Experimental contributions regarding numerical modeling of the relative wear of the tool-electrode at EDM process

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ABSTRACT: The purpose of this work is to present an experimental study regarding the influence of the mains parameters of the working process on the technological parameter "wear of tool electrode- γ_{ES}", at electrical discharge machining with a massive tool-electrode. Thus, an experimental mathematical model has been created, that establishes interdependence between γ_{ES} parameter and other parameters of EDM process, using Taguchi method. On the other hand, the optimal conditions for which it could be obtained a minimal value for technological parameter, wear of the tool-electrode γ_{ES} have been evaluated. The experimental study performed, has begun with the pieces of information from technical documentation for machine tool.

Key words: EDM, modeling, relative wear of tool-electrode

1 INTRODUCTION

The EDM process is a non-conventional machining process; the developing of this process was beginning since 1940. Electrical discharge machining is defined as the removing process of material from a piece using trains of pulses of electrical discharges at short period of time. These discharges take places between two poles (tool-electrode and piece).

The main advantages in rapport with other processes are: the possibility of machining of some intricate forms with minimal lose of material, the possibility of machining of difficult to machine materials, machining accuracy, and very good quality of surface and so on. Because on abroad, with the developing of new materials and increasing the necessity to reduce the consumption of material and energy, a performance parameter, $\gamma_{ES,}$ has been established. By means of researching over the wear parameter of tool-electrode in the working process, the main tendency is to improve the process efficiency.

The correlation between working process and technological parameters at EDM gave us important information over the EDM working process [1, 2, 3].

2 EXPERIMENTAL RESEARCH STRATEGIES (MATERIALS, TESTING CONDITIONS AND MEASURING)

It must be taken into account the system EDM (including, at the workplace level, the tool-electrode, piece and gripping-positioning devices) as an open system with inputs and outputs. In the system the following parameters are involved: a) input parameters – the main features of tool-electrode (shape, dimensions, material, mass, hardness and roughness), the main features of piece (form, dimensions, material, mass, hardness and roughness), working machine; b) output parameters that are described by technological parameters that could be objective functions. The output parameters are: wear of tool-electrode γ_{ES}; productivity of machining Qp; absolute wear of tool-electrode U_a, working speed V_p, roughness of machined surface R_a, gap size S; c) adjusting parameters are: intensity I, pulse time t_a, time between pulses $t_{b,}$ working depth $h,$ polarity of tool-electrode P(-) and tool-

piece $P(+)$ and d) perturbations.
The values of adjusting parameters were established according with the recommendations from technical documentation of machine tool [4].
For performing the experiments, an EDM machine tool endowed with a thick electrode, with numerical control, type FORM 20ZNC (manufactured by Charmilles Company) was used [4].
A schematically representation of the machine is shown in figure 1 [4].

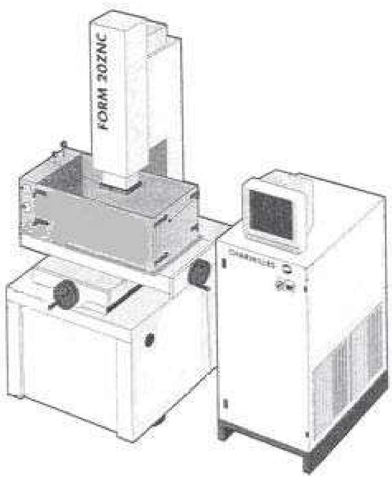

Fig. 1. EDM machine with a thick electrode type FORM 20ZNC [4]

Thus, for the achieved experimental plan, the working depth h=2 mm, and the polarity of tool-electrode $P(-)$ and tool–piece $P(+)$ was retained as a constant, as soon as, the values of the parameters I, duration of a pulse t_a and duration between pulses t_b was considered at two levels. It is defined as level of a certain factor the value that could take a factor during the experiments.
The values established for I are 8 A and 12 A, for duration of pulses t_a has been chosen the following two levels: 50 µs and 300 µs and for the duration between pulses t_b 100 µs and 500 µs.
The pieces used for experiments had a prismatic shape, with length L=18 mm, width l =13 mm and thickness g=7 mm. The pieces required for experimental tests has been made from steel with the following chemical composition: 6.16 % tungsten, 4.58 % molybdenum, 4.34 % chromium, 1.65 % vanadium, 0.94 % carbon, 0.63 % silicon, 3.433 % manganese, 0.0029 % sulphur, 0.027 % phosphor, 0.57 % cobalt, 0.309 % nickel.
The tool–electrode is made of cooper, having also a prismatic shape with active zone having the following dimensions: length: L= 28 mm, width l = 3.5 mm.

3 DESIGN OF EXPERIMENT BASED ON TAGUCHI METHOD. THE STUDY OF INFLUENCE OF INPUT PARAMETERS ON THE RELATIVE WEAR PARAMETER OF TOOL–ELECTRODE γ_{ES}

For designing an experimental plan, it is used the Taguchi method for planning the experiment. It is preferred to use this method because it offers the following advantages in comparison with traditional methods: diminishing of the number of experimental tests, possibility of study of influences of a great number of factors, establishing thus certain interactions between factors, relative easy interpretation of results, finding out optimal values, and finding out the results with a good precision, modeling in matrix form of results and so on. The purpose of experiments is to obtain the required results, in condition of maximum fiability and minimum cost [5, 6]. There are certain steps proposed by G. Taguchi for establishing the conditions for developing/programming the experiment: Step 1: Creating the problem that supposes the following stages: defining the problem, finding out of the objective, creating a work-team, finding out the constraints, defining the answer, selecting the factors, establishing the levels for each factor, identifying the interactions; Step 2: Building an experiment plan; Step 3: Performing the tests and measuring the results; Step 4: Choosing the configuration for different levels of factors taken into account, in order to optimize the criteria required for quality; Step 5: Performing of a validation essay in order to confirm that all the results expected are achieved. In order to develop the experiments, a complete factorial plan type 2^3 has been chosen.
The experimental plan and also the results of tests are shown in table 1. Relative wear of tool-electrode, parameter $\gamma_{ES,}$ could be defined by means of the ratio between the volume of material removed from tool-electrode ΔV_{ES} and the volume of material removed from electrode-piece ΔV_{EP}, in percents (equation 1):

$$\gamma_{ES} = \frac{|\Delta V_{ES}|}{|\Delta V_{EP}|}[\%] \qquad (1)$$

Table 1. Experimental plan and the values of parameters γ_{ES}

No.	Essay factors						γ_{es} [%] - exp.
	I	t_a	t_b	$I \cdot t_a$	$I \cdot t_b$	$t_a \cdot t_b$	
1.	1	1	1	1	1	1	0.756
2.	1	1	2	1	2	2	1.434
3.	1	2	1	2	1	2	0.165
4.	1	2	2	2	2	1	0.142
5.	2	1	1	2	2	1	0.984
6.	2	1	2	2	1	2	1.656
7.	2	2	1	1	2	2	0.093
8.	2	2	2	1	1	1	0.133

The experimental model, in matrix shape, that describes the effects of factors and interactions between these over the answer of the system is [5, 6]:

$$Y = M + \sum_{i=1}^{n}\left(\left[EF_{i1}, EI_{i2} .....F_{ik}\right]AF_i\right) + \\ + \sum_{\substack{i,j=1 \\ i \neq j \\ i<j}}^{n}\left({}^{t}\left[AF_j\right]\begin{bmatrix} IF_{i,1}F_{j,1} & \cdots & IF_{i,1}F_{j,k} \\ & & \\ IF_{i,k}F_{j,1} & \cdots & IF_{i,k}F_{j,k}\end{bmatrix}\right)\left[AF_2\right] \quad (1)$$

in which: Y is the answer of the system, M is the average number of the experiments, $[AF_i]$ and ${}^{t}[AF_i]$ are the matrix of the factor i and the transposed of this matrix, EFi, k are the effects of factors I at level k, $IF_{i,k}, F_{j,l}$ - interactions between parameters i and j, at the levels k and l.

The experimental model $\gamma_{ES}\sim$, that describes the influence of factors I, t_a, t_b, on the relative wear of tool–electrode and interactions between those factors (model established in accordance with the requirements from Taguchi method), could be described as:

$$\gamma_{ES} \sim= 0.670 + \left[-0.046 \quad 0.046\right] \cdot I + \\ \left[0.536 \quad -0.536\right] \cdot t_a + \left[-0.170 \quad 0.170\right] \cdot t_b + \\ + {}^{t}I \cdot \begin{bmatrix} -0.066 & 0.066 \\ 0.066 & -0.066 \end{bmatrix} \cdot t_a + {}^{t}I \cdot \begin{bmatrix} 0.007 & -0.007 \\ -0.007 & 0.007 \end{bmatrix} \cdot t_b \quad (2) \\ + {}^{t}t_a \cdot \begin{bmatrix} -0.166 & 0.166 \\ 0.166 & -0.166 \end{bmatrix} \cdot t_b$$

Comparing the relative effects of factors could be realized more easily if the effects of three factors and the interactions between these are transposed in graphics (figure 2).

The objective function, namely function relative wear of tool-electrode- γ_{ES}, must be achieved a minimal value. According to the pieces of information showed in figure 2, this minimum is achieved for displacing the factors at the following levels: I at level 1, t_a at level 2, t_b at level 1.

On the other hand, studying the interactions between factors, it could be noticed that the objective function achieves minimum for the following combinations: I_2t_{a2}, I_1t_{b1}, $t_{a2}t_{b1}$.

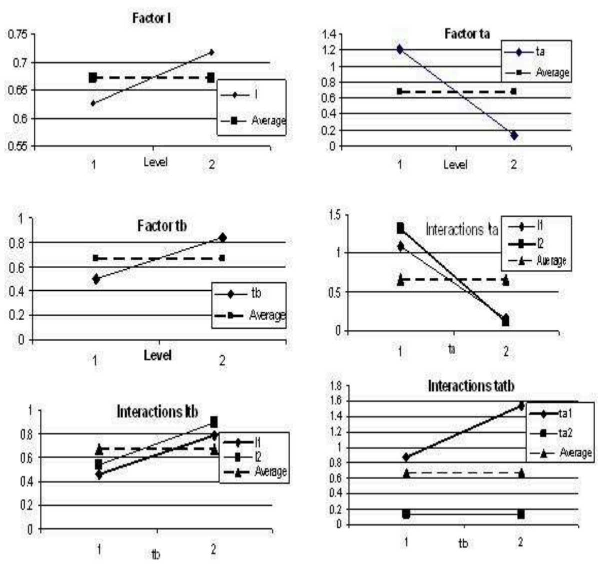

Fig. 2. Effects of factors and interactions at levels 1 and 2 over parameter γ_{ES}

The experimental values obtained by solving the matrix model $\gamma_{ES}\sim$ for the eight experimental points, and also the values γ_{ES} found in experimental way, are included in table 2.

Table 2. The values of the measured answers, calculated answers and residues

No. Exp.	$\gamma_{ES\,i\,meas}$	$\gamma_{ES\,i\,calc}$	Res.
1.	0.7561	0.76483	-0.00874
2.	1.4342	1.42546	0.00873
3.	0.1654	0.15666	0.00873
4.	0.1426	0.15133	-0.00874
5.	0.9845	0.97576	0.00873
6.	1.656	1.66473	-0.00874
7.	0.0934	0.10213	-0.00874
8.	0.1339	0.12516	0.00873

The graphical representations of the experimental values $\gamma_{ES}\sim$ and also obtained in experimental mode for the relative wear γ_{ES} could be found in figure 3.

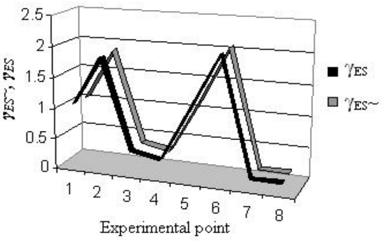

Fig. 3. Values γ_{ES} and γ_{ES} ~

From the study presented in figure 3, it could be noticed a very small difference between the measured values and the values obtained after solving the model; this shows a good approach of the experimental values in comparison with the experimental model. It could be noticed also, a small influence of the uncontrollable factors and a very good accuracy of the measurements performed for the parameter taken into account.

In order to simplify the matrix model, it must be established influence in base of Fisher test. [1], [4]. For the level of credibility adopted α=85 % (Test Snedecor), the values calculated of the Fischer F coefficient are higher than those presented in the table F_α, so that, the parameters I, t_a, t_b and also for interactions It_a, t_at_b (table 3) become significant; the interaction It_b, for which $F<F_\alpha$ remains insignificance so that it could be neglected.

Table 3. Analysis of variance of parameter γ_{ES}

Source	Variability	Variant Dispersion	F	F_α $\alpha=85$ [%]	Significance $F > F_\alpha$
I	0.017	0.01706	27.93	17,35	Sig.
t_a	2.306	2.30641	3774.8	17,35	Sig.
t_b	0.233	0.23368	382.46	17,35	Sig.
I t_a	0.035	0.03523	57.66	17,35	Sig.
I t_b	0.0004	0.00040	0.657	17,35	Insig.
t_a t_b	0.221	0.22174	362.92	17,35	Sig.
Res.	0.0006	0.00061			
Total	2.814				

The matrix model could be written in a simplified shape, after the elimination of the insignificance interactions as follows (equation 3):

$$\gamma_{ES} \sim= 0.670 + \begin{bmatrix}-0.046 & 0.046\end{bmatrix} I + \begin{bmatrix}0.536 & -0.536\end{bmatrix}\cdot t_a + \begin{bmatrix}-0.170 & 0.170\end{bmatrix}\cdot t_b + {}^tI\begin{bmatrix}-0.066 & 0.066\\ 0.066 & -0.066\end{bmatrix}\cdot t_a + {}^tt_a\begin{bmatrix}-0.166 & 0.166\\ 0.166 & -0.166\end{bmatrix}\cdot t_b \quad (3)$$

4 CONCLUSIONS

Minimal wear could be achieved for t_a at level 2 (300 µs) and t_b at level 1 (100 µs); for the steel from which the experimental pieces were machined, the relative wear of tool–electrode is minimum if the factor I is adjusted at level 1 (I=8 A).Factor I is a kind of factor with a small degree of significance (minimum), so that it has a small influence on the results of tests. In order to achieve a smaller wear of tool-electrode, the values of factors t_a and t_b must be adjusted with priority and no more the values of factor I; in this case, the factor t_a has a favorable influence as soon as the factor t_b has not favorable influence on the parameter γ_{ES}, so that it must be intensified the action of factor t_a and diminished the action of factor t_b. The objective γ_{ES}=minim is achieved for a maximum value of factor t_a and a value of factor t_b minimum.

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