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MACHINING SPEED AT OBTAINING EXTERNAL CYLINDRICAL EXTERNAL SURFACES BY ELECTRICAL DISCHARGE MACHINING USING PLATE TYPE TOOL ELECTRODES

BY

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Abstract. The electrical discharge machining using plate type tool electrodes is one of the methods that could be applied to obtain external cylindrical surfaces. The analysis of the machining process showed that due to the tool electrode wear, a diminishing of the machining speed is possible. To test this hypothesis, some results of the experimental research were mathematically processes, and a power type empirical mathematical model was determined. The empirical model showed that if the pulse on time, pulse off time and process duration increase, the machining speed decreases, while when the peak current intensity increases, an increase of the machining speed is the result.

Keywords: electrical discharge machining; plate type tool electrode; machining speed; power type empirical model; process input factors influence.

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1. Introduction

The electrical discharge machining is a machining method which uses electrical discharges thermal effects to remove small quantities from the workpiece material, so that a new surface is gradually generated (Nichici *et al*., 1983; Slătineanu *et al*., 2004). The electrical discharges appear between the closest asperities peaks existing on the tool electrode surface and the workpiece surface to be machined, when the distance between these peaks is low enough. The electrical discharges generate also a material removal from tool electrode, but the machining conditions are established so that the quantity of material removed from workpiece is higher than the quantity of material removed from tool electrode. This material removal from tool electrode characterizes the wear of the tool electrode.

The electrical discharge machining is applied when the workpiece material is too hard to be machined by so-called classical machining methods or when the surfaces to be obtained could be machined in less efficient conditions or really such surfaces could not be obtained by classical machining methods.

Various types of surfaces could be obtained by electrical discharge machining, eventually combining the movements achieved by the tool electrode and workpiece. In such conditions, some electrical discharge machining techniques could be applied to obtain external cylindrical surfaces.

Over the years, the researches were interested in investigation of the possibilities of obtaining external cylindrical surfaces by electrical discharge machining.

Thus, Janardhan and Samuel investigated the process of wire electrical discharge turning. They proposed the use of a simple and cost-effective spindle, able to ensure the rotation of the workpiece, while the wire tool electrode has a travelling movement in a plane perpendicular on the rotation axis and a longitudinal feed movement (Janardhan and Samuel, 2010). As results of the machining process, they considered the material removal rate, surface roughness and roundness error.

Aravind Krishnan and Samuel addressed also the problem of obtaining external revolution surfaces by wire electrical discharge turning (Aravind Krishnan and Samuel, 2013). They focused their research on the multi-objective optimization when the followed results are the material removal rate and the surface roughness. The experiments were based on the use of the Taguchi design to train a neural network.

Periyanan *et al.* studied the influence of some process input factors (feed rate, capacitance and voltage on the material removal rate at micro-wire electrical discharge grinding process (Periyanan *et al*., 2011)). The objective of their research was to optimize the machining process so that a maximum material removal rate is obtained. As research methods, they applied the Taguchi technique and a Pareto analysis of variance.

The wire electrical discharge grinding method was also investigated by Rees *et al.* (2013). As the objective of the optimization process, they considered the surface roughness. The applying of inductive learning allowed establishing of a surface roughness prediction model on the base of the data acquisition when monitoring on-line the machining process.

Within the research presented in this paper, the attention was focused on the evolution of machining speed when external cylindrical surfaces are obtained by electrical discharge machining and using a plate type tool electrode.

2. Premises for Evaluation of the Machining Speed

Taking into consideration the available experimental conditions, the machining scheme showed in Fig. 1 was taken into consideration to obtain external cylindrical surfaces by electrical discharge machining. One may see that both plate type tool electrode and workpiece are connected in the electric circuit of a pulse generator *G*. Due to the presence of some holes having circular cross sections in the plate type tool electrode and to the work movement achieved along a vertical linear direction by the tool electrode, the additional material is removed from the workpiece, so that cylindrical columns are generated on the workpiece.

The electrical discharges between the closest asperities existing on the tool electrode active surfaces and the workpiece surface to be machined are initiated when the distance between them is lower than a certain value *s*, corresponding to the relation:

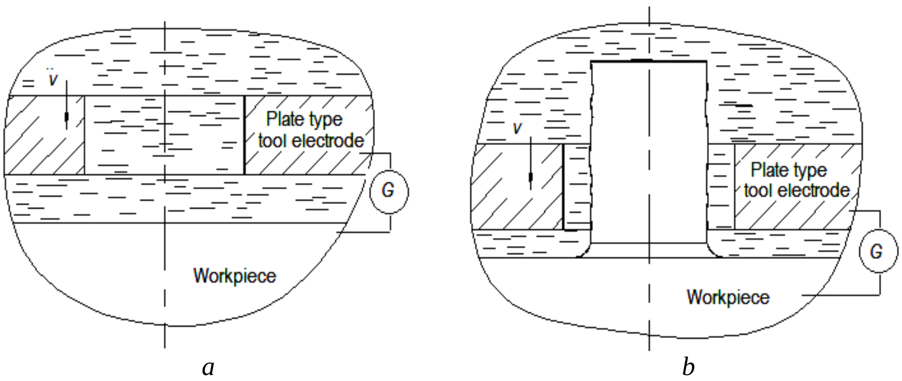
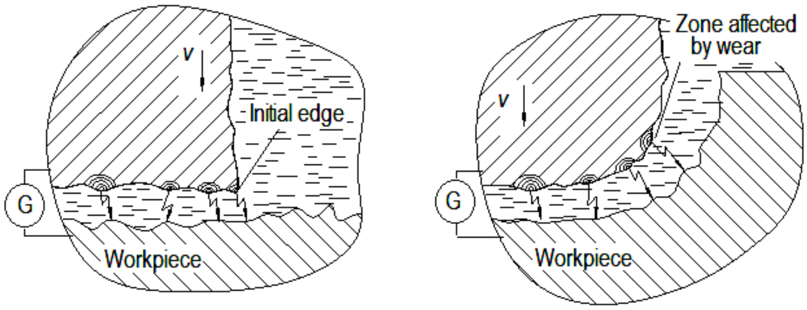


Fig. 1 – Generation of a cylindrical column as a result of electrical discharge machining process when a plate type tool electrode with cylindrical holes is used: *a* – before developing the machining process; *b* – after a certain duration of the machining process.



a *b*

Fig. 2 – Tool electrode initial wedge which is not affected by the wear process (*a*) and wear zone generated as a consequence of the machining process (*b*).

$$s < \frac{U}{E} \quad (1)$$

where *U* is the voltage applied to the electrodes and *E* is the dielectric rigidity of the material found in the machining gap.

As main parameters of technological interest, the following could be used: the material removal rate, the machining accuracy, the roughness of the machined surface, the thickness of the layer affected by the machining process, the tool electrode wear.

To evaluate the material removal rate, there is the possibility of using the ratio of the quantity of material removed from workpiece to the process duration. This means that the workpiece must be weighted before and after each machining test, in certain working conditions. Another image concerning the process productivity could take into consideration the machining speed *v* of tool electrode penetration in the workpiece material.

If the height *h* of the column generated for a certain process duration *t* is determined, the machining speed *v* could be determined by the relation:

$$v = \frac{h}{t} \quad (2)$$

Fig. 3 – Plate type tool electrode used for experimental investigation of the influence exerted by some process input factors on the machining speed at electrical discharge machining of external cylindrical surfaces.

There are many groups of factors able to affect the size of the machining speed *v*: the chemical composition of the workpiece material, the characteristics of electrical pulses (amplitude, frequency, peak current and voltage, pulse on time, pulse off time etc.), the way in which the particles detached from workpiece and tool electrode are removed from the machining gap, the tool electrode wear etc.

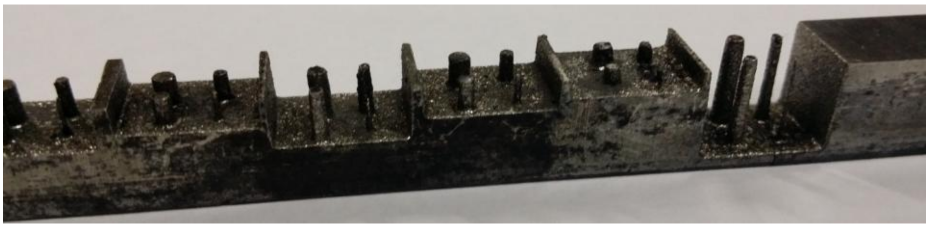


Fig. 4 – Columns generated by using plate type tool for electrical discharge machining.

Because of the electrical discharges, small quantities of electrodes materials are melted and even vaporized; since the vaporization is accompanied by a micro explosion phenomenon, the melted and vaporized material is thrown in the machining gap, from which the circulation of the dielectric liquid ensures the removal of the small quantities of material removed from electrodes. It is expected that due to conditions of heat dissipation in the zones corresponding to the initial edges of the holes existing in the plate type tool electrode, a more intense wear phenomenon will affect these zones and a conical zone will appear instead of the initial cylindrical zone (Fig. 2). Thus, the work area increases and, in the same machining conditions, the density of energy corresponding to the electrical discharge will decrease; the result could be materialized in a decrease of the machining speed *v*.

3. Experimental Conditions and Results

To investigate the possible variation of the machining speed *v* because of developing an electrical discharge machining process of external cylindrical surface using a plate type tool electrode, in accordance with the above-mentioned premises, an experimental research was designed and materialized.

Thus, a plate type tool electrode having a thickness $g = 1.96$ mm was drilled, thus generating distinct active zones able to be used within experimental research. Holes with distinct diameters (0.84 mm, 1.4 mm, 1.56 mm and 2 mm) were achieved in the tool electrode (Fig. 3). To clamp the tool electrode in the tool holder device type Erowa ER-010793, a parallelepipedal part was attached to it by using adequate screws. Two materials were used for teste piece: a high-speed steel HS18-1-1 (containing 0.659% C, 4.04% Cr, 1.28% Mo, 1.19% V, 17.7% W) and a medium carbon steel 1 C 45.

The experimental tests were achieved on a ram electrical discharge machine type Sodick A3DL (made in Japan). The equipment has a subsystem for computer numerical control. On a work panel, the distance of the tool electrode penetration in the workpiece material is highlighted and the values indicated on the work panel were noted at certain process durations.

As process input factors, one considered the pulse on time t_p, the pulse off time t_b, the peak current intensity I_p, and the process duration t.

The values corresponding to the process input parameters were included in the columns no. 2-5 from Tables 1 and 2. The values of the pulse on time, pulse of time and peak current intensity were established to develop a full factorial experiment with three independent variables and two levels of variation.

In the column no. 6, the values h of tool electrode penetration in the workpiece (read on the work panel of the computer numerical control subsystem) were inscribed. An average machining speed v was calculated by considering the depth h of tool electrode penetration (column no. 6) and the process duration t (column no. 5); the column no. 7 includes the values of the machining speed v.

To illustrate the variation of the machining speed v as the tool electrode penetrates in the workpiece material, the graphical representation from Fig. 3 were elaborated. One could notice the diminishing of the machining speed v when the process duration t increases.

4. Processing and Analysis of the Experimental Results

The experimental results concerning the change in time of the machining speed v were mathematically processed by means of a specialized software based on the method of the last squares (Crețu, 1992). The software allows the determination of some mathematical empirical models type polynomial of first and second decree, power function, exponential function and hyperbolic function. As a way of evaluation of the adequacy of a certain empirical model to the experimental results, the so-called Gauss's criterion is used. The value of the Gauss's criterion could be calculated as the sum of squares of the differences between the ordinates corresponding to the experimental points and the ordinates corresponding to the selected empirical mathematical model.

In this way, for the test pieces made of high speed steel HS18-1-1, the following mathematical empirical model was found as adequate for the experimental results:

$$v = 0.806 + \frac{23.269}{t_p} + \frac{0.649}{t_b} - \frac{4.525}{I_p} + \frac{0.0570}{t} \tag{3}$$

the value of the Gauss's criterion being $S_G = 0.001379299$.

Since usually in the manufacturing processes the power type functions are preferred, and such a function offers direct information about the influence exerted by the process input factors on the parameter of technological interest, a power type function was also determined by means of the above-mentioned specialized software:

$$v = 0.129 t_p^{-0.482} t_b^{-0.0477} I_p^{1.882} t^{-0.0840} \tag{4}$$

in this case the Gauss's criterion having the value $S_G = 0.001821642$.

In the case of steel 1C45, the determined power type function is the following:

$$v = 79.647 t_p^{-1.739} t_b^{-0.0336} I_p^{1.824} t^{-0.148} \tag{5}$$

the value of Gauss's criterion being in this case $S_G = 0.0007022837$.

Taking into consideration the mathematical empirical functions corresponding to the relations (4) and (5), the graphical representation from Figs. 5-7 were elaborated. If the power type empirical mathematical models and the graphical representations from Figs. 5-7 are analyzed, some remarks could be formulated. Thus, one could notice that in the case of both steels, the peak current intensity I_p exerts the most significant influence on the average machining speed v, since the exponent attached to this size in the Eqs. (5) and (6) has the highest value, in comparison with the values of the other exponents. One could notice also that when the pulse on time t_p, pulse off time t_b and process duration t increase, the average machining speed v is affected by a decrease, while the increase of the peak current I_p determines, as expected, an increase of the average machining speed v. Indeed, when the peak current intensity I_p increases, a higher quantity of workpiece material is removed from workpiece and this means an increase of the machining speed v. These results are in accordance with the results obtained when the material removal rate (in g/min) is used to evaluate the productivity of the electrical discharge machining process (Stoica *et al.*, 2014).

Table 1

Experimental Results Obtained in the Case of Test Piece Made of Steel 1C45

Current number	Pulse on time, t_i [μs]	Pulse off time, t_b [μs]	Current intensity, I_p [A]	Time, t [min]	Depth of penetration, h [mm]	Machining speed, v [mm/min]
Column no. 1	2	3	4	5	6	7
1	230	40	8.6	6	1.33	0.2217
2				9	1.68	0.1867
3				12	2.01	0.1675
4				15	2.31	0.1540
5				18	2.74	0.1522
6				24	3.51	0.1463
7				25	3.68	0.1472

Table 1

Continuation

Current number	Pulse on time, t_i [μs]	Pulse off time, t_b [μs]	Current intensity, I_p [A]	Time, t [min]	Depth of penetration, h [mm]	Machining speed, v [mm/min]
Column no. 1	2	3	4	5	6	7
8	230	40	6.4	6	0.83	0.1383
9				12	1.34	0.1117
10				18	1.91	0.1061
11				24	2.46	0.1025
12				25	2.56	0.1024
13	230	50	8.6	9	2.02	0.2244
14				24	4.16	0.1733
15				25	4.59	0.1836
16	230	50	6.4	6	0.87	0.1450
17				12	1.56	0.1300
18				18	2.05	0.1139
19				24	2.61	0.1088
20				25	2.67	0.1068
21	180	40	8.6	6	1.93	0.3217
22				12	3.99	0.3325
23				18	6.07	0.3372
24				24	8.21	0.3421
25				25	8.58	0.3432
26	180	40	6.4	6	1.12	0.1867
27				12	2.02	0.1683
28				18	2.87	0.1594
29				24	3.66	0.1525
30				25	3.80	0.1520
31	180	50	8.6	6	1.77	0.2950
32				12	3.38	0.2817
33				18	4.80	0.2667
34				24	6.39	0.2663
35				25	6.63	0.2652
36	180	50	6.4	6	1.02	0.1700
37				12	1.81	0.1508
38				18	2.56	0.1422
39				24	3.28	0.1367
40				25	3.39	0.1356

Table 2
Experimental Results Obtained in the Case of Test Piece Made of High Speed Steel HS18-1-1

Current number	Pulse on time, t_p [μs]	Pulse off time, t_b [μs]	Peak current intensity, I_p [A]	Process duration, t [min]	Height of column, h [mm]	Machining speed, v [mm/min]
1	230	40	8.6	2	0.85	0.4250
2				3	1.20	0.4000
3				4	1.56	0.3900
4				6	2.51	0.4183
5	230	40	6.4	1	0.20	0.2000
6				2	0.43	0.2150
7				3	0.64	0.2133
8				4	0.84	0.2100
9				5	1.01	0.2020
10				6	1.19	0.1983
11	230	50	8.6	1	0.47	0.4700
12				2	0.93	0.4650
13				3	1.37	0.4567
14				4	1.81	0.4525
15				5	2.32	0.4640
16				6	2.69	0.4483
17	230	50	6.4	1	0.29	0.2900
18				2	0.49	0.2450
19				3	0.70	0.2333
20				4	0.89	0.2225
21				5	1.08	0.2160
22				6	1.23	0.2050
23	180	40	8.6	1	0.41	0.4100
24				3	1.31	0.4367
25				4	1.76	0.4400
26				5	2.22	0.4440
27				6	2.69	0.4483
28	180	40	6.4	1	0.43	0.4300
29				2	0.69	0.3450
30				3	0.89	0.2967
31				4	1.16	0.2900
32				5	1.42	0.2840
33				6	1.59	0.2650
34	180	50	8.6	1	0.47	0.4700
35				2	0.81	0.4050
36				3	1.24	0.4133
37				4	1.59	0.3975
38				5	2.06	0.4120
39				6	2.56	0.4267

Table 2
Continuation

Current number	Pulse on time, t_p [μs]	Pulse off time, t_b [μs]	Peak current intensity, I_p [A]	Process duration, t [min]	Height of column, h [mm]	Machining speed, v [mm/min]
40	180	50	6.4	1	0.29	0.2900
41				2	0.51	0.2550
42				3	0.73	0.2433
43				4	0.99	0.2475
44				5	1.19	0.2380
45				6	1.42	0.2367

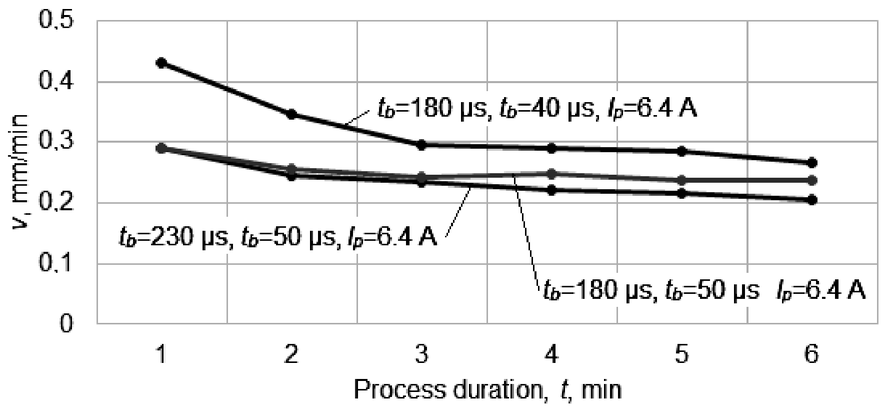


Fig. 5 – Decrease of the average machining speed v during the machining process.

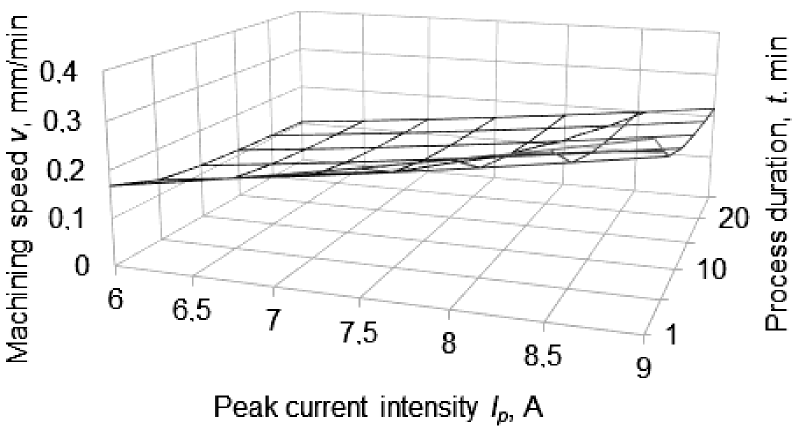


Fig. 6 – Influence exerted by process duration t and peak current intensity I_p on the machining speed v at the electrical discharge machining of external cylindrical surfaces using a plate type tool electrode (t_p = 210 μs, t_b = 45 μs, test piece material: HS18-1-1).

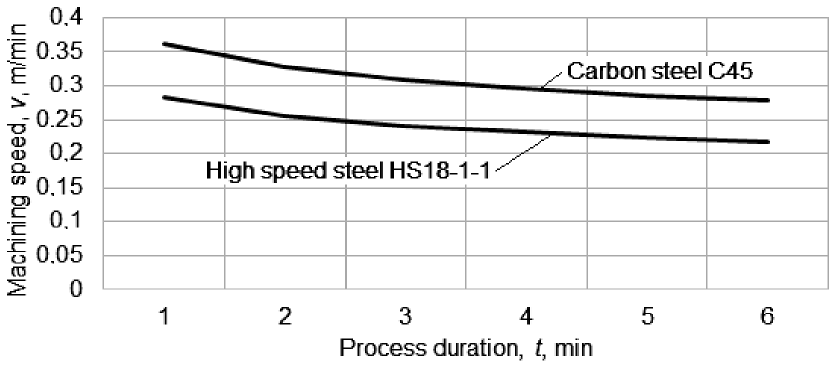


Fig. 7 – Decrease in time of the machining speed at the electrical discharge machining of external cylindrical surfaces when using plate type tool electrodes (t_p = 210 µs, t_b = 45 µs, I_p = 7.5 A) and two distinct materials for test pieces.

3. Conclusions

Small diameter external cylindrical surfaces could be obtained in workpiece made of difficult to cut materials by using the electrical discharge machining and a plate type tool electrode with holes having diameters in correspondence with the dimeters of the external cylindrical surface to be obtained.

To obtain a general image concerning the machining speed in the case of such a machining scheme, an experimental investigation was designed and materialized. As process input factors, the pulse on time, the pulse off time, the peak current intensity and the process duration were considered. By means of the computer numerical control subsystem of the machine tool, the height of the column generated during the machining process was determined. Taking into consideration the height of the cylindrical columns and the process durations, the machining speed was evaluated for distinct work conditions. The experimental results were mathematically processed using a specialized software based on the method of last squares. In this way, mathematical empirical models were determined. On the base of the analysis of the empirical mathematical models and of the graphical representations elaborated by considering the empirical models, some remarks concerning the influence exerted by the process input factors on the machining speed were formulated. One noticed that the increase of the pulse on time, pulse off time and process duration, the machining speed diminishes, while when the peak current intensity increases, the machining speed increases also. In the future, there is the intention to extend the experimental research to validate the empirical mathematical models and take into considerations other possibilities to evaluate the parameters of technological interests valid in the case of obtaining external cylindrical surfaces using plate type tool electrodes.

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VITEZA DE PRELUCRARE LA OBȚINEREA SUPRAFEȚELOR CILINDRICE EXTERIOARE PRIN ELECTROEROZIUNE FOLOSIND ELECTROZI SCULE DE TIP PLACĂ

(Rezumat)

Prelucrarea prin eroziune electrică folosind electrozi-scule de tip placă este una din metodele care pot fi aplicate pentru a obține suprafețe cilindrice exterioare. Analiza procesului de prelucrare a arătat că datorită uzurii electrodului sculă, este posibilă o diminuare a vitezei de prelucrare. Pentru a testa această ipoteză, unele rezultate ale cercetării experimentale au fost prelucrate matematic şi a fost determinat un model matematic empiric de tip funcție putere. Modelul empiric a arătat că dacă durata impulsului, durata pauzei dintre impulsuri și durata procesului cresc, viteza de prelucrare scade, în timp ce atunci când intensitatea curentului de vârf creşte, rezultă o creștere a vitezei de prelucrare.