WORK SPEED AT RAM ELECTRICAL DISCHARGE MACHINING OF EXTERNAL CYLINDRICAL SURFACES

Ciprian MIRCESCU[1], Laurenţiu SLĂTINEANU[1], Margareta COTEAŢĂ[1], Irina BEŞLIU[2], Oana DODUN[1], Miroslav RADOVANOVIC[3]

ABSTRACT: The electrical discharge machining can be sometimes applied in order to obtain external cylindrical surfaces. Such a problem appeared as a consequence of the necessity to extract a cylindrical test sample from a part made of difficult to cut material. The analysis proved the possibility to use a tubular tool electrode and a classical machining scheme valid in the case of ram electrical discharge machining. The method of full factorial experiment was applied in order to design the experimental research. As input parameters, one considered the pulse on time, off time and discharge peak intensity. An investigation concerning the influence exerted by these input parameters on work speed was developed. A power type empirical mathematical model was determined by mathematical processing of the experimental results. The power type function and graphical representations proved the significant influence exerted by discharge peak current.

KEY WORDS: ram electrical discharge machining, tubular tool electrode, work speed, influence factors, empirical model.

1 INTRODUCTION

Electrical discharge machining is based on the erosive effect of pulse electrical discharges initiated between the tool electrode and workpiece. Electrical energy is transformed in thermal energy and, subsequently, in mechanical energy of material dislocation.

Practically, the electrical discharge determines a fast and intense increase of temperature in the electrodes surface layers and small quantities of electrodes materials are melted and vaporized; the material is expulsed from the electrodes as a consequence of microexplosions developed after the extinction of the electrical discharge.

The electrical discharge machining could be applied in manufacturing of various tools, stamps, obtaining complex surfaces in workpieces made of hard materials (Nichici et al., 1983, Slătineanu et al., 2004).

[1] "Gheorghe Asachi" Technical University of Iaşi, Department of Machine Manufacturing Technology, Blvd. D. Mangeron, 39 A, 700050 Iaşi, Romania

[2] University "Ştefan cel Mare" of Suceava, Department of Mechanics and Technologies, Universităţii Street 13, 720229 Suceava, Romania

[3] University of Niš, Department of Production Engineering, Aleksandra Medvedeva 14, 18000 Niš, Serbia

E-mail: mircescuciprian@yahoo.com, slati@tcm.tuiasi.ro, mcoteata@tcm.tuiasi.ro, irinabesliu@yahoo.com, oanad@tcm.tuiasi.ro, mirado@masfak.ni.ac.rs

Nowadays, there are two main groups of electrical discharge machining methods;

One can say that the electrical discharge machining is preferred when the workpiece material is difficult to be cut by classical machining methods or the surface to be machined is too complex to be obtained in convenient conditions by classical machining methods.

a) Ram electrical discharge machining methods, based on the use of massive electrode tools; if initially only a rectilinear work movements was used in order to copy the active surface of tool electrode in the workpiece material, nowadays complex numerical controlled work movements allow obtaining profiled surfaces which are not similar to the active surface of the tool electrode;

b) Wire electrical discharge machining, which uses a wire found in ongoing from a deposit coil to a rotating roll on which the wire is accumulated. Complex movements performed by workpiece and/or by tool electrode ensure conditions for obtaining ruled surfaces in plate type workpiece.

In machine building, external cylindrical surfaces could be met essentially in cases of shafts bushes, gears, punches etc.; when the workpiece material has a good machinability by cutting, such surfaces can be obtained by turning, milling, grinding, broaching etc. If the workpiece material is too hard, some nonconventional machining methods could be applied and some electrical discharge machining methods could be used in order to obtain external cylindrical surfaces.

Wire electrical discharge machining of external cylindrical surfaces allows obtaining a high machining accuracy, but material removal rate is relatively low, due especially to lower electrical discharge energy; there are limits of pulses energy, in order to avoid the tool electrode wire vibration under the action of the electrical discharges.

Over the years, the researchers directed their investigations to the wire electrical discharge machining of external cylindrical surfaces.

Thus, Deneş and Grecu developed an investigation concerning the possibility to obtain small diameters revolution surfaces by using a machining scheme in which the axis of the machined revolution surface is placed in a plane perpendicular on the wire direction in the work zone. They applied the Taguchi method in order to highlight the influence exerted by some input factors (pitch between two consecutive passes, discharge current intensity, current pulse on time, dielectric conductivity, wire speed, tensile force) on the machining accuracy (Deneş & Grecu, 2013).

The results of cylindrical wire electrical discharge turning process were investigated by Haddad et al.; their research was focused on the generation of cylindrical surfaces in parts made of difficult to machine materials, by using a computer numerical controlled wire electrical discharge machine. A mix full factorial experiment was designed in order to characterize the influence exerted by power, pulse off time, voltage, spindle rotation speed on the surface roughness and roundness of the machined surface (Haddad et al., 2010).

Guu and Hocheng proposed a machining method essentially characterized by the rotation of workpiece. They analyzed the effect exerted by pulsed current, pulse on-time, workpiece rotation on material removal rate and surface roughness. They concluded that the workpiece rotation improves the dielectric flow, determining finally an increased material removal rate, and an improved surface roughness (Guu and Hocheng, 2001).

Richter et al. referred to a 3D manufacturing method obtained by combining microelectrical discharge machining and electrochemical polishing; they investigated inclusively the machining of microshaft by means of microwire electrical discharge grinding. They considered that in order to optimize the machining process from the point of view of surface quality, a more attention could be paid to the selection of some single erosion parameters, such as energy, pulse frequency and spark gap (Richter et al., 2012).

Gil et al. showed that cylindrical surfaces of micropins could be obtained by inverse slab electrical discharge milling. They considered that the geometrical characteristics of the cylindrical part, rotational speed and discharge energy exert influence on the material removal rate, surface finish and micropin accuracy. Micropins characterized by an aspect ratio of 90:1 a 0.2 mm diameter were obtained in economical conditions (Gil et al., 2013).

If the external cylindrical surfaces are placed near surfaces characterized by higher dimensions of cross section, the wire electrical discharge machining cannot be applied in order to obtain external cylindrical surfaces. The paper contains some results obtained in the investigation of the electrical discharge machining of external cylindrical surfaces by means of tubular tool electrodes.

2 THEORETICAL CONSIDERATIONS

Various machining schemes could be applied in order to obtain external cylindrical surfaces by ram electrical discharge machining; some of these machining schemes are presented in figure 1.

If there is a possibility to rotate both the tool electrode and the workpiece around their axes with rotations speeds n_{TE} and n_{WP}, the machining scheme from figure 1, *a* could be applied. When the tool electrode could perform a revolution movement around the workpiece axis, one could select the machining schema from figure 1, *b*. The tool electrode is clamped on the machine tool work head, while the workpiece is located and clamped in a chuck fixed on the machine tool table. The both schemes (from figure 1, *a* and *b*) ensure a convenient evacuation of the material detached from electrodes by electrical discharges. Rotation movement of the tool electrode generates a relatively uniform wear of the tool electrode on its periphery and this could ensure a higher machining accuracy.

The machining schema from figure 1, *c* is simple, it involving the performing of only a linear vertical work movement by the tubular tool electrode clamped on the machine tool work head. In comparison with this machining schema, that presented in figure 1, *d* supposes performing the linear vertical work movement by the workpiece clamped in this case in a device attached to the machine tool work head. The last machining scheme could ensure a better evacuation of the particles detached from the electrodes, as a consequence of the electrical discharges; the fact that these particles do not stay longer time in the gap between tool electrode and workpiece could diminish the number of spurious electrical discharges (facilitated by the presence of particle detached from electrodes) and a higher machining accuracy could be expected in this case.

On the other hand, it is known that sometimes the machine tool work head could perform a vibratory motion characterized by low amplitude and frequency, in order to generate effects of absorption and pressing on the dielectric liquid, so that finally fresh dielectric liquid penetrates in the work gap and the particles detached from electrodes are remove.

3 CONDITIONS CONCERNING THE EXPERIMETNAL RESEARCH

The researches were initiated as a consequence of a request to detach cylindrical proves from a part made of an electroconductive difficult-to-cut material. An initial experiment was developed in accordance with the machining scheme presented in figure 1, *c*, but one noticed that in the case of this massive part (workpiece), the metallic particles detached from electrodes are maintained longer time in the work gap and the spurious electrical discharges generated by the presence of these particles leads to a certain connicity of the proves detached from the initial part.

For this reason, the machining scheme presented in figure 1, *d* was preferred; one appreciated that in such a case, the metallic particles detached from electrodes could be easier removed, just under the action of the gravitation force.

Figure 2 presents some details concerning the adopted solution. One can see that a parallelipipedic workpiece was clamped in the Erowa device, which usually is used in order to clamp the tool electrode; the Erowa device was attached to the machine tool work head. The tubular tool electrode was clamped in a chuck attached to the machine tool table.

The workpiece was made of high speed steel (HS 18-4-1), containing 0.659 % carbon, 17.7 % tungsten, 4.04 chromium, 1.19 % vanadium, 1.28 % molybdenum, 0.158 % nickel. Tubes made of electrotechnic copper, having an internal diameter of 5 mm and an external diameter of 6 mm were used as tool electrodes.

Before each experiment, tool electrodes and test sample were weighted by means of an analytical balance type Partner Radwag AS20.

The experiments were developed on a ram electrical discharge machine type Sodick AD3L; the equipment has a subassembly for computer numerical control.

Preliminary experiments proved that in the final stage of the machining process, when the cylindrical part is detached from the workpiece by penetration of the workpiece material by the tubular tool electrode, an eventual inclination of the detached part could significantly affect the cylindrical shape of the detached part; in order to avoid such a situation, a fixed depth (9.55 mm) of the cavity performed in workpiece was established by means of computer numerical control subassembly of machining equipment; a final subsequently grinding operation allowed complete detaching of the part from the workpiece. Because the depth of the cavity performed in the workpiece could be affected by a possible wear of tool electrode, this depth was measured for each experiment by means of a dial

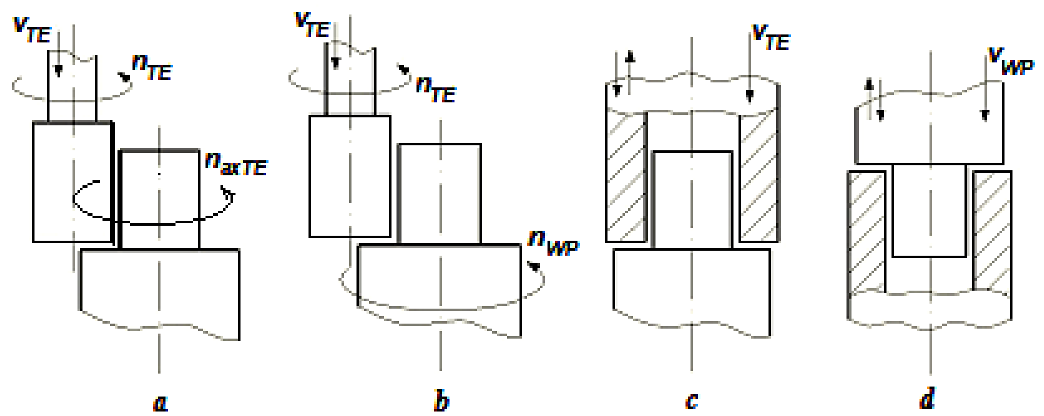

Figure 1. Machining schemes possible to be applied in order to obtain external cylindrical surfaces by ram electrical discharge machining (n_{TE} – rotation movement of the tool electrode, n_{WP} – rotation movement of tool electrode around its axis, n_{axTE} – rotation movement performed by tool electrode around workpiece axis, v_{TE} – rectilinear work movement of tool electrode, v_{WP} – rectilinear work movement of the workpiece)

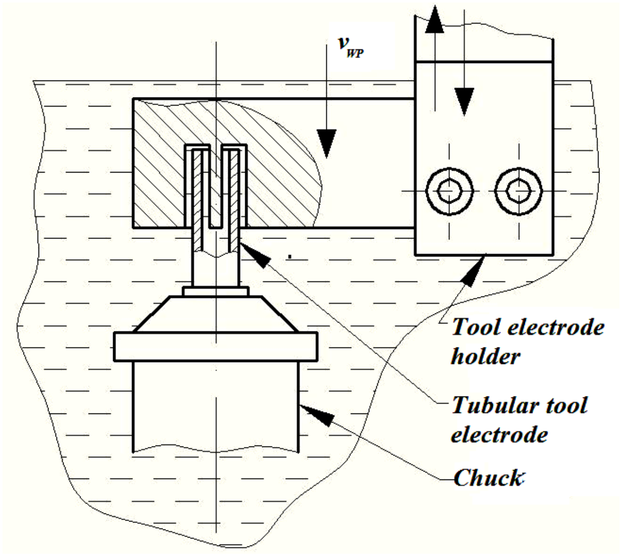

Figure 2. Work zone in the case of detaching cylindrical proves form a workpiece by ram electrical discharge machining

gauge whose measuring probe was completed with a thin rod. The differences appeared among the values of the cavity depth included in column no. 5 from table 1 could be justified by the high roughness of the bottom machined surface, due to rough machining conditions applied during the experimental test.

It is known that various input parameters could affect the speed of tool electrode penetration (work speed) in workpiece: such input parameters could be chemical composition of the workpiece material, the electrical parameters (pulse on time t_p, off time t_b, discharge peak current I_p etc.), the dielectric liquid type and the solution applied in order to circulate the dielectric liquid in the work gap, the movements performed by the tool electrode and workpiece etc. Considering that the pulse characteristics could exert a significant influence on the material removal rate, one established as process variables the pulse on time t_p, off time t_b and peak current I_p. As initial values for these work parameters, one used those proposed by the CAM software attached to the machining equipment, for the proper experimental conditions (t_p=110 µs, t_b=30 µs, I_p=15.3 A). One must mention that from the stages proposed by software, only the first stage (characterized by the same values for the input factors) was applied, due to the fact that one of the research objectives was to highlight how the input factors exert influence on the work speed at the ram electrical discharge machining.

For the other experimental tests, one took into consideration the rules valid in the case of a full factorial experiment with three variables at two levels. Thus, the second values for the input parameters were established so that a difference of about 25 % to the initial values was taken into consideration.

In this way, the values of the input parameters had the values indicated in the columns nos. 2, 3 and 4 from table 1. In the column no. 5 from this table, the depths of cavities performed in test piece were inscribed. The durations of the machining process were mentioned in the column no. 6; the work speed calculated as a ratio between the cavity depth and process duration was inscribed in the column no. 7.

4 PROCESSING OF THE EXPERIMENTAL RESULTS

The experimental results were processed by means of a software based on the method of least squares (Creţu, 1992); this software allows selecting the most convenient empirical models by taking into consideration the values of the so-called Gauss's criterion; these values are calculated as

Table 1. Experimental conditions and results

Exp. no.	Machining parameters			Depth of cavity, h_c, mm	Process duration, *t*, min	Work speed, *v*, mm/min
	Pulse on time, t_p, µs	Pulse off time, t_b, µs	Peak current, I_p, A			
Column no. 1	2	3	4	5	6	7
1	110	30	15.3	8.74	66	0.1324
2	140	40	15.3	8.79	110.44	0.0796
3	140	30	19.3	9.94	49.54	0.2006
4	110	40	19.3	8.70	36.31	0.2396
5	110	30	19.3	8.68	27.26	0.3184
6	110	40	15.3	8.84	59.26	0.1492
7	140	30	15.3	8.89	112.02	0.0794
8	140	40	19.3	8.94	41.19	0.217

sums S_G of squares corresponding to differences between the values measured and the values allocated on the basis of the proposed function, for the same experimental points.

By mathematical processing of the experimental results, the following empirical model was established for the work speed:

$$v = 0.441 + \frac{33.751}{t_p} + \frac{1.361}{t_b} - \frac{9.873}{I_p}, \qquad (1)$$

the Gauss criterion having the value S_G=5.27049·10^{-4}.

Because in the machining processes met in machine building frequently the power type functions are preferred (such functions offer a more direct image about the order of factors, if their influence is taken into consideration and about the intensity of their influences), one determined also a power type empirical model:

$$v_c = 0.0441 t_p^{-1.763} t_b^{-0.0729} I_p^{3.531}, \qquad (2)$$

for which the Gauss's criterion has the value S_G=7.307657·10^{-4}.

On the base of the relation (2), the graphical representations from figure 3, 4 and 5 were

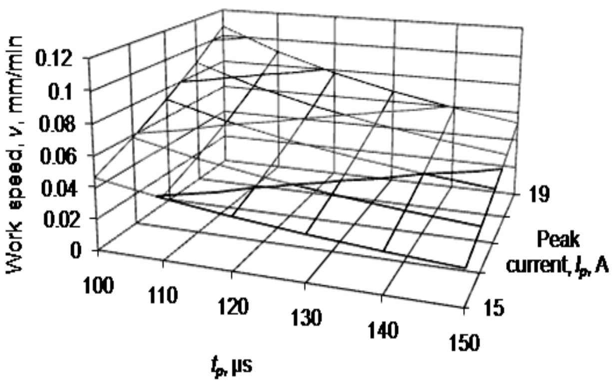

Figure 3. Influence exerted by the pulse on time t_p and peak current I_p on the work speed v (pulse off time t_b=40 µs)

elaborated. The analysis of the power type function (relation (2)) shows that the most significant influence on the work speed is exerted by the discharge peak current I_p, since the exponent attached to this factor has the maximum absolute value; on the second place, from this point of view, there is the pulse on time t_p, while the pulse off time t_b exerts a very low influence. One can notice also that for the investigated interval of input parameters variation, increase of the discharge peak current determines an increase of the work sped v, while the

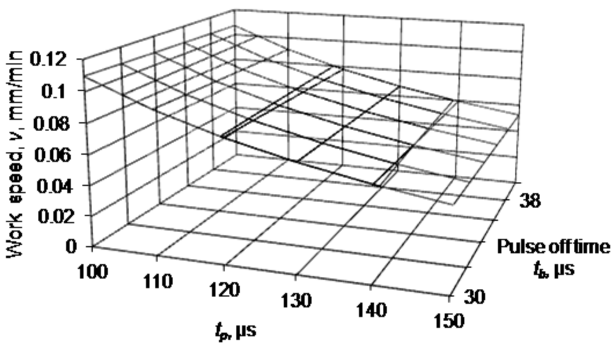

Figure 4. Influence exerted by the pulse on time t_p and off time t_b on the work speed v (discharge peak current I_p=19 A)

increase of the pulse on time has as a result a diminishing of the work speed v.

Another set of measurements were directed to the material removal rate, evaluated by means of the quantity of material removed in a time unit; by measuring the masses of the test piece before and after each machining process and by mathematical processing of the experimental results, the following empirical relation was determined:

$$Q = 0.0117 t_p^{-1.908} t_b^{0.0356} I^{3.439}, \qquad (3)$$

As one can see, the influence of the significant factors exerted on the material removal rate Q, in accordance with the relation (3), is similar to those corresponding to the work speed v; indeed, the increase of the pulse time t_p determines a decrease both of the work speed v and of the material removal rate Q, while the increase of the discharge current peak I_p has as a result the increase of the work speed v and material removal rate Q. One can also notice the close values of the exponents attached to the pulse of time t_p (1.763 and 1.908)

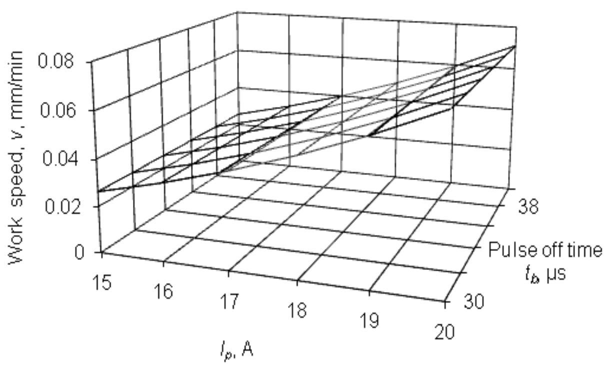

Figure 5. Influence exerted by the pulse off time t_b and discharge peak current I_p on the work speed v (pulse on time t_p=140 µs)

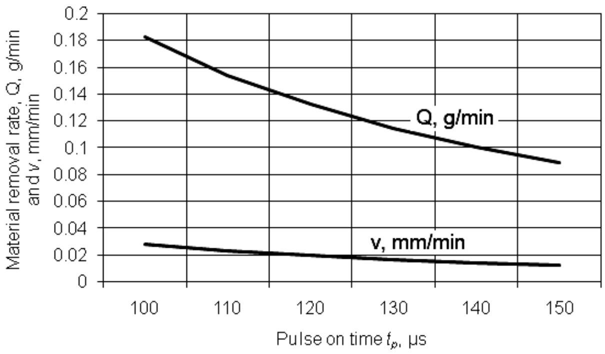

Figure 6. Influence exerted by the pulse on time t_p on the material removal rate *Q* and work speed *v* (pulse off time t_b=30 μs, discharge peak current I_p=16 A)

and discharge current I_p (3.531 and 3.439), both in relation (2) and (3) and this justifies once again the influence exerted by the factors t_p and I_p on various indicators of material removal rate.

Figure 6 was elaborated by considering both the relation (2) and (3), in order to highlight the influence exerted by the pulse on time t_p on the material removal rate *Q* and work speed *v*.

5 CONCLUDING REMARKS

Electrical discharge machining can be used in order to obtain external cylindrical surfaces. Up to now, especially the wire electrical discharge machining was investigated as a technological solution able to allow machining of external cylindrical surfaces. A processing scheme based on the ram electrical discharge machining and using tubular tool electrode was studied and some experimental results were presented in this paper. Within this machining scheme, the work motion was achieved by test piece clamped in the machine tool work head, in vertical direction, to the tool electrode placed on the machine tool table. One considered that the main input work factors able to exert influence on the material removal rate evaluated by means of work speed are the pulse on time, pulse off time and discharge peak current. A full factorial experiment was designed and performed; by mathematical processing of the experimental results, empirical models were established. One noticed that the most significant influence on the work speed is exerted by the discharge peak current. In the future, there is the intention to investigate some possibilities to increase the machining accuracy and roughness of the machined surface.

6 REFERENCES

► Creţu, G. (1992). *Fundamentals of experimental research. Laboratory handbook* (in Romanian), “Gheorghe Asachi” Technical University of Iaşi, Romania, (1992).

►Deneş, C., Grecu, V. (2013). *Experimental research on dimensional precision of small revolution surfaces processed by WEDM*, Nonconventional Technologies Review, No. 3, 31-36.

►Gil, R., Sánchez, J.A., N. Ortega, N., Plaza, S., Izquierdo, B., Pombo, I. (2013). *High-aspect ratio micro-pin manufacturing using inverse slab electrical discharge milling (ISEDM) process*, International Journal of Advanced Manufacturing Technology Vol. 65, No. 9-12, 1459-1469

►Guu, Y.H., Hocheng, H. (2001). *Effects of workpiece rotation on machinability during electrical-discharge machining.* Materials and manufacturing processes, Vol. 16, No. 1, 91–101.

►Haddad, M.J., Alihoseini, F., Hadi. M., Hadad, M., Tehrani, A.F., Mohammadi, A. (2010). *An experimental investigation of cylindrical wire electrical discharge turning process*, International Journal of Advanced Manufacturing Technology Vol. 46, No. 9-12, 1119–1132.

►Nichici, A., Popovici, V., Nica, M., Achimescu, N., Popa, H., Paulescu, G. (1983). *Machining by erosion in machine building* (in Romanian), Publishing House Facla, Timişoara.

►Richter, C., Krah, T., Büttgenbach, S. (2012). *Novel 3D manufacturing method combining microelectrial discharge machining and electrochemical polishing*, Microsystem Technologies, Vol. 18, No. 7-8, 1109–1118.

►Slătineanu, L., Nagîţ, Gh., Dodun, O., Coteaţă, M., Chinesta, F., Gonçalves-Coelho, A., Pamies Teixeira J., San Juan, M., Santo, L., Santos, F. (2004). *Non-traditional manufacturing processes*. Editura Tehnica Info, 2004, ISBN 9975-63-164-9, Chişinău.