DOI: 10.21791/IJEMS.2023.1.7.

Efficiency of the Machining Process of Circular Shapes by Electrical Discharge Technology

Ľ. STRAKA[1], P. KUCHTA[2]

[1] Technical University of Kosice, Faculty of Manufacturing Technologies with a seat in Presov, Department of Automobile and Manufacturing Technologies, luboslav.straka@tuke.sk
[2] Technical University of Kosice, Faculty of Manufacturing Technologies with a seat in Presov, Department of Automobile and Manufacturing Technologies, patrik.kuchta@tuke.sk

Abstract. Due to its high machining precision, EDM technology is nowadays very important in the production of high-precision parts for various industries. The high precision of the machined surface in combination with the ability to machine circular surfaces brings, in addition to several advantages, some negatives. The most significant negative of this machining technology is the relatively low productivity as well as the overall production efficiency. The latter is affected by many accompanying phenomena. The main accompanying phenomenon that contributes to the decline in the overall economic efficiency of EDM is the microgeometry errors that occur due to the non-homogeneity of the EDM process. Another accompanying negative phenomenon is the geometric accuracy errors of the machined surface, as a consequence of systematic destruction of the wire tool electrode, faulty interpolation in its guidance, and, last but not least, its vibration. These aspects consequently lead to the requirement for multiple applications of additional finishing cuts, which significantly reduces the overall economic efficiency of the machining process. Therefore, the experimental research aimed to search for options that can effectively help to achieve higher productivity but especially the overall economic efficiency of the machining process.

Keywords: circular shape, efficiency productivity, quality, Wire Electrical Discharge Machining (WEDM).

Introduction

EDM technology is one of the most unconventional machining technologies. It is based on the principle of material removal by cyclically repeating electrical discharges between a tool electrode and an electrically conductive material in the presence of a dielectric fluid. The primary link in the material removal process in this machining technology is the tool electrode, which predetermines not only the resulting quality parameters of the machined surface but also the efficiency of the EDM process itself [1]. It is well known that EDM technology has extraordinary potential in the field of the electrothermal process, mainly due to the possibility of achieving a high quality of the machined surface [2,3]. Therefore, in practice, it is predominantly used in the piece production of standard machining tools such as moulds, shear tools, and the like [4]. At the same time, it is also used for special purposes in the production of parts with a wide range of applications in various industries such as automotive, aerospace, food industry, and so on [5,6]. In addition to the tool electrode itself, the selection of an appropriate combination of the main technological and process parameters contributes significantly to the overall quality of the machined surface and the productivity of the machining process. Their appropriate combination could achieve not only high quality of the machined surface but also high manufacturing productivity [7]. However, this task is rather a challenging and complicated one in the conditions of EDM technology due to the presence of a large number of input process parameters [8,9]. It is one of the most complicated advanced machining technologies in this respect. For this reason, quite a large number of research studies have been carried out in the recent period, mainly aimed at increasing the productivity of the EDM process. However, satisfactory results have still not been achieved. Therefore, there is still a need to conduct further research in this problematic area, the aim of which is to achieve a systematic approach regarding the optimization of the achieved qualitative and performance parameters of the electroerosive process to maximize them. One of the appropriate ways to solve the problem may be to establish a relationship between the input technological and process parameters and the output quality and performance parameters of the process. All this, of course, while taking into account the individual requirements placed on the electroerosive process itself. Moreover, the given solution is also supported by the primary requirements of technical practice, which in the long term focuses on the performance indicators of the EDM technology in order to achieve the highest possible economic efficiency of the entire machining process. In addition to the appropriate combination of the main input technological and process parameters, the given goal can be more quickly achieved also with the support of the development in the field of new materials of tool electrodes, or their appropriate composition, which will guarantee not only high quality of the machined surface but also high productivity of the electroerosive process itself [10,11].

1. Conditions and technical means for carrying out experimental measurements

An important task for the correct execution of the experimental measurements is the careful preparation of the whole experimental procedure. In the case of EDM technology, it is a financially and time-consuming experiment and a possible error in the sample preparation process would not only prolong but also make the whole experiment more expensive. Most importantly, there would be an error in the final interpretation of the experimental measurement results [12]. Therefore, a detailed preparation of the experiment based on a thorough preliminary analysis of the current state of the field should be carried out. For this reason, a detailed search of the current state of the subject was carried out based on the research carried out so far by renowned authors dealing with the subject [13-21]. Only then was it proceeded to the realization of experiments based on a detailed defined database of input data necessary for their realization.

The fabrication of the experimental samples was carried out on the Agiecut Classic 3S electroerosive machine. The material used for the production of the experimental samples was EN 40CrMnMoS8-6 (W.Nr.1.2312), a tool steel that is supplied hardened and tempered with a tensile strength of 880-1080 MPa as standard. The tool steel in question can also be nitrided and has relatively good polishability. It is often used for the production of tools for plastics processing, but also the production of moulds for die casting. Table 1 below shows the basic physical properties of the EN 40CrMnMoS8-6 tool steel used in the experiment.

Parameter	Value
Modulus of elasticity	10^3 N.mm^{-2}
Density	7.83 g.cm^{-3}
Thermal conductivity	33.3 W.m^{-1}.K^{-1}
Electrical resistance	0.19 Ohm.mm^2 .m^{-1}
Specific thermal capacity	0.46 J.g^{-1}.K^{-1}

Table 1. Physical properties of tool steel EN 40CrMnMoS8-6.

In addition to the physical properties of the machined material, of which the thermal conductivity and electrical resistance have a significant influence on the quality of the machined surface and the productivity of the EDM process, the chemical composition of the material also has a significant influence on the above-mentioned output parameters of the process. The percentages of the individual elements of the tool steel EN 40CrMnMoS8-6 used for the experimental samples are given in Table 2 below.

Chemical components	C	Si	Mn	Cr	Mo	$P_{max.}$	$S_{max.}$
Content of elements in %	0.35-0.45	0.30-0.50	1.40-1.60	1.80-2.0	0.15-0.25	0.030	0.05-0.10

Table 2. Chemical components of tool steel EN 40CrMnMoS8-6.

A wire tool electrode with the trade name BEDRA MEGACUT type pro TWO was used for the production of the experimental samples. It is a second-generation brass wire electrode suitable for Agie EDM machines. This electrode delivers longer maintenance-free machining cycles, ensures maximum operational safety even under the demanding conditions of typical batch production, and delivers high tolerances for modern closed-wire routing.

An essential step in the production of the experimental samples was the exact setting of all the main technological and process parameters based on a detailed analysis carried out in advance. This included in particular the parameters related to the electrical discharge itself as well as the parameters associated with the dielectric fluid.

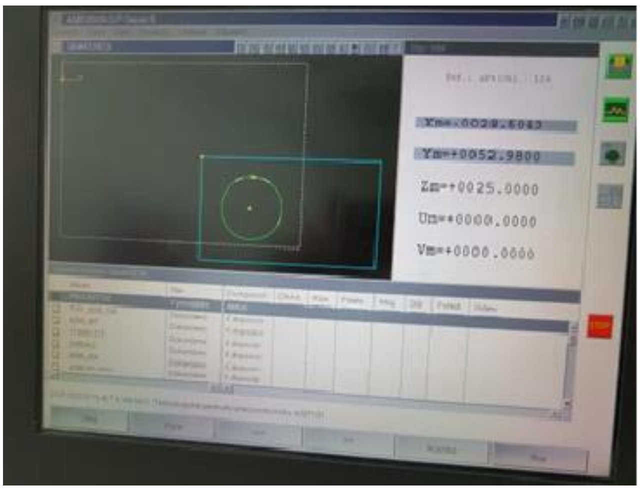


Figure 1. Setting the main technological and process parameters in the process of production of experimental samples by WEDM technology.

DOI: 10.21791/IJEMS.2023.1.7.

All input parameters related to the electroerosive process were set using the appropriate software via computer. Experimental samples of circular cross-section with a diameter of 40 mm were made from EN 40CrMnMoS8-6 tool steel using a wire tool electrode with a diameter of 0.25 mm with the trade name BEDRA MEGACUT type pro TWO using WEDM technology.

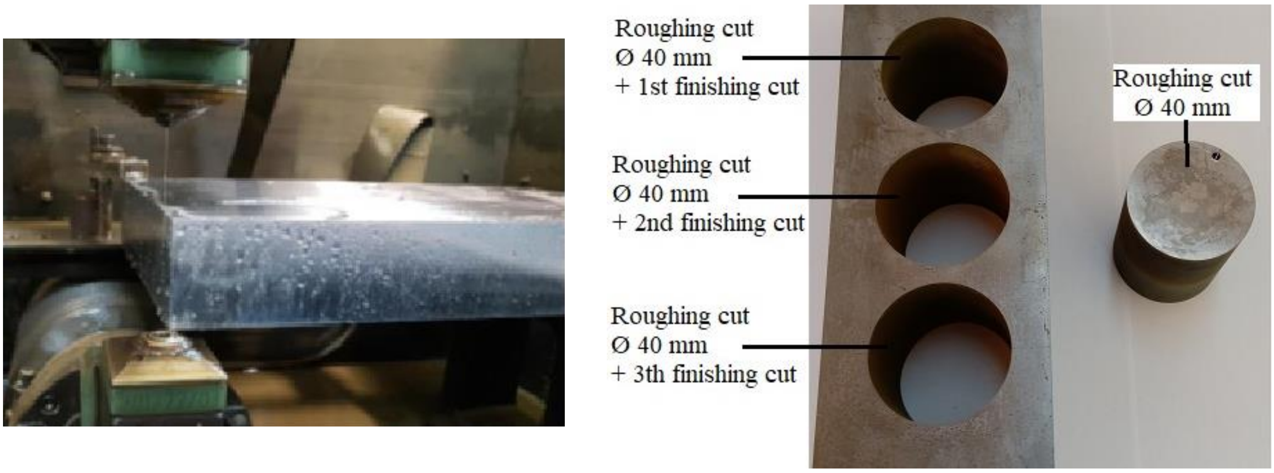


Figure 2. Production of experimental samples by WEDM technology.

The quality of the machined surface of the experimental samples was carried out in terms of the surface roughness parameters *Ra* and *Rz*. It was recorded using a Mitutoyo SJ 400 contact roughness tester.

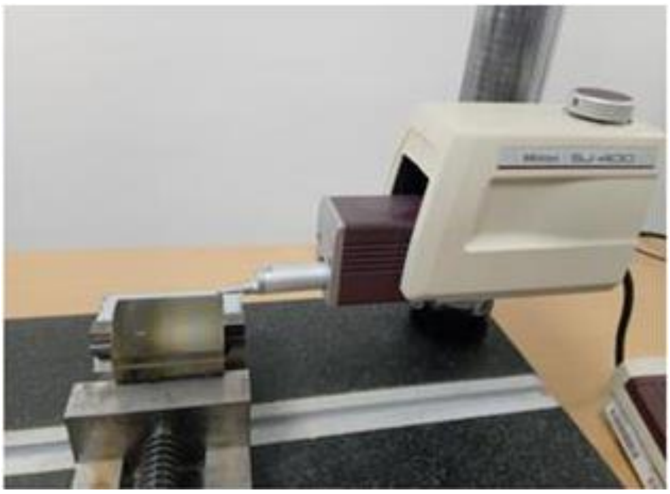
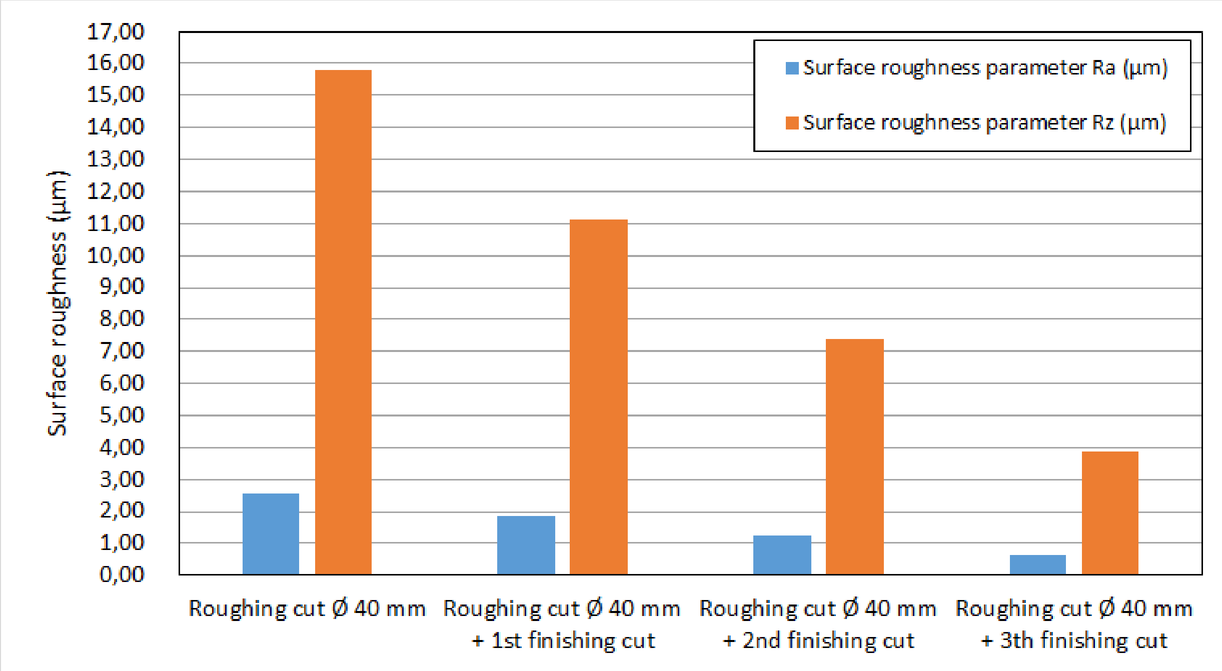


Figure 3. Measurement of surface roughness parameters Ra and Rz of samples made by electroerosive technology.

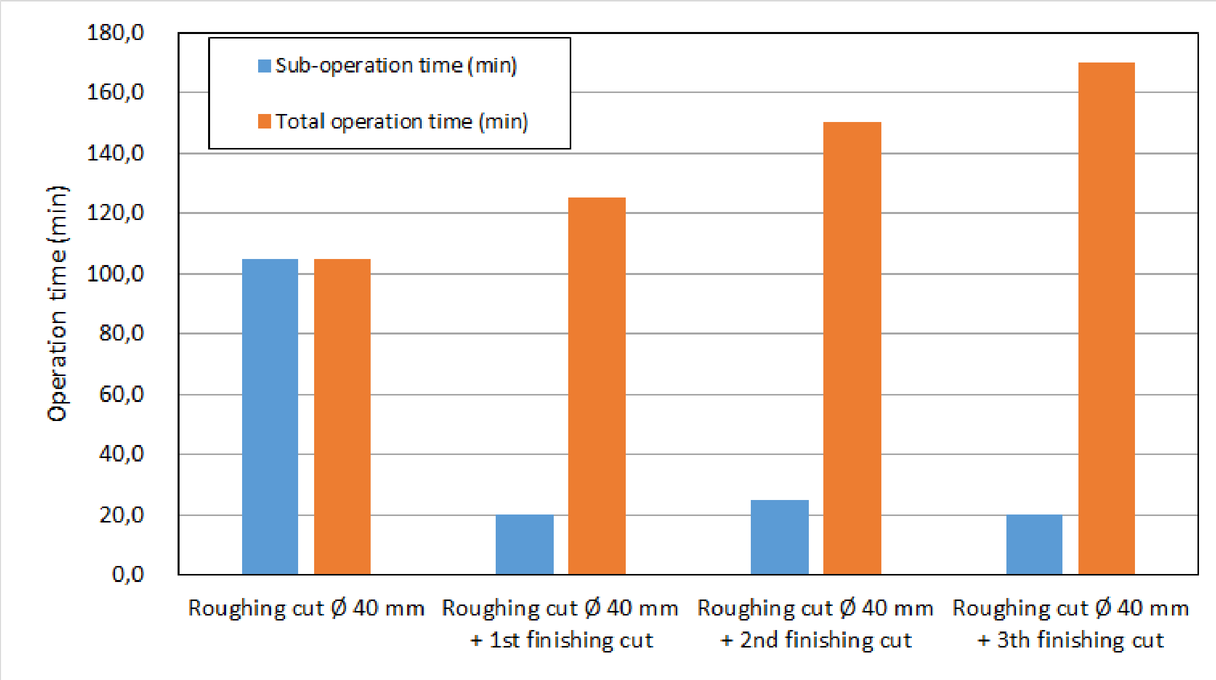
The surface roughness parameters *Ra* and *Rz* of the experimental samples with a diameter of 40.0 mm made by electrical discharge machining technology were recorded on three outer cylindrical surfaces which were made by full roughing cut and on three inner surfaces which were additionally machined by 2nd, 3rd, and 4th finishing cut.



	Roughing cut Ø 40 mm	Roughing cut Ø 40 mm + 1st finishing cut	Roughing cut Ø 40 mm + 2nd finishing cut	Roughing cut Ø 40 mm + 3th finishing cut
Surface roughness parameter Ra (µm)	2,57	1,84	1,25	0,65
Surface roughness parameter Rz (µm)	15,78	11,13	7,41	3,86

Figure 4. Measured values of surface roughness parameters Ra and Rz of experimental samples made by WEDM technology.

From the graphical dependence in Fig. 4, it can be observed that the best quality of the machined surface in terms of roughness parameters *Ra* and *Rz* after EDM of circular surfaces was recorded after the 3rd finishing cut. The latter was at *Ra* = 0.65 µm and *Rz* = 3.86 µm. On the other hand, the worst quality of the machined surface in terms of roughness parameters *Ra* and *Rz* was recorded at the full roughing cut. It ranged at the level of *Ra* = 2.57 µm and *Rz* = 15.78 µm. However, one fact should be pointed out here and that is that the 3rd finishing cut must be preceded by a full roughing cut and two finishing cuts. Hence, the overall production time to achieve the required quality level of the machined surface after EDM is increased. Therefore, in order to comprehensively assess the overall production efficiency for achieving a specific quality level of the machined area, the cumulative time of the operation must also be taken into account. At the same time, in addition to the output qualitative parameters of the roughness of the machined surface, an output quantitative parameter was also recorded during the production of the experimental samples, which is the sub-times of the individual operations performed.



	Roughing cut Ø 40 mm	Roughing cut Ø 40 mm + 1st finishing cut	Roughing cut Ø 40 mm + 2nd finishing cut	Roughing cut Ø 40 mm + 3th finishing cut
Sub-operation time (min)	105,0	20,0	25,0	20,0
Total operation time (min)	105,0	125,0	150,0	170,0

Figure 5. Recorded values of the times during individual operations in the production of experimental samples by WEDM technology

From the graphical dependence in Fig. 5, it can be observed that the shortest operation time was recorded at the 3rd finishing cut. On the contrary, the longest operation time was recorded at the full roughing cut. However, one fact should be pointed out here and that is that the 3rd finishing cut must be preceded by a full roughing cut and two finishing cuts. Hence, the total time after the 3rd finishing cut is the sum of the time required for the full roughing cut and the two finishing cuts. From this, it is evident that the total application time of the full roughing cut was 105 min, the roughing + one finishing cut was 125 min, the roughing + two finishing cuts was 150 min, and the roughing + three finishing cuts was 170 min.

In conclusion, the overall shortest machining time was achieved with the full roughing cut and, conversely, the operation consisting of a full roughing cut and three finishing cuts took the longest. However, considering the objectivity of the claim, it should be pointed out that the best surface quality was obtained when the surfaces were machined with a full roughing cut and three finishing cuts and, conversely, the worst when an operation with one full roughing cut was applied. Therefore, the choice of an acceptable quality level of the machined surface after WEDM is very important [22,23]. Any unjustified qualitative increase in the machined surface level in terms of machined surface roughness parameters leads to an increase in the overall production time, which has a very negative impact on the overall cutting economy. At the same time, from the point of view of the objectivity of the comprehensive evaluation of the quality of the machined area versus the economic efficiency of its production, further

DOI: 10.21791/IJEMS.2023.1.7.

research should be oriented towards their mutual optimization. However, further experiments should be carried out with the orientation to search for further possibilities of increasing the productivity of the electroerosive process.

Conclusion

The aim of the paper was to show the importance of productivity and overall efficiency of the EDM process in the machining of circular surfaces by WEDM technology. Circular samples with a diameter of 40 mm, whose surface was machined with a full roughing cut and subsequently machined with three finishing cuts, were analysed. Output parameters related to qualitative and quantitative parameters were observed in the experiment. In terms of qualitative parameters, the surface roughness values and in terms of quantitative parameters, the time data of each operation were considered. It was found that by increasing the number of finishing cuts, the overall productivity and efficiency of EDM decrease to a significant extent. Therefore, in order to sustain a favourable value of the overall productivity and efficiency of the EDM process, it is necessary to select the number of finishing cuts very sensitively with respect to the requirements of the final quality of the machined surface in terms of the roughness parameters *Ra* and *Rz*. At the same time, a recommendation for further experimental research is to extend the scope of experiments with an orientation toward optimization of these two output parameters of the electroerosive process.

Acknowledgments

This work was supported by the project VEGA 1/0371/23.

References

[1] S. Dzionk, M.S. Siemiatkowski, *Studying the effect of working conditions on WEDM machining performance of super alloy Inconel 617*, Machines, 2020, 8(3), 54, ISSN 2075-1702.

[2] S. Hamed, L.A. Al-Juboori, V.N. Najm, A.M. Saleh, *Analysis the impact of WEDM parameters on surface microstructure using response surface methodology*, Proceedings of the ASET 2020, Advances in Science and Engineering Technology International Conferences, Dubai, United Arab Emirates, 4-9 February 2020, 9118208.

[3] S. Hašová, Ľ. Straka, *Design and verification of software for simulation of selected quality indicators of machined surface after WEDM*, Academic Journal of Manufacturing Engineering, 2016, 14(2), 13-20, ISSN 1583-7904.

[4] B. Jabbaripour, M.H. Sadeghi, S. Faridvand, M.R. Shabgard, *Investigating the effects of EDM parameters on surface integrity, MRR and TWR in machining of Tie6ALe4V*, Machining Science and Technology, 2012, 16, 419-444, ISSN 1091-0344.

[5] Y.C. Lin, Y.F. Chen, C.T. Lin, H.J. Tzeng, *Electrical discharge machining (EDM) characteristics associated with electrical discharge energy on machining of cemented tungsten carbide*, Materials and Manufacturing Processes, 2008, 23, 391-399, ISSN 1042-6914.

[6] J. Mascenik, S. Pavlenko, *Determination of stress and deformation during laser welding of aluminium alloys with the PC support*, MM Science Journal, 2020, 2020, 4104-4107, ISSN 1803-1269.

[7] A. Mičietová, M. Neslušan, M. Čilliková, *Influence of surface geometry and structure after non-conventional methods of parting on the following milling operations*, Manufacturing Technology, 2013, 13(2), 199-204, ISSN 1213-2489.

[8] K. Mouralova, R. Zahradnicek, P. Houska, *Evaluation of surface quality of X210Cr12 steel for forming tools machined by WEDM*, MM Science Journal, 2016, 5, 1366-1369, ISSN 1803-1269.

[9] A. Panda, V.M. Anisimov, V.V. Anisimov, K.O. Diadiura, I. Pandova, *Increasing of wear resistance of linear block-polyurethanes by thermal processing methods*, MM Science Journal, 2021, 10, 731-4735, ISSN 1803-1269.

[10] M. Pollak, M. Kocisko, A. Basistova, S. Hlavata, *Production of fiber as an input material for the 3D printing process*, MM Science Journal, 2021, 6, 4414-4419, ISSN 1803-1269.

[11] B.B. Pradhan, M. Masanta, B.R. Sarkar, B. Bhattacharyya, *Investigation of electro-discharge micro-machining of titanium super alloy*, International Journal of Advanced Manufacturing Technology, 2009, 41, 1094-1106, ISSN 0268-3768.

[12] A.K. Rouniyar, P. Shandilya, *Fabrication and experimental investigation of magnetic field assisted powder mixed electrical discharge machining on machining of aluminum 6061 alloy*, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 2019, 233, 2283-2291, ISSN 2041-2975.

[13] J.A. Sanchez, J.L. Rodil, A. Herrero, L.N.L. De Lacalle, A. Lamikiz, *On the influence of cutting speed limitation on the accuracy of wire-EDM corner-cutting*, Journal of Materials Processing Technology, 2007, 182, 574-579, ISSN 0924-0136.

[14] Ľ. Straka, I. Čorný, J. Piteľ, S. Hašová, *Statistical Approach to Optimize the Process Parameters of HAZ of Tool Steel EN X32CrMoV12-28 after Die-Sinking EDM with SF-Cu Electrode*, Metals, 2017, 7(2), 1-22, ISSN 2075-4701.

[15] Ľ. Straka, I. Čorný, *Identification of geometric errors of circular profiles at WEDM caused by the wire tool electrode vibrations and their reduction with support of acoustic emission method*, Engineering Failure Analysis, 2022, 134, 1-18, ISSN 1350-6307.

[16] Ľ. Straka, J. Piteľ, I. Čorný, *Influence of the main technological parameters and material properties of the workpiece on the geometrical accuracy of the machined surface at WEDM*, The International Journal of Advanced Manufacturing Technology, 2021, 115(9-10), 3065-3087, ISSN 0268-3768.

[17] Ľ. Straka, I. Čorný, *Adjustment of Wire Vibrations in Order to Improve Geometric Accuracy and Surface Roughness at WEDM,* Applied sciences, 2021, 11(11), 1-17, ISSN 2076-3417.

[18] R. Świercz, D. Oniszczuk-Świercz, *Experimental Investigation of Surface Layer Properties of High Thermal Conductivity Tool Steel after Electrical Discharge Machining*, Metals, 2017, 7, 550, ISSN 2075-4701.

[19] J. Wang, J.A. Sánchez, B. Izquierdo, I. Ayesta, *Experimental and numerical study of crater volume in wire electrical discharge machining*, Materials 2020, 13, 577, ISSN 1996-1944.

[20] M.T. Yan, P.W. Wang, J.C. Lai, *Improvement of part straightness accuracy in rough cutting of wire EDM through a mechatronic system design*, International Journal of Advanced Manufacturing Technology, 2016, 84, 2623-2635, ISSN 0268-3768.

[21] W. Zhang, X. Wang, *Simulation of the inventory cost for rotable spare with fleet size impac*t, Academic Journal of Manufacturing Engineering, 2017, 15, 124-132, ISSN 1583-7904.

[22] Z. Zhu, D. Guo, J. Xu, J. Lin, J. Lei, B. Xu, X. Wu, X. Wang, *Processing Characteristics of Micro Electrical Discharge Machining for Surface Modification of TiNi Shape Memory Alloys Using a TiC Powder Dielectric*, Micromachines, 2020, 11, 1018, ISSN 2072-666X.

[23] W. Zhang, X. Wang, *Simulation of the inventory cost for rotable spare with fleet size impact*, Academic Journal of Manufacturing Engineering, 2017, 15(4), 124-132, ISSN 1583-7904.