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DETERMINATION OF PROCESS FUNCTION FOR PITCH DIAMETER D_2 IN ELECTRO-EROSION MACHINING OF THREADS FROM SINTERED METALLIC CARBIDES TYPE G20

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ABSTRACT

The use of electro-technologies is one of the most important directions of technological development in our country. A special domain belongs to the procedures involved in machining the hard and extrahard materials. These materials are used extensively in fields like aeronautics, precision mechanics, cutting tools, etc.

In this paper, the authors present some of the results obtained in the theoretical and experimental researches concerning the electro-erosion machining of interior threads made in sintered metallic carbides type G20. These researches revealed the influences of electro-technological parameters on geometrical characteristics of thread (pitch diameter, pitch and profile angle). The present paper shows how was determined the process function associated to pitch diameter D_2. This function is useful for the establishment of electro-technological parameters in machining interior threads in sintered metallic carbides.

KEYWORDS: electro-erosion, metallic carbide, threading, response surfaces

1. INTRODUCTION

The technical and scientific discoveries of the last century have lead to the development of new branches of science, such as: electronics, cybernetics, computer science, astronautics, etc. The new scientific discoveries had strong influences on traditional technical fields, determining significant qualitative advances.

So, the metallurgical and chemical industries produced new types of materials and alloys: sintered metallic carbides, glass fibres, carbon fibres, etc.

The emergence of new materials and alloys, especially of hard and extrahard ones, leads to the necessity of industrial use of non-conventional machining procedures and amongst them - the electro-technologies. [1, 4, 5, 6, 9]

Even, in some cases, the non-conventional technologies are not the most economical technologies, they are fundamental, because they answer to technological problems that cannot be solved by conventional procedures.

The current movement in electro-erosion machining is very focused on the generation of various inner surfaces in metallic carbides [1, 2, 3, 12], because these surfaces cannot be made by conventional technologies.

The machining of threads in metallic carbides requires special threading devices [1, 8, 12] that may exist in the endowment of the machine-tools produced by certain companies [11, 14, 18, 19] or can be designed and manufactured for specific demands [15, 16, 17].

The researches performed by the authors focused on the determination of process function for pitch diameter D_2 of the thread in machining of sintered metallic carbides type G20 with screw-type electrode.

2. MEANS EMPLOYED IN EXPERIMENTAL RESEARCH

The experiments were carried out in the non-conventional machining laboratory of I.C.T.C.M. – Romania on the electro-erosion machine CHARMILLES D4, which is equipped with an ISOPULSE P3 generator.

Table 1. Pulse duration at CHARMILLE D4 machine

Position of selector switch	1	2	3	4	5	6	7	8	9	10	11	12
Pulse duration [μs]	2	3	4	6	12	25	50	100	200	400	800	1600

The pulse time is adjusted by the selector switch A with 12 positions. The corresponding values of each position are presented in Table 1.

Also, the pause time is adjusted by a selector switch with 12 positions. The intensity levels of ISOPULSE P3 generator are: level 1 = 25 A; level 1/2 = 12.5 A; level 1/4 = 6.25 A; level 3/4 = 18.75 A.

During the experiments carried out by the authors, threads M12 x 1.5 were machined in steel OLC45 – considered as reference material – and, also, in sintered metallic carbide G20.

The machining of threads was done using electrodes made from cathode copper (Fig. 1). The electrode was block, screw-type.

Fig.1. One electrode used in experiments

The probes were sectioned by laser in order to measure the geometrical parameters of the thread. The measurement of geometrical parameters was performed using the universal microscope 19JA (Fig. 2). This microscope has the following features:

- longitudinal measuring range: 0 - 200 mm;
- transversal measuring range: 0 -100 mm;
- angles (from 0° to 360°) are measured by an ocular protractor with a precision of 1';
- graduation: 0.001 mm.

The POLYVAC installation was used to determine the chemical composition of electrodes. The resulted composition is displayed in Table 2.

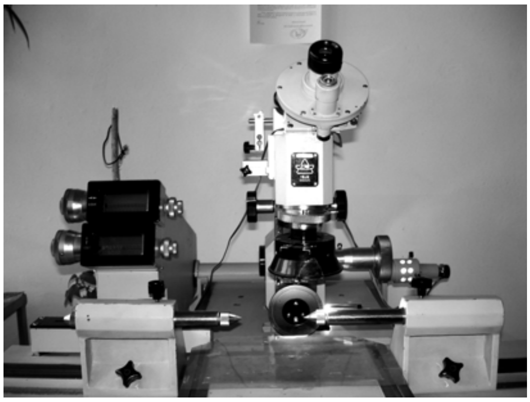

Fig.2. Universal microscope 19JA

Table 2. Chemical composition of electrodes

Chemical element	Cu	Al	Sn	Fe
Concentration [%]	99.5	0.0032	0.288	0.1576

S.C. CARMESIN S.A., the producer of metallic carbides, offered the mechanical, physical and metallographic characteristics of G20 metallic carbides samples (Table 3) and the sinterisation and cooling conditions of the metallic carbides mixture.

The sinterisation conditions were:

- sinterisation temperature - 1400°C;
- retardation time - 40 min;
- cooling in vacuum to 1150°C;
- cooling in CH_2 atmosphere from 1150°C.

3. ESTABLISHMENT OF INDEPENDENT AND DEPENDENT VARIABLES

After the study of the specialised literature [7, 10, 13], the authors selected as independent variables the following: mean intensity of the discharge current, i_e; pulse duration, t_i, and pause duration, t_0. As dependent variables, there were considered: work time, t; productivity of work, Q_{wo}; relative volume wear of electrodes, V_{Eo}; dimensional wear of electrodes, U_{Eo}; pitch diameter, D_2; thread's pitch, p; flank angle, α; flank roughness, R_a.

Table 3. Characteristics of samples made of G20

Characteristics	Unit of measurement	Company standard	Sample's value
Horizontal contraction after sinterisation (1500)	%	-	19.40
Diametric contraction after sinterisation (1500)	%	-	19.79
Density	g/cm^3	14.2 – 14.5	14.32
Hardness	HV50	1120 - 1240	1240
Fracture strength	N/mm^2	min. 1800	2038
Magnetic saturation	Tcm^3/g	min. 177 x 10^{-4}	176 x 10^{-4}
Cobalt magnetic	%	min. 8.82	8.75

Considering the general framework of research, there were determined the process functions for dependent variables. The process functions were mathematically described as:

$$y = A_0 \cdot i_e^{A_1} \cdot t_i^{A_2} \cdot t_0^{A_3} \quad (1)$$

and the relative indices were calculated for the established values:

- finishing: i_e = 12.5 A; $t_i = t_o$ = 12 µs.
- semifinishing: i_e = 25 A; $t_i = t_o$ = 50 µs.

All experiments were carried out with the voltage U = 80 V. According to the recommendations from specialised literature [1, 10, 13], the steel OLC45 was considered the reference material.

The natural levels of variables i_e, t_i, t_0 and the structure of experimental programme are presented in Tables 4 and 5.

Table 4. Natural levels of independent variables

Independent variables	Natural levels x_j		
	Minimum	Mean	Maximum
i_e [A]	12.5	18.75	25
t_i [µs]	12	25	50
t_0 [µs]	12	25	50

Table 5. Structure of experimental programme

x_j / No. experiment j	Variable level		
	x_1	x_2	x_3
1	12.5	12	12
2	12.5	12	50
3	12.5	50	12
4	25	12	12
5	25	50	50
6	25	50	12
7	25	12	50
8	12.5	50	50
9	18.75	25	25
10	18.75	25	25
11	18.75	25	25
12	18.75	25	25

There were performed 6 experimental programmes (P1 ÷ P6) for determination of workability functions for electro-erosion of threads. The workpiece's materials were steel OLC45 and sintered metallic carbide G20. There were used three types of electrodes: block electrode (screw type), milled electrode and grooved electrode. So, 2 types of material and 3 types of electrode lead to 6 experimental programmes.

In this paper, there are presented only some of the results of the P4 experimental programme (type of electrode: block electrode). Also, there was studied only one process function, respectively pitch diameter D_2.

The mathematical processing of experimental data was performed using MATLAB 7.0 software. Using this software, there were calculated the indicators of regression analysis. The indicators allowed the establishment of the weight and the influence of input variables (i_e, t_i and t_0) on process function (D_2.).

4. ANALYSIS AND RESULTS OF PROGRAMME P4

There will be presented the experimental results obtained at electro-erosion of thread M12 x 1.5 in sintered metallic carbide G20 with a screw-type electrode made from cathode copper. The results refer to process function D_2 (pitch diameter). The approximation equation for this function is of same type as equation (1). The natural independent variables are presented in Table 4.

In order to model statistically the pitch diameter D_2, there are presented in Tables 6, 7 and 8 the following: experimental programme and the results of the pitch diameter model; verification of model's adequacy; verification of coefficients' significance.

Table 6. Experimental programme and the results of the pitch diameter model, D_2

No. exp.	Variables			Responses		Confidence interval 95%	Error Δ (%)
				Measured	Calculated		
	i_e [A]	t_i [µs]	t_0 [µs]	D_2 [mm]	$\tilde{D}_2$ [mm]		
1	12.5	12	12	11.799	11.766	11.754 ÷ 11.778	0.27884
2	12.5	12	50	11.783	11.771	11.759 ÷ 11.782	0.10602
3	12.5	50	12	11.875	11.903	11.891 ÷ 11.915	-0.023557
4	25	12	12	11.609	11.669	11.658 ÷ 11.681	-0.5178
5	25	50	50	11.803	11.809	11.798 ÷ 11.821	-0.054962
6	25	50	12	11.856	11.805	11.794 ÷ 11.816	0.43077
7	25	12	50	11.684	11.674	11.662 ÷ 11.685	0.088079
8	12.5	50	50	11.885	11.907	11.896 ÷ 11.919	-0.18828
9	18.75	25	25	11.792	11.782	11.777 ÷ 11.787	0.088583
10	18.75	25	25	11.712	11.782	11. 777 ÷ 11. 787	-0.59044
11	18.75	25	25	11.852	11.782	11. 777 ÷ 11. 787	0.59785
12	18.75	25	25	11.782	11.782	11. 777 ÷ 11. 787	0.0037

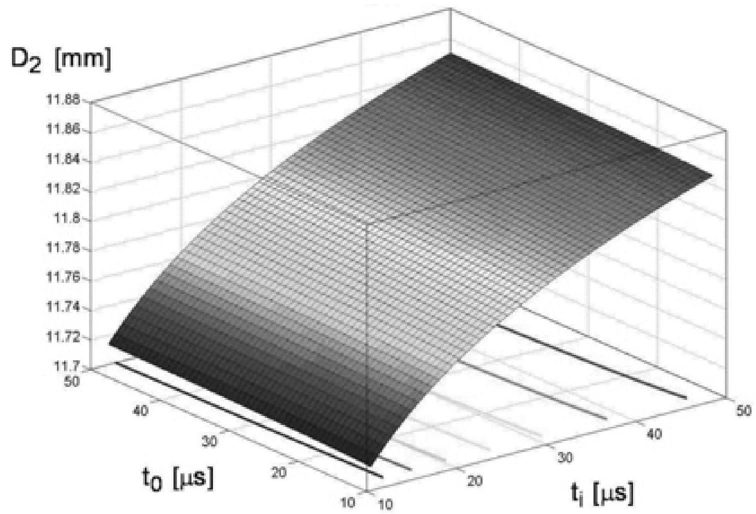

Fig. 3. Response surface for pitch diameter D_2 [mm] at constant i_e = 18.75 A

After statistical calculations, the mathematical model proved to be adequate (Table 7).

Table 7. Verification of model's adequacy

Dispersion	Values
$SR_{rz} = Y'Y - B'(X'X)$	0.00067074
$f_{rz} = n - m - 1$	8
$PM_{rz} = SP_{rz} / f_{rz}$	8.34843e-005
$SP_{er} = (Y - \bar{Y})'(Y - \bar{Y})$	7.1154e-005
$f_{er} = n_0 - 1$	3
$PM_{er} = SP_{er} / f_{er}$	2.3718e-005
$SP_{in} = SP_{rz} - SP_{er}$	0.00059959
$f_{in} = f_{rz} - f_{er} = n - m - n_0$	5
$PM_{in} = SP_{in} / f_{in}$	0.00011992
$F_{ci} = PM_{in} / PM_{er}$	5.056
$F_T\ (f_{in}, f_{er}, 95\%)$	9.01
$F_{ci} < F_T$	adequate

It can be observed that the responses predicted by the model (Table 6) present very small errors. The highest error is 0.59785% at 11th experience.

From the verification of coefficients' significance (Table 8), it results that the most influent factor upon the machining process is the mean intensity of the discharge current i_e, followed by pause duration t_0 and pulse duration t_i. The three associated coefficients are highly strong significant, both for 95% and 99% probability.

On the basis of measured responses, the coefficients of proposed model were determined using the least squares method. It resulted the following equation:

$$D_2 = 11.8763 \cdot i_e^{-0.011914} \cdot t_i^{0.0081027} \cdot t_0^{-0.00025781} \quad (2)$$

Using this model, the response surfaces for pitch diameter were produced using the determined model. For each response surface, two parameters were varied and the third was maintained constant at the middle of it's' variation interval (Figs. 3, 4 and 5).

Considering the variation intervals presented in Table 4, there are possible the following cases:

a) The mean intensity of the discharge current i_e is constant at 18.75 A and the pulse duration t_i and the pause duration t_0 vary between 12 and 50 µs. The associated graphic is displayed in Fig. 3. Figure 3 indicates that the value of pitch diameter D_2 increases when pulse duration t_i increases. Also, it can be observed that the value of pitch diameter D_2 increases linearly when pause duration t_0 increases, but at a low rate.

The results after mathematical processing of data offered by the response surface are presented in programme P4.1 (Table 9).

b) The pulse duration t_i is constant at 25 µs, the pause duration t_0 varies between 12 and 50 µs and the mean intensity of the discharge current i_e varies between 12.5 and 25 A. The associated graphic is displayed in Fig. 4. Figure 4 indicates that the value of pitch diameter D_2 increases almost to its maximum, when the value of mean intensity of the discharge current i_e is decreasing. It can be observed that the value of pitch diameter D_2 increases linearly when pause duration t_0 increases, but at a low rate.

Table 8. Verification of coefficients' significance

Coefficient		PM_{bi}	F_{cs}	$F_{T\,[1;\,12;\,(1-\alpha)x100]}$	
Symbol	Value			α	
				0.05	0.01
				4.84	9.33
b_0	2.4745	73.253	873700	√	√
b_1	-0.011914	-1.0198	-12163	√	√
b_2	0.0081027	0.76909	9173	√	√
b_3	0.00025781	-0.024462	291.76	√	√

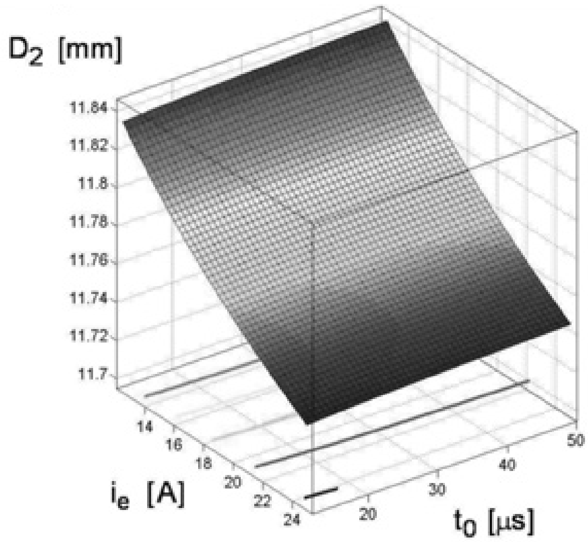

Fig. 4. Response surface for pitch diameter D_2 [mm] at constant t_i = 25 μs

Table 9. Programme P4.1

Data processing for pitch diameter D_2 response surface at constant i_e = 18.75 A	
% i_e = 18.75 - constant; t_i; t_0	
b_0	2.474546892289
b_1	-0.01191408482071
b_2	0.00810272251249
b_3	-0.00025780533763
i_e	18.75
t_{i1}	12:((50-12)/50):50
t_{01}	12:((50-12)/50):50
[t_i,t_0]	meshgrid(t_{i1},t_{01})
A_0	exp(b_0)
x_1	i_e.^b_1
x_2	t_i.^b_2
x_3	t_0.^b_3
y=A_0*x_1.*x_2.*x_3	
surfc(t_i,t_0,y)	

The results after mathematical processing of data offered by the response surface are presented in programme P4.2 (Table 10).

c) The pause duration t_i is constant at 25 μs, the pulse duration t_0 varies between 12 and 50 μs and the mean intensity of the discharge current i_e varies between 12.5 and 25 A. The associated graphic is displayed in Figure 5.

Fig. 5 indicates that the value of pitch diameter D_2 increases to its maximum with the increase of pulse duration t_i. Also, it can be observed that the value of pitch diameter D_2 has the tendency to decrease when mean intensity of discharge current i_e increases.

The experimental results after mathematical processing of data offered by the response surface are presented in programme P4.3 (Table 11).

Table 10. Programme P4.2

Data processing for pitch diameter D_2 response surface at constant t_i = 25 μs	
% t_i = 25 - constant; i_e; t_0	
b_0	2.474546892289
b_1	-0.01191408482071
b_2	0.00810272251249
b_3	-0.00025780533763
i_{e1}	12.5:((25-12.5)/50):25
t_i	25
t_{01}	12:((50-12)/50):50
[i_e,t_0]	meshgrid(i_{e1},t_{01})
A_0	exp(b_0)
x_1	i_e.^b_1
x_2	t_i.^b_2
x_3	t_0.^b_3
y=A_0*x_1.*x_2.*x_3	
surfc(i_e,t_0,y)	

Table 11. Programme P4.3

Data processing for pitch diameter D_2 response surface at constant t_0 = 25 μs	
% t_0 = 25 - constant; i_e, t_i;	
b_0	2.474546892289
b_1	-0.01191408482071
b_2	0.00810272251249
b_3	-0.00025780533763
i_{e1}	12.5:((25-12.5)/50):25
t_{i1}	12:((50-12)/50):50
t_0	25
[i_e,t_i]	meshgrid(i_{e1},t_{i1})
A_0	exp(b_0)
x_1	i_e.^b_1
x_2	t_i.^b_2
x_3	t_0.^b_3
y=A_0*x_1.*x_2.*x_3	
surfc(i_e,t_i,y)	

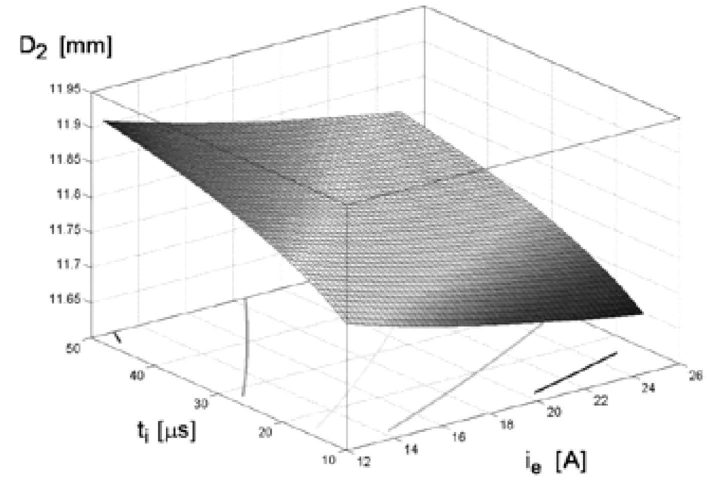

Fig. 5. Response surface for pitch diameter D_2 [mm] at constant $t_0 = 25$ µs

5. CONCLUSIONS

In this paper, there are presented some results of experiments performed by authors in order to obtain process functions for machining of interior threads in sintered metallic carbide G20 using electrodes made from cathode copper.

The extensive experimental research included 6 research programmes (P1 ÷ P6), but only programme P4 is presented in this paper. The programme P4 was aimed to determine the process function that expresses the diameter pitch D_2.

The discovered process function is useful for the prescription of electro-technological parameters that are used for machining of interior threads in sintered metallic carbide with block electrodes made from cathode copper.

From another point of view, this paper can be considered a model of complex research, where the strategy of experimental modelling and data processing had a central role. The paper can be useful for doctoral students and also for the academics that work in the field of non-conventional technologies.

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