conductivity of 150 W.m^{-1} K^{-1} and melting point of 610°C. The following Table 3 shows the basic chemical composition and mechanical properties of Al alloy EN AC-42200 (AlSi7Mg0.6) that was used in the experiment.

Table 3: Basic chemical composition and mechanical properties Al alloy EN AC-42200 (AlSi7Mg0.6)

Chemical composition EN AC-42200 (AlSi7Mg0.6) (%)							
Al	Si	Mg	Ti	Fe	Mn	Zn	Cu
91-93.1	6.5-7.5	0.45-0.7	0-0.25	0-0.19	0-0.1	0-0.07	0-0.05

Mechanical Properties EN AC-42200 (AlSi7Mg0.6)						
Tensile Stren. Rm$_{0,2}$ (Mpa)	Thermal Conduct. (W.m^{-1}K^{-1})	Electrical Conduct. (% IACS)	Specific Heat Capacity (J.kg^{-1}K^{-1})	Density (g.cm^{-3})	Melting Complet. (°C)	Thermal Expansion (µm.m^{-1}K^{-1})
210	150	40	910	2.6	610 °C	22

3.2 *Experiment conditions*

Measurements of the total AlSi7Mg0.6 alloy melting time including the measurement of the total natural gas consumption (m^3) during one melting cycle in the melting furnace KOV 010/1998 were performed in the experiment. There were five separate measurements performed together within the selected operating modes. Each experimental measurement was performed in other operating mode of the melting furnace KOV 010/1998 with approximately 7.9t of melt. During the first operation mode OM_1 of the melting furnace was the gas burner no. 1 set to low power, while the gas burner no. 2 was out of service. The gas burner no. 1 as well as the gas burner no. 2 were set to low power during the second operation mode OM_2 of the melting furnace. During the third operating mode OM_3, the gas burner no. 1 was set to high power while the gas burner no. 2 was out of service. During the fourth operation mode OM_4, the gas burner no. 1 was set to high power with the gas burner no. 2 that has been set to low power. There was the gas burner no. 1 as well as the gas burner no. 2 set to high power during the fifth operating mode OM_5 of the melting furnace.

The melting furnace KOV 010/1998 was during the experimental measurement preheated to approximately 700°C before its first loading. The furnace temperature dropped below 600°C after the loading. Measurements of time and gas consumption which is required for melting and heating of Al alloy EN AC-42200 (AlSi7Mg0.6) to be at temperature of about 720°C were performed within the individual operating modes after each time the first load was completed. It was necessary to perform the two-phase loading process due to the melting mechanism of Al alloy AlSi7Mg0.6. Approximately 3.55t of pure aluminium was loaded in the first phase. It melted at the temperature about 700°C and the second phase of loading Aluminium was performed. The second phase of loading was about 4.35t, including the added alloying elements necessary to achieve the required chemical composition of Aluminium alloy according to EN AC-42200 standard. Experimental measurement of the total time within the individual operating modes of the melting furnace KOV 010/1998 and the corresponding natural gas consumption was always completed when the melt temperature reached approximately 720°C.

3.3 *Results of experimental measurement*

The total AlSi7Mg0.6 alloy melting times and the measured values of natural gas consumption were detected within individual operating modes of the melting furnace KOV 010/1998. These values are listed in the following Table 4.

Table 4: Detected values of the total melting time of Al alloy AlSi7Mg0.6 and the total natural gas consumption for the individual operating modes of the melting furnace KOV 010/1998

Operating mode	Gas burner operation		Total natural gas consumption (m^3)	Melting time (h)
	No.1	No.2		
OM_1	Low power	Out of service	1148	14.0
OM_2	Low power	Low power	1043	13.5
OM_3	High power	Out of service	967	13.0
OM_4	High power	Low power	915	11.5
OM_5	High power	High power	952	10.0

Substantial differences between the total AlSi7Mg0.6 alloy melting time and the natural gas consumption during individual operating modes of the melting furnace KOV 010/1998 can be observed from data in the Table 4. Figure 5 illustrates the dependence of the total natural gas consumption on the operation time of the melting furnace KOV 010/1998 during Al alloy AlSi7Mg0.6 melting within individual operating modes. It is based on the recorded data from Table 4.

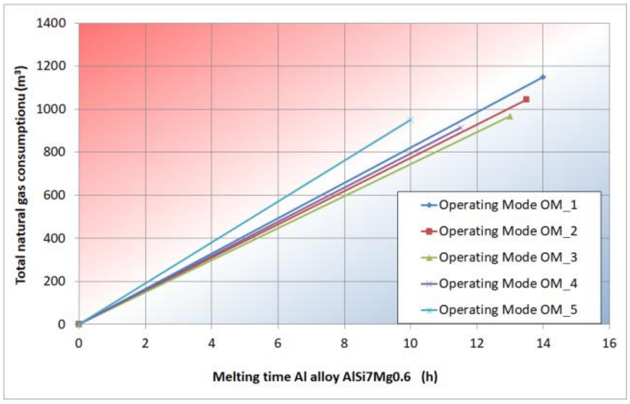

Figure 5: Dependence of the total natural gas consumption (m^3) on the operation time (h) of the melting furnace KOV 010/1998 during Al alloy AlSi7Mg0.6 melting within individual operating modes

As can be observed from the Figure 5, the lowest value of the total melting time of Al (10h) was detected during operating mode OM_5 and on the other hand, the highest (14h) was detected during operating mode OM_1. The lowest natural gas consumption (915m^3) needed to achieve melt temperature of about 720°C was measured during the OM_4 operating mode, while the highest (1148m^3) during the OM_1 operating mode. From the above-mentioned report it is evident that the most disadvantageous variant of the operation of the melting furnace KOV 010/1998 for the melting of the Al alloy AlSi7Mg0.6 in terms of the total AlSi7Mg0.6 Al alloy melting times and the natural gas consumption can be considered the OM_1 operating mode.

The optimization of the operating mode of the melting furnace KOV 010/1998 was performed at the melting of Al alloy AlSi7Mg0.6 on the basis of the dependence of the total natural gas consumption (m^3) on the operating time (h). The optimization was based on the optimization criterion, which was to minimize the total melting time while minimizing the total natural gas consumption during one melting cycle. The result of the optimization process can be seen from the chart in Figure 6.

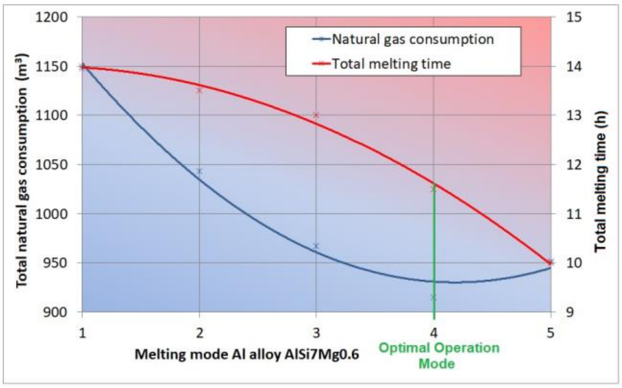

Figure 6: Result of the optimization process of the melting furnace KOV 010/1998 operation mode at melting Al alloy AlSi7Mg0.6

There are several facts evident in the melting of Al alloy AlSi7Mg0.6 from the chart in Figure 6 for the optimization of the operating mode of the melting furnace KOV 010/1998. First, a slight increase in total gas consumption can be seen in reducing the burner power. At the same time, there is a slight increase in the total time of one melting cycle with a decrease in the burner power. The lowest total natural gas consumption per melting cycle (915m^3) was detected during the OM_4 operating mode, as can be observed from the chart in the Figure 6. However, there was a slight increase by 37 m^3 in the total natural gas consumption under this mode of operation, when compared to mode OM_4. It is clear that as the optimal operating mode can be considered the OM_4 mode in which the burner no. 1 was set to high power and burner no. 2 to low power. The operating mode OM_3 is partially approaching the operating mode OM_4 with its burner no. 1 set to high power and the burner no. 2 out of service. The total time of one melting cycle is by 1.5 hours longer than in the operating mode OM_4. At the same time, there was 52m^3 more of natural gas consumed in this mode of operation when compared to the operating mode OM_4. This operating mode can also be considered as an "emergency mode" in which only one of the burners is in the operation and working at full power. Its main problem is partial cooling of melt. This is due to the construction of the melting furnace KOV 010/1998, which does not allow closing of the air supply through the burner opening that is out of service. This causes the internal space of the melting furnace to cool and hence the cooling of melt itself. Therefore, it would be convenient for the given mode of operation to make minor constructional modifications of the melting furnace, which would allow to close the air supply through the burner opening that is out of operation. It is a realistic assumption that the total time of one melting cycle during the operation mode OM_3 would be shortened, as well as it would come to the reduction of the total natural gas consumption needed for one melting cycle by performing these design modifications on the melting furnace KOV 010/1998.

4 CONCLUSIONS

One of the important criteria placed on almost every technical device is economic efficiency of its operation. As mentioned earlier, this is particularly about indicators of productivity, performance, energy intensity, and overall economic efficiency. The range of these indicators is primarily determined by the construction of a technical device itself, but also by its operating mode. The structural modification of technical device operation would be in many cases too costly in order to meet the requirement of economy and economic efficiency. Rarely, it is even impossible. The optimization of technical device operating mode appears to be a more appropriate alternative for achieving a favourable economic efficiency of the its operation. The aim of the experimental measurements was to determine the optimum operating parameters of the melting furnace KOV 010/1998 for Al alloy AlSi7Mg0.6 and its appropriate operating mode. The optimization process was aimed at minimizing the total time of one melting cycle while taking into account the smallest natural gas consumption. The mode of operation OM_4 of the melting furnace KOV 010/1998 was chosen as the most suitable variant for the AlSi7Mg0.6 Al alloy melting operation on the basis of the experimentally measured data. The lowest natural gas consumption (915m^3) was measured with a favourable overall time (11.5h) of one melting cycle in this mode of operation of the melting furnace.

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REFERENCES

[Birolini 2014] Birolini, A. Reliability Engineering, Theory and Practice. Springer, 2014, 630 p., ISBN 3642395341.

[Cacko 2014] Cacko, P., Krenicky, T., Dobransky, J. Impact of an Excessive Wear of Bearing on the Mechatronic Devices. Applied Mechanics and Materials, 2014, Vol. 460, pp. 99-106, ISSN 1660-9336.

[Dhillon 2004] Dhillon, B.S. Reliability, Quality, and Safety for Engineers, CRC Press, 2004, 240 p.

[Dubjak 2016] Dubjak, J., Pitel, J. and Majovska, M. Diagnostics of aluminum alloys melting temperature in high pressure casting. Key Engineering Materials, 2016, Vol. 669, pp. 110-117. ISBN 978-3-03835-629-5, ISSN 1013-9826.

[Edward 2009] Edward, M.W., Donald, L.S. and Ken, O. Evaluating aluminum melting furnace transient energy efficiency. In: Proceedings of Symposia TMS 2009, Warrendale TMS, 2009, pp. 43-51.

[Famfulik 2007] Famfulik, J., et al. Theory of maintenance (Teória údržby). VSB TU Ostrava, 2007, 237 p. (in Slovak)

[Jurko 2012] Jurko, J. et al. Study influence of plastic deformation a new extra low carbon stainless steels XCr17Ni7MoTiN under the surface finish when drilling. Advanced Materials Research, 2012, Vol. 538-541 pp. 1312-1315, ISSN 1022-6680.

[Li 2005] Li, T.X., Hassan, M., Kuwana, K., Saito, K. and King, P. Performance of secondary aluminum melting, Thermodynamic analysis and plant-site experiments. Energy, 2006, Vol. 31, No. 12, pp. 1433–1443.

[Lazic 2005] Lazic, L., Varga, A. and Kizek, J. Analysis of combustion characteristic in an aluminum melting furnace. Metalurgija, 2005, Vol. 44, No. 3, pp. 192–199.

[Malega 2017] Malega, P. Simulation of production systems as the effective tool of efficiency increasing. Interdisciplinarity in theory and practice, 2017, No. 12, pp. 17–22, ISSN 2344-2409.

[Michalik 2018] Michalik, P., et al. Assessment of the manufacturing possibility of thin-walled robotic portals for conveyance workplaces. Advances in science and technology, 2018, Vol. 12, No. 1, pp. 338-345, ISSN 2299-8624.

[Miskufova 2013] Miskufova, A. and Havlik, T. Processing and recycling of aluminium waste. Equilibria, 2013, 384 p., ISBN 978-80-8143-080-0. (in Slovak)

[Mohammed 2016] Mohammed, V.M., Arkanti, K. and Syed, F.H. Optimization of sand mould type and melting parameters to reduce porosity in Al-Si alloy castings. Leonardo Electronic Journal of Practices and Technologies, 2016, Issue 28, pp. 93-106, ISSN 1583-1078.

[Murcinkova 2013] Murcinkova, Z. and Krenicky, T. Implementation of virtual instrumentation for multiparametric technical system monitoring. In: SGEM 2013, Vol. 1: 16-22 June, 2013, pp. 139-144, ISBN 978-954-91818-9-0.

[Panda 2014] Panda, A. and Duplak, J. Comparison of theory and practice in analytical expression of cutting tools durability for potential use at manufacturing of bearings. Applied Mechanics and Materials, 2014, Vol. 616, pp. 300-307, ISSN 1660-9336.

[Panda 2017] Panda, A. and Dyadyura, K. Identifying the main deffects in the manufacturing of engineJuering products. Border Technology, Gorzów, ISRE, 2017, pp. 57-63.

[Rimar 2018] Rimar, M. et al. Analysis of forced ventilation and conditioning in summer conditions. TEM Journal - technology education management informatics, 2018, Vol. 7, No. 2, pp. 255-262, ISSN 2217-8309.

[Salcedo 2017] Salcedo, A.T., Arbizu, P.I. and Perez, C.J.L. Analytical modelling of energy density and optimization of the EDM machining parameters of inconel 600. Metals, 2017, Vol. 7, No. 5, art. no. 166, ISSN 2075-4701.

[Straka 2011] Straka, L., Rimar, M., Corny, I. and Mihalcova, J. Increasing of operational reliability of technical system. In: Annals of DAAAM 2011 & Proceedings of the 22nd International DAAAM Symposium, Vienna, pp. 1089-1090.

[Straka 2016] Straka, L., Gerkova, J. and Hasova, S. Proposal of preventive maintenance plan of experimental equipment. Key Engineering Materials, 2016, Vol. 669, pp. 523-531.

[Straka 2017] Straka, L. and Dittrich, G. Improving reliability indicators of technical systems. In: ISCAME 2017, University of Debrecen, 2017, pp. 508-512, ISBN 978-963-473-304-1.

[Swiercz 2018] Swiercz, R. et al. Optimization of machining parameters of electrical discharge machining tool steel 1.2713 In: AIP Conference Proceedings, EM 2018, 13th International Conference Electromachining 2018, Bydgoszcz, 9-11 May, 2018, Vol. 2017, article no. 020032, ISSN 0094-243X.

[Turtelli 2006] Turtelli et al. Magnetic and structural characterization of as-cast and annealed melt- spun Fe80-xSi20Crx. Journal of Magnetism and Magnetic Materials, 2006, Vol. 304, No. 2, pp. E687-E689.

[Wanga 2012] Wanga, J.M. et al. Optimization of parameters for an aluminum melting furnace using the Taguchi approach. Applied Thermal Engineering, 2012, pp. 33-43, ISSN 1359-4311.

[Yan 2017] Yan, S. et al. Study on point bar residual oil distribution based on dense well pattern in Sazhong area. Journal of Mines, Metals and Fuels, 2017, Vol. 65, No.12, pp. 743-748, ISSN 0022-2755.

[Zidek 2017] Zidek, K., Maxim, V., Pitel, J. and Hosovsky, A. Embedded vision equipment of industrial robot for inline detection of product errors by clustering-classification algorithms. International Journal of Advanced Robotics Systems, 2017, Vol. 13, No. 5, pp. 1-10, ISSN 1729-8814.

[Zhang 2017] Zhang, W. and Wang, X. Simulation of the inventory cost for rotable spare with fleet size impact. Academic Journal of Manufacturing Engineering, 2017, Vol. 15, No. 4, pp. 124-132.

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