BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LXI (LXV), Fasc. 3, 2015
Secţia
CONSTRUCŢII DE MAŞINI

EVOLUTION OF RING CAVITY DEPTH AT ELECTRICAL DISCHARGE MACHINING USING TUBULAR TOOL ELECTRODES

BY

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Received: July 20, 2015
Accepted for publication: August 25, 2015

Abstract. In the case of materials difficult to be cut by classical machining methods, the electrical discharge machining method could be applied for obtaining cylindrical surfaces, using tubular tool electrodes. In order to establish the machining conditions, it is necessary to have information concerning the influence exerted by process main input factors on the evolution of the ring cavity depth. An experimental research aiming to highlight the influence exerted by pulse on time, pulse off time, peak current intensity and process duration on the ring cavity depth was designed and achieved. In this way, a power type empirical mathematical model was determined.

Key words: electrical discharge machining, tubular tool electrode, ring cavity depth, process input factors, empirical mathematical mode

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1. Introduction

Electrical discharge machining is a machining method based on the effects of electrical discharges between the closest asperities existing on the active surface of the tool electrode and the workpiece surface, when in the machining gap a dielectric liquid circulates and removes the particles detached by the electrical discharges from the two electrodes. In the zones of contact between the plasma column corresponding to the electrical discharge and the surfaces layers of the electrodes, high temperature develops and small quantities of materials are affected by melting and even vaporizing phenomena (fig. 1). Due to explosive character of metallic material vaporization, these small quantities of the electrodes materials are thrown in the dielectric liquid, whose circulation contributes to the metallic particles removal from the work gap.

There are various machining processes of electrical discharge machining, but two principle machining schemes are usually taken into consideration: *a)* machining using the so-called massive tool electrodes and *b)* wire electrical discharge machining, when a thin wire tool electrode found in a continuous movement along its axis determines a separation of a part from the plate type workpiece, as a consequence of numerical controlled relative movements between tool electrode and workpiece.

Processes included in the both groups of electrical discharge machining methods are used in order to obtain external cylindrical surfaces. Within the laboratory of nonconventional technologies from the "Gheorghe Asachi" Technical University of Iaşi, the problem of detaching cylindrical test samples from a massive part made of thermal high resistant metallic material was formulated. Taking into consideration the existence of a ram electrical discharge machine, the idea of using electrical discharge machining process was analyzed and some preliminary experiments showed that a machining schema in which the workpiece achieves a vertical work movement to the tubular tool electrode placed on the machine tool table could be convenient, from the point of view of obtaining a certain machining accuracy.

Over the years, the researchers were interested in evaluation of material removal rate specific to processes of electrical discharge machining.

Thus, Beşliu and Coteaţă developed a research concerning the use of a tubular tool electrode in order to obtain small diameter cylindrical surfaces and to evaluate the material removal rate in electrical discharge machining process. They used a statistical method in analyzing the experimental results and established a power type empirical mathematical model (Beşliu & Coteaţă, 2015).

The evaluation of material removal rate in electrical discharge machining process of test samples made of aluminum 2618 alloy reinforced with silicon nitride, aluminum nitride and zirconium boride was the subject of a research developed by Mathan Kumar et al. They noticed an increase of material removal rate in the case of composite aluminum alloy (Mathan Kumar *et al.*, 2015).

Torres et al. took into consideration the study of the influence exerted by current intensity, duty cycle, pulse time and polarity on some output parameters (inclusively on the material removal rate) in the case of electrical discharge machining of an INCONEL 600 alloy; they noticed a high material removal rate when the negative polarity is applied (Torres *et al.*, 2015).

One noticed that there is relatively few published information concerning the electrical discharge machining of external cylindrical surfaces by means of tubular tool electrode. In order to obtain such surfaces, the researchers applied wire electrical discharge machining or processes which could be included in the group of electrical discharge grinding (based on the rotation movement achieved by the workpiece).

2. Experimental Research

An extended experimental research by considering fulfill factorial experiment with three independent variables at two variation levels was designed and materialized. The experiments were developed on a ram electrical discharge machine Sodick AD3L; this equipment ensures the numerical control along three rectilinear axes. As above mentioned, the workpiece was clamped on the work head of the machine tool, by means of the Erowa device, while the

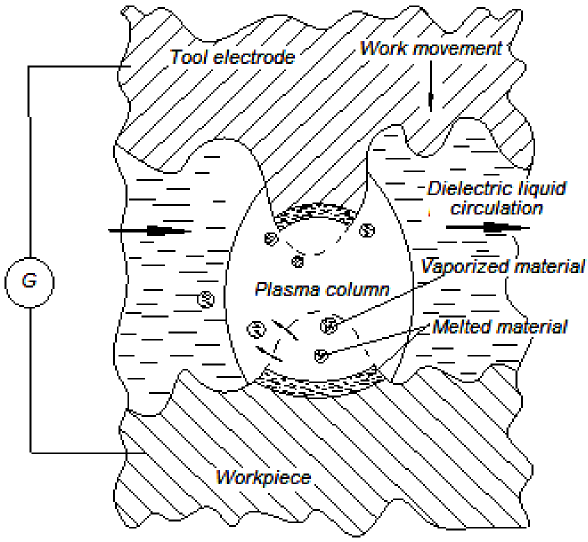

Fig. 1 − Material removal from workpiece as a result of melting and vaporizing phenomena

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tubular tool electrode was fixed in a vice placed on the machine tool table. Tubular tool electrodes made of copper and having an internal diameter d_i=5 mm and external diameter d_e=6 mm were used. The material of the workpiece was a high speed steel HS18-1-1-0.

The thickness of the workpiece was of 10 mm. One did not achieved a complete perforating of the wokpiece by means of the tubular tool electrode, in order to avoid a possible inclination of the detached machined piece in the final stage of the machining process; such an inclination could significantly affect the machining accuracy. For this reason, the machining process was stopped when the depth of the ring cavity obtained in the workpiece was of about 9.55 mm, by means of the machining system. Subsequently, the cylindrical parts were separated from the workpiece by a classical plan grinding method. A machine tool subassembly for highlighting the length of the machine tool work head stroke facilitated the periodical reading of the information concerning the position of the machine tool work head and one considered that in this way, information concerning the depth of the ring cavity machined in the workpiece could be obtained.

As input factors, one selected the pulse on time t_p, pulse off time t_b and the average value of the peak current intensity. The initial values of this input factors were established on the base of the machine tool manufacturer recommendations; the second value was established so that there is a difference of about 25 % in comparison with the initial value.

The values of the input factors were included in table 1, where the eight experiments corresponding to fulfill factorial experiment with three independent variables at two levels were inscribed along a horizontal line. In this way, along each column corresponding to a certain experiment, the values of the cavity depths were mentioned; these values were measured from 5 to 5 minutes.

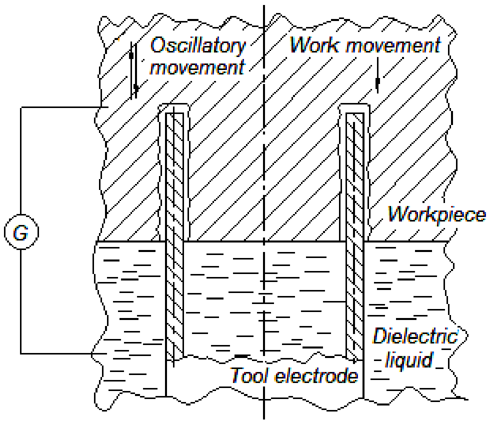

Fig. 2 − Machining scheme applied in order to obtain external cylindrical surfaces by electrical discharge machining with tubular tool electrodes.

Table 1
Experimental results

Machi-ning time, *t*, min	Ring cavity depth, mm in experiment no.:							
Column no. 0	1	2	3	4	5	6	7	8
	t_p=110 μs t_b=30 μs I_p=15.3 A	t_p=140 μs t_b=40 μs I_p=15.3 A	t_p=140 μs t_b=30 μs I_p=19.3 A	t_p=110 μs t_b=40 μs I_p=19..3 A	t_p=110 μs t_b=30 μs I_p=19.3 A	t_p=110 μs t_b=40 μs I_p=15.3 A	t_p=140 μs t_b=30 μs I_p=15.3 A	t_p=140 μs t_b=40 μs I_p=159.3 A
	1	2	3	4	5	6	7	8
5	1.11	0.61	1.52	1.88	2.08	1.08	0.62	1.38
10	1.93	0.99	2.61	3.50	3.91	1.89	1.07	2.81
15	2.69	1.32	3.57	4.98	5.64	2.64	1.43	3.98
20	3.53	1.68	4.50	6.18	7.29	3.40	1.82	5.09
25	4.40	2.07	5.33	7.28	8.75	4.15	2.25	6.21
30	5.20	2.48	6.12	8.35	9.42	4.97	2.68	7.26
35	6.00	2.87	7.05	9.14		5.75	3.12	8.27
40	6.75	3.30	7.88	9.40		6.58	3.58	9.21
45	7.31	3.71	8.78			7.39	4.02	9.43
50	7.72	4.13	9.44			8.17	4.49	
55	8.27	4.56				8.87	4.93	
60	8.73	5.02				9.44	5.36	
65	9.14	5.43					5.80	
70		5.86					6.24	
75		6.32					6.64	
80		6.73					7.08	
85		7.15					7.46	
90		7.55					7.86	
95		7.94					8.22	
100		8.30					8.58	
105		8.68					8.96	
110		9.02					9.28	
115		9.33					9.43	

In this way, by mathematical processing of the experimental results, an empirical mathematical model able to show the influence exerted by the initial input factors (pulse on time, pulse off time, peak current intensity) and by the time *t* could be determined. One must mention that the final values of the cavity depth were previously used in order to evaluate the influence exerted by the considered input factors on the penetration speed of the tool electrode into workpiece (Slătineanu *et al.*, 2014) and also, for a single situation, a study referring to the evolution in time of the penetration speed was developed (Slătineanu *et al.*, 2013).

3. Mathematical Processing and Analysis of Experimental Results

The experimental results were processed by means of a software based on the method of least squares (Creţu, 1992). The software facilitates the selection of the most adequate mathematical empirical model by considering the so-called Gauss's criterion.

In this way, the following mathematical empirical model was determined:

$$h = 0.427 t_p^{\ 1.555} t_b^{\ 0.448} I_p^{\ 3.117} t^{0.807}, \tag{1}$$

for which the Gauss's criterion has the value S_G=0.9263872.

On the base of the mathematical empirical model (1), the diagrams from figures 3 and 4 were elaborated.

The analysis of the empirical mathematical model and of the graphical representations from figure 3 and 4 shows that, in accordance with the experimental results, the increase of the pulse on time and pulse off time, the depth of cavity obtained for a certain process duration and for a certain current intensity, the cavity depth decreases, while when the current intensity and process duration increase, the depth cavity is also affected by an increase.

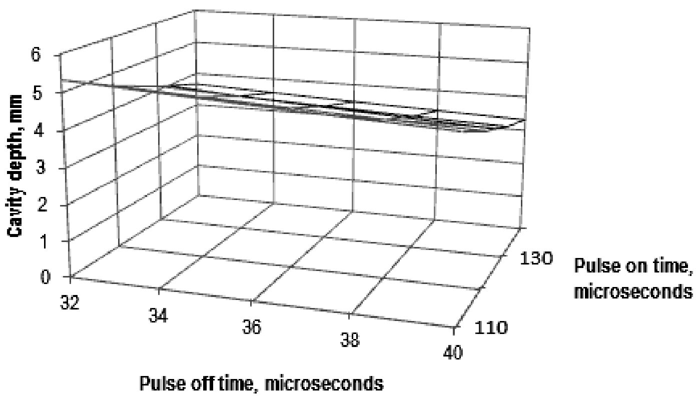

Fig. 3 − Influence exerted by pulse on time and pulse off time on the cavity depth (I_p=16 A, t=30 min).

Among the input factors, as expected, the most significant influence is exerted by the current intensity I_p, whose exponent (3.117) in the mathematical empirical model has the maximum value, if compared with the values of the exponents attached to the other input factors.

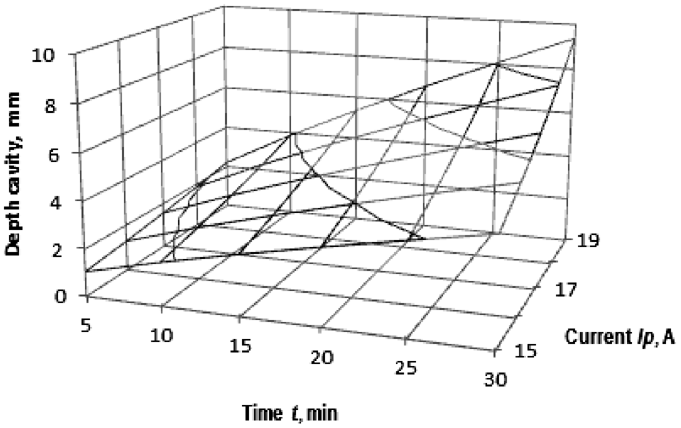

Fig. 4 − Influence exerted by current intensity I_p and process duration on the cavity depth (t_p=110 µs, t_b=30 µs).

5. Conclusions

The electrical discharge machining is a machining which may be applied in order to obtain ring cavities in workpieces made of materials difficult to be cut by classical machining methods. An experimental research was designed and achieved in order to highlight the influence exerted by the pulse on time, pulse off time, peak current intensity and process duration on the depth of ring cavity obtained by electrical discharge machining. By mathematically processing of the experimental results, a power type empirical model was determined. One noticed that the most significant influence on the ring cavity depth is exerted by the peak current intensity

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EVOLUȚIA ADÂNCIMII CAVITĂŢII INELARE LA PRELUCRAREA PRIN EROZIUNE ELECTRICĂ FOLOSIND ELECTROZI SCULE TUBULARI

(Rezumat)

În cazul materialelor dificil de prelucrat prin metode de clasice, ar putea fi utilizată prelucrarea prin eroziune electrică folosind electrozi scule tubulari, în scopul obţinerii unor suprafeţe cilindrice exterioare. Pentru stabilirea condiţiilor concrete de prelucrare, sunt necesare informaţii privind influenţa exercitată de către principalii factori de intrare în proces asupra evoluția adâncimii cavității inelare în curs de realizare. A fost conceput şi realizat un program de cercetare experimentală care să permită relevarea influenţei exercitate de către durata impulsului, durata pauzei dintre impulsuri, intensitatea medie a curentului şi durata procesului asupra adâncimii cavității inelare. Prin prelucrarea matematică a rezultatelor experimentale, a fost determinat un model matematic empiric de tip funcţie putere.