GEOMETRIC PRECISION OF THE CYLINDERS SURFACES MACHINED WITH WEDM TECHNOLOGY

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One of the progressive production technologies through which it is possible to machine complicated shapes in materials characterized by high hardness is electrical discharge machining with a wire electrode. However, as with other progressive technologies, in the case of electrical discharge machining technology, demanding customer requirements for the geometric accuracy of the machined surface are not always met. These errors occur for various reasons. These are, for example, the vibrations of the wire tool electrode, its destruction during the machining process, the setting of technological and process parameters, but also errors in the design of the machine and the software control of the tool path. These and other errors have a primary role in the emergence of geometric inaccuracy of the machined surface after electrical discharge machining with a wire tool electrode. A special problem in the case of electrical discharge technology is the machining of internal and external cylindrical surfaces. As a result of the mentioned causes, deviations occur during their machining, which subsequently cause problems for the manufactured products during their assembly as well as the operation itself. Therefore, the objective of the experimental research was to identify the extent of these geometric deviations on the inner and outer cylindrical surfaces during electrical discharge machining with a wire tool electrode.

KEYWORDS

Geometric accuracy, optimization, quality, wire electrode, Wire Electrical Discharge Machining (WEDM).

1 INTRODUCTION

Due to its high machining precision, electrical discharge machining technology currently occupies a very important position in the production of high-precision parts for various industries [Firouzabadi 2015]. In technical practice, it is mainly used in the piece production of standard machining tools such as moulds for pressure casting, shears and other cutting tools. 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 the aviation, space and automotive industries [Panda 2014], where high demands are placed on the quality of the machined surface in terms of roughness parameters but also in terms of geometric accuracy [Yaman 2020]. The high precision of the machined surface in combination with the possibility to machine curved surfaces brings, in addition to a whole range of advantages, some negatives of this progressive machining technology [Oniszczuk-Swiercz 2020]. The essential negative of this machining technology is the need to perform multiple offset cuts in order to achieve the required quality of the machined surface both in terms of its roughness and in terms of geometric accuracy [Hasova 2016]. This is a consequence of the frequent destruction of the wire tool electrode, its vibrations, but also faulty hardware and software wiring. In addition to the tool electrode itself, the main technological and process parameters also contribute significantly to the overall quality of the machined surface after electrical discharge machining with a wire tool electrode. With their appropriate combination, it is possible to significantly increase the quality of the machined surface, both in terms of roughness parameters and in terms of geometric accuracy [Zhang 2017]. However, this task is a relatively demanding and complicated task in the conditions of electrical discharge machining technology due to the presence of a large number of process input parameters [Mouralova 2016]. Basically, it is one of the most complicated progressive machining technologies in this respect. Although a number of research studies have been carried out in this area in recent times, not all problems associated with geometrical accuracy in the machining of inner and outer cylindrical surfaces have been eliminated [Selvakumar 2016]. These problems mainly concern geometrical deviations of roundness and cylindricity. Therefore, there is still a need to conduct further research in this problematic area, where one of the suitable ways to eliminate the mentioned quality deficiencies of the machined surface can be the creation of a relationship between input process parameters and output quality parameters [Swiercz 2017]. All this, of course, while simultaneously taking into account the individual requirements placed on the electroerosive process itself. The solution to the mentioned problem is based on the primary requirements of technical practice, which in the long term, in addition to the performance parameters of the electroerosive process, mainly focuses on the qualitative output parameters of the machined surface [Straka 2021]. Therefore, the aim of the performed experimental research was to identify in detail the geometric accuracy errors of the machined surface that occur during electrical discharge machining cylindrical surfaces by means of a thin wire tool electrode and to propose suitable measures to minimize them.

2 MATERIAL AND METHODS OF THE EXPERIMENT

2.1 Preparation of the experiment

As already mentioned in the introduction, the primary factor contributing to the insufficient quality of the machined surface after WEDM in terms of the geometric accuracy of the cylindrical surfaces is, in addition to faulty hardware and software guidance of the wire tool electrode, also an inappropriate choice of the main technological and process parameters [Evin 2020]. These, in combination with an inappropriate type of wire tool electrode, have a significant contribution to the poor quality of the machined surface after WEDM, not only in terms of roughness parameters, but also in terms of the geometric accuracy of the machined surface. Therefore, in order to achieve favourable results, a suitable choice of the combination of these input parameters of the electroerosive process is essential [Antar 2011]. At the same time, in order to achieve relevant results of experimental measurements, the exact preparation of the entire course of experiments is also important [Raksiri 2010]. Since in the case of electrical discharge machining technology, it is a relatively expensive and time-consuming experiment, the occurrence of a possible error as a result of inconsistent preparation of the experiment would prolong the entire experiment and make it more expensive [Chen 2014]. Therefore, it was necessary to carry out a detailed preparation of the experiment based on a rigorous preliminary analysis [Meshram 2020] of the current situation in the given area [Carlini 2020]. At the same time, a detailed research of the current situation in the given issue was carried out based on the researches of renowned authors dealing with the given issue. It was only subsequently that the experiments were carried out on the basis of a detailed database of input data necessary for their implementation [Habib 2017].

2.2 Technical devices used in the experiment

The experimental samples were made on the electrical discharge machine Agiecut Classic 3S of the Swiss company GF Agie Charmilles (Fig. 1). It is a three-dimensional vertical electrical discharge machine, which is used in technical practice for machining flat as well as curved surfaces with a high achieved quality of the machined surface in terms of roughness parameters but also in terms of geometric accuracy.

Figure 1. Elektrical discharge machine Agiecut Classic 3S of the Swiss company GF Agie Charmilles used in the experiment

The basic technical parameters of the electrical discharge machine Agiecut Classic 3S of the Swiss company GF Agie Charmilles used in the experiment are listed in the following Table 1.

Table 1. Basic technical parameters of electrical discharge machine Agiecut Classic

Electrical discharge machine Agiecut Classic 3S	
Machine dimensions	1 940 x 2 300 x 2 607 mm
Machine weight	3 900 kg
Rated power	9,7 kW
Working scope (*X* / *Y* / *Z*)	500 / 350 / 426 mm
Axis range *U*, *V*	±70/±70 mm
Max. workpiece size	1 050 x 650 x 420 mm
Angle and bevel height	30°/100 mm
X, *Y* axis fast feed	900 mm.min^{-1}
U / *V* / *Z* axis fast feed	600 mm.min^{-1}
Wire diameter	0,2 – 0,33 mm

The Roundtest RA-120 contact measuring device from the Japanese company Mitutoyo was used to measure the geometrical deviations of the outer cylindrical surfaces machined using electrical discharge machining technology with a thin wire electrode (Fig. 2, Table 2).

Table 2. Basic technical parameters of contact measuring equipment Roundtest RA-120

Roundtest RA-120	
Table diameter	150 (mm)
Centring range	±3 (mm)
Max. sample diameter	440 (mm)
Measurement range	±1000 (µm)
Sampling points	3600 (point.turn^{-1})

It is a compact measuring device that allows you to measure deviations of circularity, flatness, coaxiality, and thickness with the output of the measured data to a computer.

Figure 2. Roundtest RA-120 contact measuring device used in the experiment

Thome Rapid CNC contact 3D measuring device was used to measure the geometric deviations of the inner cylindrical surfaces machined by means of electrical discharge machining technology with a thin wire electrode (Fig. 3, Table 3).

Figure 3. Thome Rapid CNC contact measuring device used in the experiment

Table 3. Basic technical parameters of contact measuring equipment Thome Rapid CNC

Thome Rapid CNC	
Travel in axis *X* and *Y*	600 mm x 500 mm
Travel in the *Z* axis	400 mm
Working height	850 mm
Measuring accuracy	MPEE 2,2+(L/350) µm
Smallest resolution	0,0001 mm
Fast forward	250/430 mm.min^{-1}
Max. sample weight	450 kg
Air consumption	25 l.min^{-1}

2.3 Material used in the experiment

The experimental samples were made of tool steel marked EN 40CrMnMoS8-6 (W.Nr.1.2312). It is a tool steel that is used in technical practice for the production of moulds for plastic injection, for the production of moulds for pressure casting and other special tools. It is a standard tool steel suitable for heat treatment. High strength and hardness of the base material can be achieved through appropriate heat treatment. Through

WEDM technology, this material can be machined both in its basic state and in its heat-treated state. The following Table 4 lists the selected physical properties and chemical composition of the used tool steel EN 40CrMnMoS8-6.

Table 4. Selected physical properties and chemical composition of the used tool steel EN 40CrMnMoS8-6

Chemical composition	Physical properties
C (0.35-0.45%)	Density 7.83 $g.cm^{-3}$
Si (0.30-0.50%)	Electrical resistance 0.19 $Ohm.mm^{2}.m^{-1}$
Mn(1.40-1.60%)	Thermal conductivity 33.3 $W.m^{-1}.K^{-1}$
Cr (1.80-2.0%)	Specific heat capacity 0.46 $J.g^{-1}.K^{-1}$
Mo (0.15-0.25)	Modulus of elasticity 10^{3} $N.mm^{-2}$

A wire tool electrode with Ø0.25 mm and trade mark BEDRA MEGACUT type pro TWO was used in the production of experimental samples (Fig. 4). It is a second generation brass wire electrode suitable for Agie EDM machines. This electrode brings longer maintenance-free machining cycles, ensures maximum safety of operation even in demanding typical serial production conditions and brings high tolerances for modern closed wire routing.

Figure 4. Wire tool electrode BEDRA MEGACUT type for TWO used in the experiment

3 EXPERIMENT RESULTS AND DISCUSSION

3.1 Geometric accuracy of internal cylindrical surfaces after WEDM

The experimental samples were made of three steel blocks with dimensions of 250 mm x 200 mm and thickness H = 10.0, 50.0 and 100.0 mm (Fig. 5). Five holes with Ø5.6, 20.6, 40.6, 80.6 and 120.6 mm were made in individual steel blocks using WEDM technology using a Ø0.25 mm BEDRA MEGACUT type pro TWO wire tool electrode.

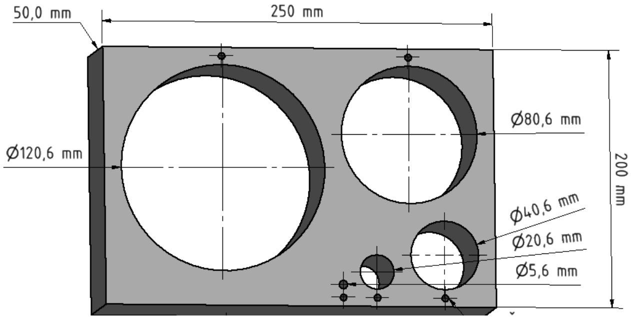

Figure 5. Experimental samples made of steel blocks with dimensions 250mm x 200mm and thickness H = 10.0, 50.0 and 100.0 mm

On experimentally made cylindrical holes with Ø5.6, 20.6, 40.6, 80.6 and 120.6 mm in steel blocks with a thickness of H = 10.0, 50.0 and 100.0 mm, geometric deviations of cylindricity were identified using the contact 3D measuring device Thome Rapid CNC. The graph in the following Fig. 6 shows the course of individual deviations of cylindricity when changing the diameter of the created hole in the range Ø5.6 to 120.6 mm and changing the thickness of the machined material in the range H = 10.0 to 100.0 mm.

From the graphical dependencies in fig. 6, it can be observed that the smallest geometric deviation of cylindricity of 23.10 µm was recorded at the material thickness H = 10.0 mm and the made cylindrical hole Ø120.6 mm. On the contrary, the largest geometric deviation of cylindricity of 87.5 µm was recorded when the material thickness H = 100.0 mm and the made cylindrical hole Ø5.6 mm.

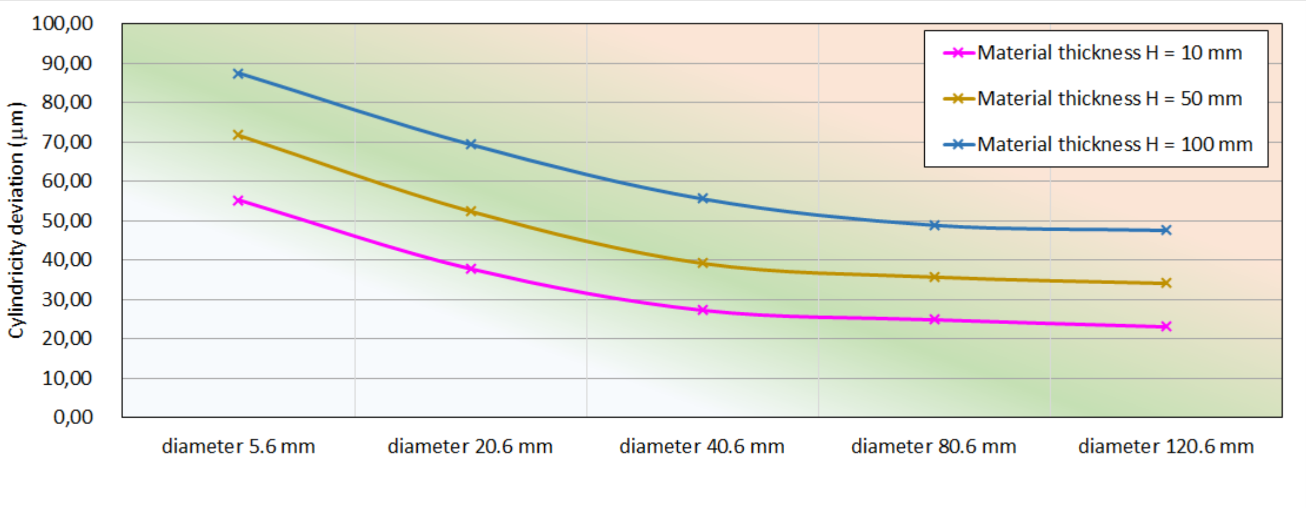

Figure 6. Measured values of hole cylindricity deviations in the range Ø5.6 to 120.6 mm and changes in the thickness of the machined material in the range H = 10.0 to 100.0 mm

3.2 Geometric accuracy of external cylindrical surfaces after WEDM

For the production of experimental samples for assessing the geometric accuracy on the outer cylindrical surfaces made by WEDM technology, opposite samples were used, which were created during the waste-free production of the inner cylindrical surfaces. There were five experimental samples with Ø5.0, 20.0, 40.0, 80.0 and 120.0 mm (Fig. 7).

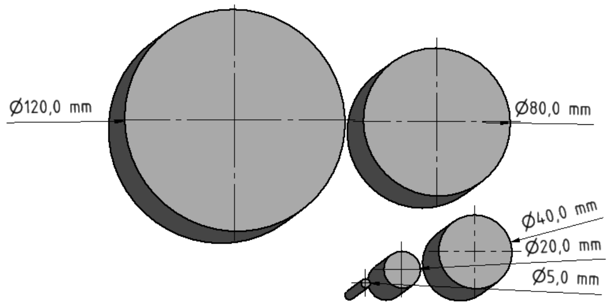

Figure 7. Experimental samples with Ø5.0, 20.0, 40.0, 80.0 and 120.0 mm and thickness *H* = 10.0, 50.0 and 100.0 mm

On experimentally made cylindrical samples with Ø5.0, 20.0, 40.0, 80.0 and 120.0 mm from steel blocks with a thickness of *H* = 10.0, 50.0 and 100.0 mm, geometric deviations of cylindricity were identified using the Roundtest RA-120 contact device. The graph in the following Figure 8 shows the course of individual deviations of cylindricity when changing the diameter of the manufactured cylindrical samples in the range Ø5.6 to 120.6 mm and when changing the thickness of the machined material in the range *H* = 10.0 to 100.0 mm.

From the graphical dependencies in fig. 8, it can be observed that the smallest geometric deviation of cylindricity on the outer cylindrical surfaces of 21.8 µm was recorded at the material thickness *H* = 10.0 mm and the diameter of the cylindrical surface Ø120.0 mm. Conversely, the largest geometric deviation of cylindricity of 85.1 µm was recorded at material thickness *H* = 100.0 mm on the outer cylindrical surface with Ø5.0 mm.

3.3 Analysis of the results of the conducted experimental research

From the mentioned results of the experimental research, it follows that with the increase in the thickness of the machined material H through the WEDM technology with a thin brass wire electrode Ø0.25 mm, there is an increase in the geometric deviation of the cylindricity. Its increase also occurs with a change in the diameter of the machined cylindrical surface. From the results of the experimental research, it is obvious that as the diameter of both the outer and the inner cylindrical surface decreases, the geometric deviation of the cylindricity increases. Based on the obtained results of the experimental research, the optimization of the geometric deviation of cylindricity during machining of tool steel marked EN 40CrMnMoS8-6 at different thicknesses H and diameters of the cylindrical surface was carried out using WEDM technology with wire brass electrode. The optimization was performed with regard to the minimization of the geometric deviation of the cylindricity.

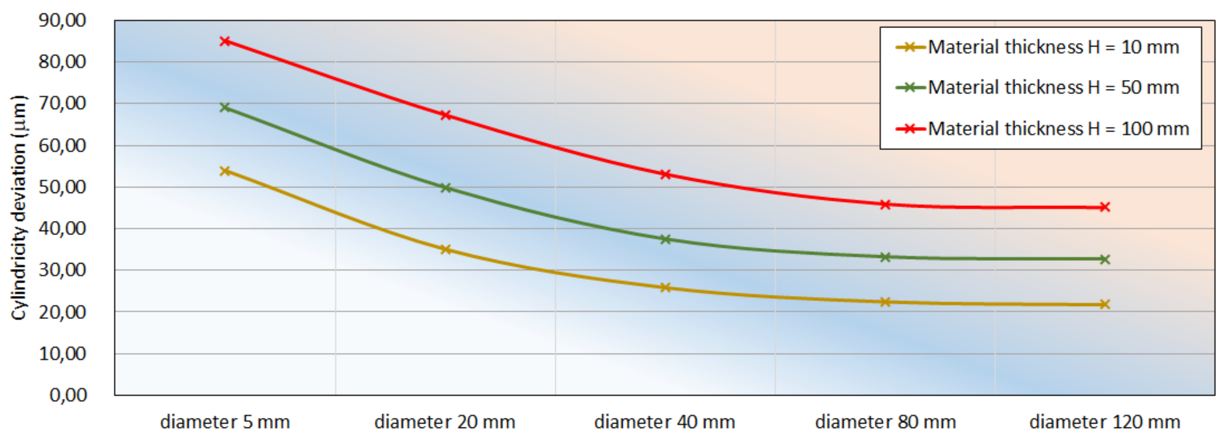

Figure 8. Measured values of cylindricity deviations of experimental samples in the range Ø5.0 to 120.0 mm with the thickness of the machined material in the range *H* = 10.0 to 100.0 mm

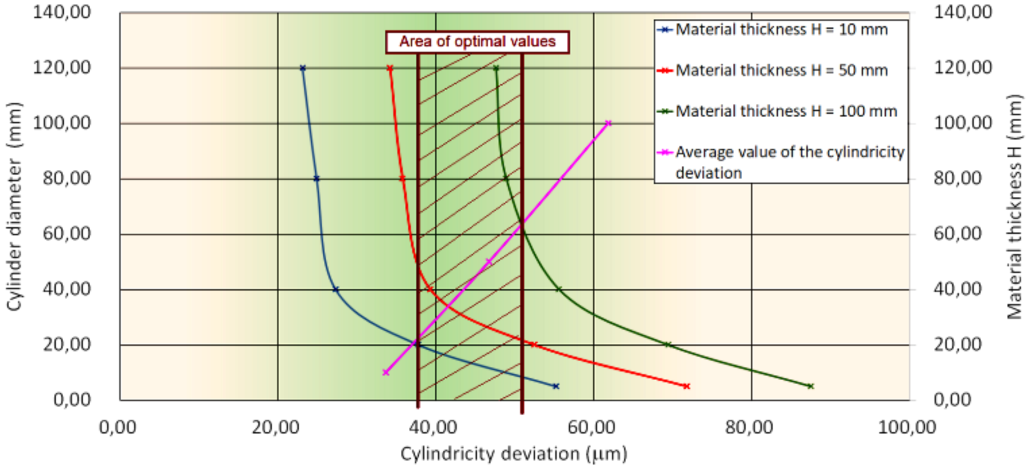

Figure 9. Optimization of geometric deviations of cylindricity during WEDM of tool steel EN 40CrMnMoS8-6 with a thin wire tool electrode Ø0.25mm

On the basis of the performed optimization with regard to the minimization of the geometric deviation of cylindricity during electrical discharge machining of tool steel marked EN 40CrMnMoS8-6 using a thin wire tool electrode Ø0.25 mm marked BEDRA MEGACUT type pro TWO, it can be concluded that the optimal value of geometric deviations of cylindricity in the range of 38 to 42 µm can be achieved when applying standard production with the thickness of the machined material in the range of $H = 20$ to 60 mm and Ø of the cylindrical surface in the range of 21 to 65 mm.

4 CONCLUSIONS

The aim of the contribution was to describe geometric deviations during electrical discharge machining of internal and external cylindrical surfaces using a thin wire tool electrode with Ø0.25 mm. Experimental samples with a diameter of 5.0 to 120.0 mm and a thickness of 10.0 to 100.0 mm were analysed, which were made of tool steel marked EN 40CrMnMoS8-6. As part of the experiment, geometric deviations of cylindricity were observed on the inner and outer cylindrical surfaces. It was found that by increasing the thickness of the machined material and decreasing the diameter of the cylindrical surface, there is an increase in geometric deviations both on the internal and external surfaces. Therefore, from the point of view of the sustainability of the favourable value of the geometric deviation of cylindricity, optimization was carried out in order to identify the thickness of the material and the diameter of the cylindrical surface at which it is possible to achieve a favourable value of the geometric deviation of cylindricity even with the application of standard machining conditions. It was found that the optimal value can be achieved when machining cylindrical surfaces in the range of Ø21 to 65 mm and the thickness of the machined material in the range of 20 to 60 mm. Based on the facts found, the recommendation for further experimental research is to expand the scope of experiments to other materials and types of wire tool electrodes.

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REFERENCES

[Antar 2011] Antar, M.T., Soo, S.L., Aspinwall, D.K., Jones, D. and Perez, R. Productivity and workpiece surface integrity when WEDM aerospace alloys using coated wires. Procedia Eng., 2011, Vol. 19, pp. 3-8.

[Carlini 2020] Carlini, G.C., Moura, C.R., Amorim, F.L., Weingaertner, W.L. On Geometrical Characteristics of WC-Co Round Cavities After ED-Machining with Different Grades of CuW Electrodes. Materials Res., 2020, Vol. 23, No. 2, pp. 1-8.

[Evin 2020] Evin, E., Tomas, M. and Kmec, J. Optimization of electro-discharge texturing parameters for steel sheets' finishing rollers. Materials, 2020, Vol. 13, Art. No. 1223.

[Firouzabadi 2015] Firouzabadi, H.A., Parvizian, J. and Abdullah, A. Improving accuracy of curved corners in wire EDM successive cutting. Inter J Adv Manuf Technol, 2015, Vol. 76, pp. 447-459.

[Hasova 2016] Hasova, S. and Straka, L. Design and verification of software for simulation of selected quality indicators of machined surface after WEDM. Acad J of Manuf Eng, 2016, Vol. 14, No. 2, pp. 13-20.

[Habib 2017] Habib, S. Optimization of machining parameters and wire vibration in wire electrical discharge machining process. Mech Adv Mater Mod Process, 2017, Vol. 3, pp.1-9.

[Chen 2014] Chen, Z., Huang, Y., Zhang, Z. et al. An analysis and optimization of the geometrical inaccuracy in WEDM rough corner cutting. Inter. J. of Advanced Manuf. Technology, 2014, Vol. 74, pp. 917-929.

[Meshram 2020] Meshram, D.B. and Puri, Y.M. Optimized curved electrical discharge machining-based curvature channel. J Braz. Soc. Mech. Sci., 2020, Vol. 42, Art. No. 82.

[Mouralova 2016] Mouralova, K., Zahradnicek, R. and Houska, P. Evaluation of surface quality of X210Cr12 steel for forming tools machined by WEDM. MM Science Journal, 2016, Vol. 5, pp. 1366-1369.

[Oniszczuk-Swiercz 2020] Oniszczuk-Swiercz, D., Swiercz, R., Chmielewski, T. and Salacinski, T. Experimental investigation of influence WEDM parameters on surface roughness and flatness deviation. In: METAL 2020, 29th International Conference on Metallurgy and Materials, Brno, 2020, Vol. 29, pp. 611-617.

[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.

[Raksiri 2010] Raksiri, Ch. and Chatchaikulsiri, P. CNC wire-cut parameter optimized determination of the stair shape workpiece. I J Mech Mechatron Eng., 2010, Vol. 4, pp. 924-929.

[Straka 2021] Straka, L., Pitel, J. and Corny, I. Influence of the main technological parameters and material properties of the workpiece on the geometrical accuracy of the machined surface at WEDM. Inter. J. of Advanced Manuf. Technology, 2021, Vol. 115, No. 9-10, pp. 3065-3087.

[Selvakumar 2016] Selvakumar, G., et al. Enhancing die corner accuracy using path modification strategy in wire electrical discharge machining of Monel 400. Proc IMechE, Part C: J Mechanical Engineering Science, 2016, Vol. 232, pp. 207-216.

[Swiercz 2017] Swiercz, R. and Oniszczuk-Swiercz, D. Experimental Investigation of Surface Layer Properties of High Thermal Conductivity Tool Steel after Electrical Discharge Machining. Metals, 2017, Vol. 7, p. 550.

[Yaman 2020] Yaman, S. and Cakir, O. Investigation of the effects of EDM parameters on surface roughness. J. Adv. in Manuf. Eng., 2020, Vol. 1, No. 2, pp. 46-55.

[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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