

OBTAINING EXTERNAL CYLINDRICAL SURFACES BY ELECTRICAL DISCHARGE MACHINING USING PLATE TYPE TOOL ELECTRODE

Oana Dodun[1], Ştefan Stoica[2], Margareta Coteaţă[3], Gheorghe Nagîţ[4], Laurenţiu Slătineanu[5], Adelina Hriţuc[6], and Irina Beşliu-Băncescu[7]
[1] "Gheorghe Asachi" Technical University of Iași, Romania, oanad@tcm.tuiasi.ro
[2] "Gheorghe Asachi" Technical University of Iași, Romania, steffan1987@yahoo.com
[3] "Gheorghe Asachi" Technical University of Iași, Romania, mcoteata@tcm.tuiasi.ro
[4] "Gheorghe Asachi" Technical University of Iași, Romania, nagit@tcm.tuiasi.ro
[5] "Gheorghe Asachi" Technical University of Iași, Romania, slati@tcm.tuiasi.ro
[6] "Gheorghe Asachi" Technical University of Iași, Romania, hrituc.adelina3295@yahoo.com
[7]"Ştefan cel Mare" University of Suceava, Romania, irina.besliu@yahoo.com

ABSTRACT: The electrical discharge machining is a machining method applied when the workpiece material has a high hardness or the shape of the surface to be machined is to complicate to be obtained by a classical machining method. A problem of actual interest is the electrical discharge machining of small diameter external cylindrical surfaces in the case of materials characterized by high hardness. Among the distinct electrical discharge machining processes capable to be used in order to obtain small diameter cylindrical surfaces, a process based on the use of a plate type tool electrode was selected. A full factorial experiment with three independent variables and two experimental levels was designed and materialized to highlight the influence exerted by the pulse on time, pulse off time and peak current intensity on the heights of the cylindrical columns generated by electrical discharge machining. By mathematical processing of the experimental results, power type empirical mathematical models were established. The empirical models confirmed the strong influence exerted by the peak current intensity on the process output parameter.
KEY WORDS: electrical discharge machining, external cylindrical surface, plate type tool electrode, empirical mathematical models, influence factors.

1. INTRODUCTION

The electrical discharge machining uses the thermal effects of the electrical discharges developed between the tops of the asperities found on the active surface of the tool electrode and the workpiece surface to be machined. As a consequence of the fast and strong heating of the workpiece material affected by the electrical discharges, small quantities of the electrodes electroconductive materials are melted and even vaporized. Due to the explosive character of melting and especially vaporizing phenomena, a detaching of the melted and vaporized material develops; if between the two electrodes there is a dielectric liquid, a re-solidifying process occurs and due to the dielectric liquid circulation, the metallic particles detached from the electrodes are gradually removed from the working gap [2, 5, 7, 9].
At present, there is a large variety of electrical discharge machining methods. It is known that the electrical discharge machining is applied when the workpiece material is hard enough so that it could not be machined or it is difficulty machined by the classical machining methods or when the surface to be machined is too complex to be efficiently machined by classical machining methods. To solve the practical machining problems, as above mentioned, distinct machining methods were defined and promoted in the industry. In principle, the electrical discharge machining methods could be classified into two main groups:

a) Ram electrical discharge machining, when massive electrodes are used;

b) Wire electrical discharge machining methods, when a wire tool electrode is rolled off a roll and wrapped on another roll; the rectilinear zone of the wire tool electrode facilitates the obtaining of various profiles from plate type workpieces. The wire tool electrode movement is necessary to avoid the possible thinning and even braking of the wire tool electrode as a consequence of the material removal from the wire under the action of the electrical discharges. A limitation of the wire electrical discharge machining is introduced by the fact that actually only ruled surfaces could be obtained, in correspondence with the rectilinear form of the wire tool electrode in the machining zone.

After the promotion of the computer numerical control subsystems, new technological possibilities were open. If initially, by ram electrical discharge machining only a copying of the tool electrode active surface in the workpiece machined surface was possible, nowadays the massive tool electrode could achieve complex rectilinear and rotation movements in the working space, so that the machined surface could have a completely distinct shape if compared with the tool electrode active surface. If we limit the investigations to the obtaining of external cylindrical surfaces of small diameter, one could notice that such surfaces could be obtained both by using ram electrical discharge machining and wire electrical discharge machining. When the surface to be machined could be obtained by means of the wire tool electrodes, higher accuracies and lower surfaces roughness are achievable, but the wire electrical discharge machining could be applied only on specialized machine tools, more expensive than the ram electrical discharge machine-tools.

Various machining schemes could be also applied when obtaining external cylindrical surfaces on the ram electrical discharge machine tools [5, 7].

One of these machining schemes could be based on the use of a plate type tool electrode, in which holes with adequate profiles and dimensions of the cross-section were previously achieved. Using only the common rectilinear work movement of the machine tool head, gradually external cylindrical surfaces could be obtained.

A problem valid both in the case of the above-mentioned machining scheme and also when applying other machining schemes is generated by the necessity of removing from the work gap of the metallic particles detached from the electrodes. If these particles are not efficiently removed, they could generate unnecessary electrical discharges and a possible negative affecting of the machined surface accuracy could be noticed. Just such an argument led probably to the use of a machining scheme in which the plate type tool electrode with holes is moved towards the workpiece placed on the machine tool table. Over the years, the obtaining of the external cylindrical surfaces and especially of small diameter cylindrical surfaces by electrical discharge machining was a preoccupation for the researchers.

Thus, Singh et al. showed that using a tool electrode that has an array of cavities and feeding the tool electrode to the workpiece within a process of reverse electrical discharge machining, surfaces that have the cross section in correspondence with the cavities from the tool electrode could be obtained [6]. Nageendrababu developed ample research concerning a machining technique named by him *reverse electrical discharge machining*, by which an adequate tool electrode was used to obtain arrayed structures, by means of copper tool electrode with a 3x3 array of holes [4]. He applied a central composite design to experimentally investigate the influence exerted by the peak current intensity, pulse-on time and flushing pressure on the material removal rate, surface roughness, taper, cylindricity, and microhardness of the surface layer. The grey relational analysis was also used to evaluate the optimal combination of the process input factors able to lead to the best values of the output parameters. Polynomials of second degree were preferred to model the influence exerted by the process input factors on some of the process output parameters. Mastud et al. investigated the possibilities of obtaining high aspect ratio arrayed features and textured surfaces using a reverse micro-electrical discharge machining process [3]. They showed that using a tool electrode vibratory motion, easier removal of the debris accumulated in the work zone could be achieved. One of their research conclusions was that the flow reversal and the reciprocating motion could improve the overall process stability of the reverse micro electrical discharge machining.

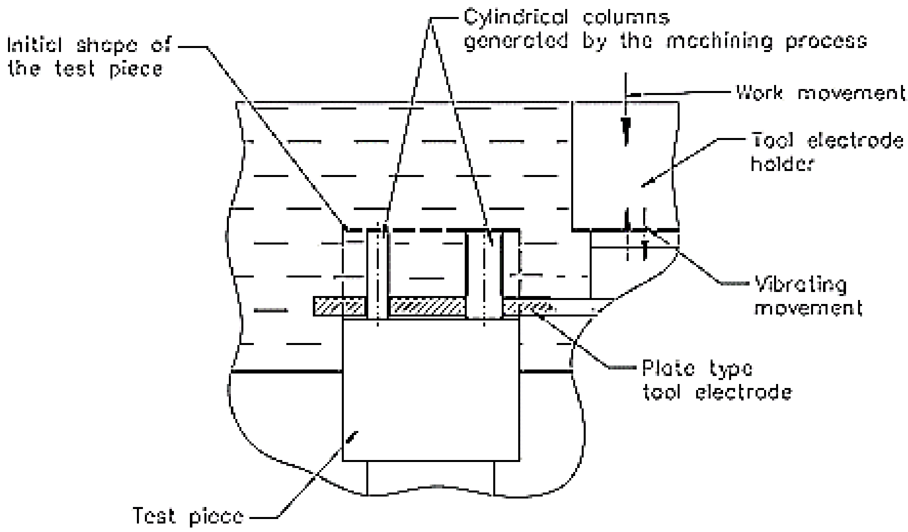

Figure 1. Machining scheme that corresponds to the obtaining of the external cylindrical surfaces of small diameter using a plate type tool electrode

The objective of the research presented in this paper was to investigate some possibilities of obtaining external cylindrical surfaces using a plate type tool electrode in which small diameter holes were previously achieved.

2. SELECTED MACHINING SCHEME

As above mentioned, various machining schemes could be used to obtain inclusively cylindrical external surfaces and even such small diameter surfaces. In the research presented in this paper, a relatively simple machining scheme was used (fig. 1). Thus, one selected a plate type tool electrode, in which holes with pre-established diameters were previously achieved. The plate type tool electrode could be positioned and clamped in a device attached to the machine tool head and will achieve the rectilinear vertical work movement together with the machine tool head. The test piece could be positioned and clamped in a vice placed on the machine tool table. Both the tool electrode and test piece will be immersed in the dielectric fluid found in the machine tool work tank. The electrical discharges will be initiated between the horizontal flat surface of the plate type tool electrode and the upper surface of the test piece. Gradually, due to the vertical work movement of the machine tool head and to the development of the electrically discharges, the tool electrode will penetrate in the test piece. In this way, in the places where there are holes in the plate type tool electrode, gradually columns will appear on the test piece. The column diameter could be estimated taking into consideration the diameter of the hole that exists in the plate type tool electrode and the size of the work gap. At its turn, the size of the work gap is dependent on the values of the machining parameters, the characteristics of the dielectric fluid and its circulation in the spaces found between the tool electrode and the test piece, etc.

It is known that to efficiently remove the dielectric liquid that contains metallic particles detached from the test piece, the machine tool head, together with the plate type tool electrode, achieves also a vibratory movement characterized by low values of the frequency and amplitude. As a consequence, the dielectric fluid is periodically absorbed and removed from the work gap and, in this way, a refreshment of the dielectric fluid is ensured. Afterward, if the dielectric fluid has a certain viscosity, the detached metallic particles enter the hydraulic circuit of the dielectric fluid and could be retained by the filters.

The above mentioned electrical discharge machining scheme was preferred due to its simplicity; a possible limitation could be generated by the process of copying the eventual shape errors of the hole that exist in the plate type tool electrode in the shape of the cross sections of the machined cylindrical columns and by the possible influence of the tool electrodes wear on the accuracy of the machined surfaces. Indeed, it is expected that when the process duration is high, the electrical discharges could detach more material from the tool electrode and the initial cylindrical holes will become conical. In the cases of the high duration machining process, an increase of the diameters of the holes found in the plate type tool electrode could occur and this will lead also to the dimensional and shape errors of the vertical columns generated by the electrical discharge machining process.

3. EXPERIMENTAL RESEARCH

To test the hypotheses presented in the previous chapter, experimental research was designed and materialized [8]. This experimental research was achieved on an electrical discharge machine type Sodick A3DL; a computer numerical control subsystem and an adequate software facilitates the selection and setting of the machining parameters and ensure a convenient development of the machining process. A plate type tool electrode with a thickness of 2 mm and 4 holes (with diameters of 1.56 mm, 2 mm, 0.84 mm, and 1.4 mm) was used. The values of the electrical discharge machining process parameters were established in accordance with the recommendations valid in the case of the full factorial experiment with three independent variables and two experimental levels. As process input factors, one considered the pulse on time t_{on}, pulse off time t_{off} and the peak current intensity I_p from the discharge circuit. The height of the columns obtained in a certain machining time interval was considered as process output parameters.

One preferred to use only two levels of the process input factors, accepting the hypothesis that there will be a monotone variation of the process output parameter when changing the values of the process input factors, along with the experimental interval of variation of the independent variables. The test pieces were made of two materials, namely the steel 1C45 (this steel is frequently used as a standard material when some machinability comparisons are necessary) and high-speed steel HS18-1-1. In the case of the medium carbon steel 1C45, a duration of the machining process of 6 minutes was considered, while in the case of the high-speed steel HS18-1-1 (that contains 0.659 % C, 4.04 % Cr, 1.28 % Mo, 1.19 % V, 17.7 % W), the duration of the machining process was of 25 minutes, to obtain significant

Table 1. Experimental conditions and results in the case of test piece made of steel 1C45

Exp. no.	Values of the process input factors			Process output parameter
	Pulse on time, t_{on}, µs	Pulse off time, t_{off}, µs	Peak current intensity, I_p, A	Column length, l_c, mm
1	230	40	8.6	3.68
2	230	40	6.4	2.56
3	230	50	8.6	4.59
4	230	50	6.4	2.67
5	180	40	8.6	8.58
6	180	40	6.4	3.80
7	180	50	8.6	6.63
8	180	50	6.4	3.39

experimental results. The length of the machined columns was evaluated by means of the machine tool subsystem of computer numerical control, by considering the values highlighted by the display that show the machining coordinates and parameters during the machining process. The initial values of the process input factors were established considering the recommendations offered by the machine tool software; the second values of the process input factors were determined considering a change of the initial value with at least 20 %. The experimental conditions and results were included in tables 1 (for the medium carbon steel 1C45) and 2 (for the high-speed steel HS18-1-1.

4. MATHEMATICAL PROCESSING OF THE EXPERIMENTAL RESULTS

The experimental results presented in tables 1 and 2 were mathematically processed by means of specialized software, based on the method of least squares [1]. The software allows determining of five types of empirical mathematical models (polynomials of first and second degree, power type function, exponential type function, hyperbolic type function). The selection of the most convenient empirical mathematical model could be made considering the so-called *Gauss's criterion* (based on the minimum sum of the squares of the differences of the ordinates that correspond to the experimental points and to the mathematical model, respectively). In this way, the following mathematical models were determined:

- In the case of medium carbon steel 1C45:

$$l_{c\ 1C45} = 2559 t_{on}^{-1.89} t_{off}^{-0.115} I_p^{2.026}, \qquad (1)$$

for which the Gauss's criterion has the value S_G=0.5282266;

- In the case of high-speed steel HS18-1-1:

$$l_{c\ HS18-1-1} = 0.321 t_{on}^{-0.464} t_{off}^{-0.0659} I_p^{2.238}, \qquad (2)$$

for which the Gauss's criterion has the value S_G=0.02226555.

In the case of the last test piece material (HS18-1-1), the software [1] signalized that a hyperbolic empirical model could be considered as more adequate to the experimental results:

$$l_{c\ HS18-1-1} = 5.516 + \frac{133.541}{t_{on}} + \frac{3.896}{t_{off}} + -\frac{31.410}{I_p}, \qquad (3)$$

the Gauss's criterion having the value S_G=0.01250829. On the base of the empirical mathematical models (1) and (2), the graphical representations from figures 2, and 3 were elaborated. On the base of the empirical mathematical models (1) and (2), the graphical representations from figures 2, and 3 were elaborated. The analysis of the empirical mathematical models (1) and (2) and of the graphical representations allows the formulation of some general remarks.

Thus, one noticed that the most important factor that exerts influence on the process output parameter (the length of the column generated by electrical discharge machining) is the peak current intensity I_p, since, in the mathematical relations (1) and (2), the exponents attached to this size have the highest absolute values. The second factor from the point of view of the influence exerted on the value of the process output parameter is the pulse on time t_{on}. At the same time, the pulse off time seems to exert a low influence. One could notice also that, as expected, the increase of the peak current intensity I_p has a result an increase of the column height (fig. 2), while the increase of the pulse on time t_{on} (fig. 2) and pulse off time t_{off} led to a decrease of the column heights, as the mathematical empirical models (1) and (2) showed. The decrease of

Table 2. Experimental conditions and results in the case of test piece made of steel HS18-1-1

Exp. no.	Values of the process input factors			Process output para-meter
	Pulse on time, t_{on}, µs	Pulse off time, t_{off}, µs	Peak current intensity, I_p, A	Column length, l_c, mm
1	230	40	8.6	2.51
2	230	40	6.4	1.19
3	230	50	8.6	2.69
4	230	50	6.4	1.23
5	180	40	8.6	2.69
6	180	40	6.4	1.59
7	180	50	8.6	2.56
8	180	50	6.4	1.42

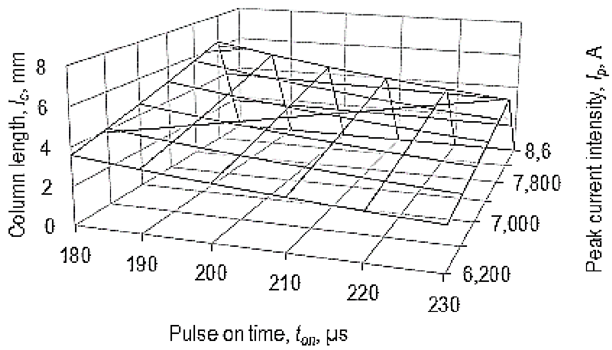

Figure 2. Influence exerted by the pulse on time t_{on} and peak current intensity I_p on the column length in the case of electrical discharge cutting of test piece made of medium carbon steel 1C45 (t_{off}=50 μs, process duration τ=6 min)

the column length l_c when the pulse on time t_{on} increases (fig. 2 and fig. 3) could be explained by the existence of a maximum of the material removal rate for a certain value of the pulse on time, whose exceeding generates a diminishing of the material removal rate [5].

5. CONCLUSIONS

Obtaining of the cylindrical external surfaces of small diameter is a problem found in the researchers' attention. There are various electrical discharge machining methods able to be used to obtain external cylindrical surfaces. The study of the specialty literature led to the selection of a machining method based on the use of a plate type tool electrode, placed on the surface of the machine tool head, while the test piece was positioned on the machine tool table. A full factorial experiment was designed to investigate the influence exerted by the pulse on time, pulse off time and peak current intensity on the height of the columns generated by electrical discharge machining. By mathematical processing of the experimental results, power type empirical models were determined. One noticed that the most important factor able to exert influence on the height of the columns obtained by electrical discharge machining was the peak current intensity, whose exponent in the power type empirical mathematical models has the highest absolute value.

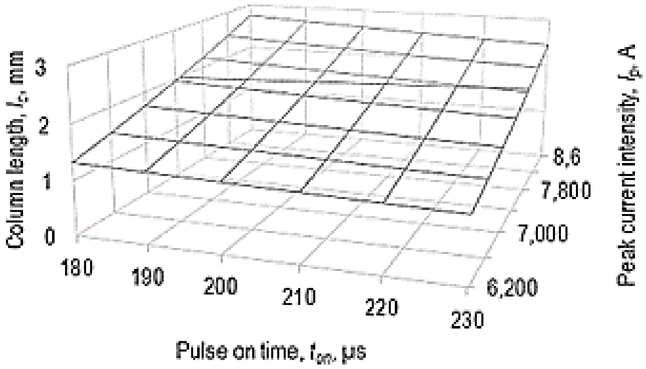

Figure 3. Influence exerted by the pulse on time t_{on} and peak current intensity I_p on the column length in the case of electrical discharge cutting of test piece made of high-speed steel HS18-1-1 (t_{off}=50 μs, process duration τ=25 min)

6. REFERENCES

1. Creţu, G., *Fundamentals of experimental research. Laboratory handbook*, "Gheorghe Asachi" Technical University of Iaşi, Romania, (1992).
2. Ghiculescu, D., *Nonconventional technologies* (in Romanian), Printech, Bucharest, Romania, (2004).
3. Mastud, S.A., Kothari, N.S., Singh, R.K., Johnson, S., and Joshi, S.S., Analysis of debris motion in vibration assisted reverse micro electrical discharge machining, ASME 2014 International Manufacturing Science and Engineering Conference collocated with the JSME 2014 *International Conference on Materials and Processing and the 42nd North American Manufacturing Research Conference, Vol. 1: Materials; Micro and Nano Technologies; Properties, Applications and Systems; Sustainable Manufacturing*, Paper No. MSEC2014-4157, (2014)
4. Nageendrababu, K., *Development of arrayed structures using reverse EDM (R-EDM).* Master thesis. National Institute of Technology Rourkela India, (2015).
5. Nichici, A., Popovici, M., Nica, M., Achimescu, N., Popa, H., Paulescu, G., *Machining by erosion in machine manufacturing* (in Romanian), Publishing House Facla, Timişoara, Romania, (1983).
6. Singh, S.K., Chourasia, A., Agarwal, P., Reverse EDM of collective electrodes in micro ECM, *International Journal of Application or Innovation in Engineering*, Vol. 3, No. 10, pp. 342-346, (2014).
7. Slătineanu, L., *Nonconventional technologies in machine manufacturing* (in Romanian), Tehnica-Info, Chişinău, Republic of Moldova, (2000).
8. Slătineanu, L., Stoica, Ş., Coteaţă, M., Dodun, O., Nagîţ, G., Beşliu, I., Machining speed at obtaining external cylindrical external surfaces by electrical discharge machining using plate type tool electrodes, *Buletinul Institutului Politehnic din Iaşi. Publicat de Universitatea Tehnică „Gheorghe Asachi" din Iaşi, Secţia Construcţii de Maşini,* Vol., No. , pp. 39-50, (2018).

Ţîţu, M., Nanu, D., *Fundamentals of machining with concentrated energies* (in Romanian), Publishing House of the "Lucian Blaga" University, Sibiu, Romania, (2002).