TOOL ELECTRODE WEAR AT WIRE ELECTRICAL DISCHARGE MACHINING

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ABSTRACT: The wire electrical discharge machining is a machining method in which the pulse electrical discharges developed between workpiece and travelling wire tool electrode are used in order to detach parts having complex ruled surfaces in plate type workpieces. The problem of evaluation of wire tool electrode wear was considered. A theoretical analysis of phenomena developed in work zone during wire electrical discharge machining process was developed. An experimental research in accordance with the rules valid in the case of a factorial experiment with six independent variables at two levels was designed and materialized. Power type empirical mathematical models were determined by mathematical processing of the experimental results, in order to highlight the influence exerted by workpiece thickness, pulse on time, pulse off time, wire tensioning force and current intensity and travelling speed on the wire tool electrode wear.
KEY WORDS: wire electrical discharge machining, wire tool electrode wear, influence factors, experimental research, empirical mathematical models.

1 INTRODUCTION

The electrical discharge machining method is included in the larger group of nonconventional machining technologies, that generally are applied when the so-called classical machining methods cannot be applied, due to high mechanical properties of the workpiece material or when the surface to be machined are complex and the classical machining methods cannot be applied or their application is not efficient. The electrical discharge machining is based on material removal from workpiece as a consequence of electrical discharges developed between the closest asperities existing on the active surface of tool electrode and on the workpiece surface to be machined. The particles detached from the tool electrode and workpiece as a consequence of thermal effects of electrical discharges are removed from the operational gap as a consequence of dielectric liquid circulation. A work movement usually achieved by tool electrode facilitate the gradual development of machined surface; if there are many work movements, achieved by tool electrode and/or by workpiece, the machined surface is an envelope of the successive relative positions appeared between the tool electrode and workpiece.

If the type of tool electrode is analysed, one can notice that essentially there are *ram electrical discharge machining techniques*, based on use of a massive tool electrode, and, on the other hand, *wire electrical discharge machining methods* that use a metallic wire as tool electrode.

During wire electrical discharge machining, the wire tool electrode achieves a travelling motion from a unwinding reel to a winding reel, while the plate type plate moves in a plane coordinate system, under computer numerical control; in this way, only ruled cylindrical type surfaces could be obtained by wire electrical discharge machining. The last decades highlighted improved machining equipment, able to offer supplementary computer numerical controlled movements, usually achieved by the upper wire guide. Thus, for example, conical type surfaces could be obtained by wire electrical discharge machining.

The main role of the wire travelling is to compensate the wear able to affect the active surface of the wire tool electrode, by feeding continuously wire unaffected by erosion process in the work zone.

The problem of highlighting the evolution of the wire tool electrode wear was approached by researchers in distinct ways. Thus, Tosun and Cogun developed an experimental investigation concerning the influence exerted by some distinct input factors (pulse duration, open circuit voltage, wire speed and dielectric fluid pressure) on the wire tool electrode wear, as a consequence of wire electrical discharge machining process applied to a

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test piece made of AISI 4140 steel and having a thickness of 10 mm (Tosun & Cogun, 2003). They found that for the considered experimental conditions, the increase of pulse duration and of open circuit voltage determine an increase of wire tool electrode wear ratio, while the increase of wire speed generates a decrease of the tool electrode wear.

The wire tool electrode wear ratio was took into consideration by Kumar et al., in a process of multi-response optimization based on response surface methodology, applied in wire electrical discharge machining process of test pieces made of pure titanium (Kumar, 2013). The experiments were developed in accordance with a Box-Behnken design. As regression equation, a quadratic model was established for wire tool electrode wear ratio. The process input factors were pulse on time, pulse off time, peak current, spark voltage, wire feed and wire tension.

Rao and Krishna took into consideration the wire wear ratio in a more complex activity of selecting the optimal process parameters in case of wire electrical discharge machining of test pieces made of Al7075/SiCp metal matrix composites (Rao & Krishna, 2014). They established an empirical polynomial of second degree in order to characterize the influence exerted by particulate size, volume of SiCp, pulse-on time, pulse-off time and wire tension on the wire wear ratio. The empirical model was used within a multi-constraint multi-objective optimization process, the aim being the minimizing surface roughness and wire wear ratio and maximizing material removal rate.

Prasad and Krishna investigated the wire wear ratio in order to develop an optimization of wire electrical discharge machining process, by considering the cutting width and wire wear ratio (Prasad & Krishna, 2015). The pulse-on time, pulse-off time, wire tension, dielectric flow rate and wire speed were considered as input variables. The technique of harmony search algorithm was applied for finding optimal values corresponding to the process input variables.

The aim of research presented in this paper was to establish an empirical mathematical model able to highlight the influence exerted by some input factors specific to wire electrical discharge machining process on wire tool electrode wear.

2 WIRE TOOL ELECTRODE WEAR PROCESS

As above mentioned, the wire electrical discharge machining method uses a wire electrode found in a continuous movement from an unwinding reel to a rotating winding reel (fig. 1). In the work zone, the wire changes the movement direction due to the presence of upper and lower guide rollers; the accurate position of the wire is ensured by means of the upper and lower guides.

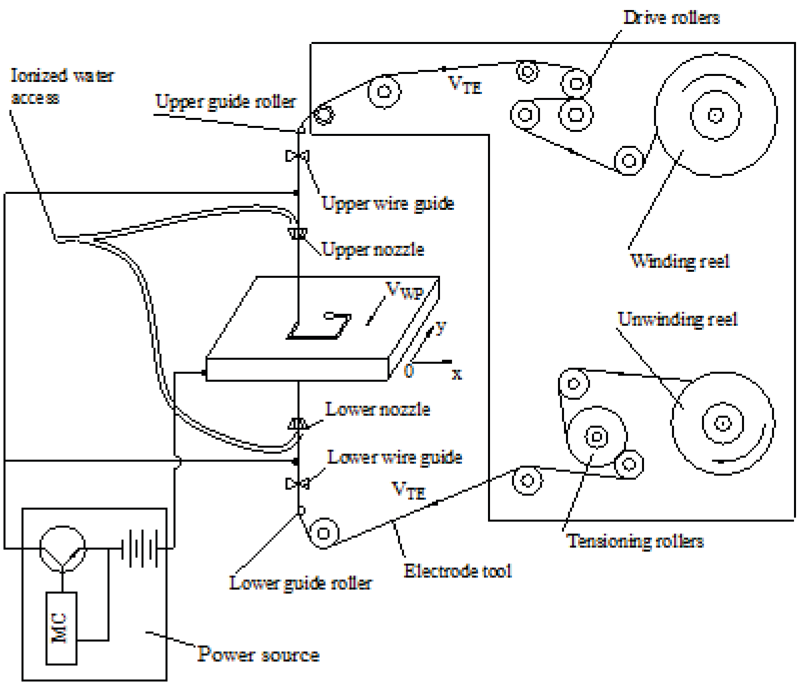

Figure 1. Machining scheme in case of wire electrical discharge machining

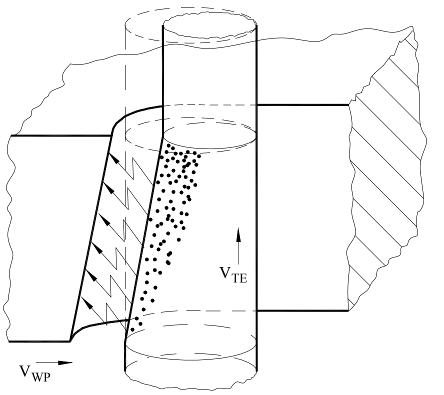

Figure 2. Erosion process that affects the wire tool electrode in the work zone

Over and under the workpiece and around the wire tool electrode, two nozzles send the dielectric fluid necessary in order to remove the particles detached from workpiece and wire tool electrode. The rectilinear shape of the wire in the work zone and the decrease of the wire possible curvature in the space between upper and lower wire guides need the introduction of a tensioning subsystem that use two tensioning rollers. The workpiece is positioned and clamped on the machine tool table that moves with a speed v_{WP} in a Cartesian coordinate system *xOy*.

The wire tool electrode and the workpiece are connected in the electric circuit of a pulse generator.

In the work zone (fig. 2), the wire tool electrode moves along its axis with the speed $v_{TE,}$ as a consequence of drive rollers presence.

Due to the self-adaptive speed of the movement achieved by workpiece, electrical discharges develop if the distance between wire and workpiece becomes lower than the discharge distance *s:*

$$s < \frac{U}{E}, \tag{1}$$

where *U* is the voltage applied to the workpiece and wire tool electrode and *E* is the electrical rigidity of the environment found in the work zone.

As a direct consequence of low distances between wire tool electrode and workpiece surface, electrical discharges develop between the closest asperities existing on the tool electrode active surface and the workpiece surface. Each electrical discharge determines the melting and even vaporizing of a small quantity of material in the zones where the electrical discharge takes contact with the workpiece and tool electrode surfaces. The explosive character of these thermal phenomena (melting and vaporizing) determines the throw of the melted and vaporized material in the dielectric fluid, where phenomena of solidifying occur. The circulation of the dielectric fluid (deionized water) ensures removal of the re-solidified metallic particles from the work zone. Along the trajectory segment in which the wire tool electrode crosses the workpiece, electrical discharges contribute to a continuous removal of material from wire tool electrode, so that the shape and dimensions of wire tool electrode at the output of workpiece are distinct if compared with the same elements valid in the zone where the wire tool electrode enters the workpiece; in fact, the cross section of wire tool electrode is lower at the enter in work zone, if compared with the cross section at exit of work zone. Along its passing through workpiece, many electrical discharges affect the wire tool electrode mass, removing material from it, but the wire tool electrode speed v_{TE} is established so that the influence of wire tool electrode wear is minim.

A possible evaluation of the wire tool electrode could be made by taking into consideration the ratio w_{TE} between the decrease of the wire tool electrode mass Δm_{TE} and the length *l* of the wire tool electrode:

$$w_{TE} = \frac{\Delta m_{TE}}{l_{wTE}} \tag{2}$$

Due to the relative high length l_{TE} of the wire tool electrode and adequate selection of the wire tool electrode speed v_{TE}, the influence exerted by wire tool electrode wear on machining accuracy is low and the wire electrical discharge machining is considered as being one of the machining methods able to ensure a high machining accuracy (actually, machining accuracy of about 0.0001 mm could be obtained).

3 EXPERIMENTAL RESEARCH

The objective of the experimental research was to highlight the influence exerted by some of process input factors on the wire tool electrode wear, as a consequence of developing a wire electrical discharge machining process.

The experiments were performed on a Japax model L250 type electrical discharge machine existing in an industrial enterprise. The equipment ensures possibilities to control some operating parameters concerning, for example, the characteristics of the electric pulses (pulse on time, pulse of time, average peak current intensity etc.), of dielectric circuit circulation (electrical conductivity, dielectric liquid flow etc.), of mechanical parameters (wire tensioning force, speed of wire movement along its axis, machining movements speed along the desired trajectory etc.).

Test pieces having distinct thicknesses were used; the test piece material was the steel 205 Cr115 (containing 2.05 % carbon and 11.5 % chromium); this material is used in order to obtain the active components of dies and moulds for machining by cold plastic deformation.

The wire tool electrode was weight by means of an electronic weighting machine type AB204 Metter Toledo, whose weighting accuracy is of ±0.0004 g. The wire tool electrode was made of copper and had a diameter of 0.2 mm.

As dielectric liquid, the deionized water was used; its conductivity and pressure were maintained constant during all the experiments.

As independent variables, one took into consideration: workpiece thickness *h*, pulse on time t_p, pulse off time t_b, wire axial tensile force F_t, average peak current average amplitude i_p (established by the position of control button), travelling wire electrode speed v_t. The starting voltage was U=215 V; one selected a relatively high starting voltage, appreciating that in such a case, the more intense wear process will facilitate a better differentiating of the influence exerted by distinct input factors on the wear able to affect the wire tool electrode.

In the columns no. 8, 9 and 10 from table 1, values corresponding to three weightings were

Table 1. Experimental conditions and results in case of studying the wire tool electrode in electrical discharge machining (initiating voltage U=190 V)

Exp. no.	Input factors, codified value/real value						Tool electrode wear, w_{TE}, mg/m			
	Test piece thick-ness, *h*, mm	Pulse on time, t_p, µs	Pulse off time, t_b, µs	Wire axial tensile force, F_t, N	Peak current intensity average amplitude, i_a, (button position)	Travel-ling wire electrode speed, v_t, mm/min	w_{TE1}	w_{TE2}	w_{TE3}	Ave-rage wire tool elec-trode wear, w_{TE}, mg/m
Co-lumn no.1	2	3	4	5	6	7	8	9	10	11
1	1/60	1/2	1/7	1/2.452	1/2	1/2500	32	34	39	35
2	1/60	1/2	1/7	2/5.394	2/9	2/2500	80	78	85	81
3	1/60	1/2	2/30	1/2.452	1/2	2/2500	24	28	26	26
4	1/60	1/2	2/30	2/5.394	2/9	1/1750	63	68	61	64
5	1/60	2/12	1/7	1/2.452	2/9	2/2500	29	35	29	31
6	1/60	2/12	1/7	2/5.394	1/2	1/1750	62	57	61	60
7	1/60	2/12	2/30	1/2.452	2/9	1/1750	38	34	36	36
8	1/60	2/12	2/30	2/5.394	1/2	2/2500	19	14	18	17
9	2/80	1/2	1/7	1/2.452	1/2	2/2500	17	14	17	16
10	2/80	1/2	1/7	2/5.394	2/9	1/1750	90	84	93	89
11	2/80	1/2	2/30	1/2.452	1/2	1/1750	40	36	41	39
12	2/80	1/2	2/30	2/5.394	2/9	2/2500	45	53	49	49
13	2/80	2/12	1/7	1/2.452	2/9	1/1750	46	49	52	49
14	2/80	2/12	1/7	2/5.394	1/2	2/2500	23	22	21	22
15	2/80	2/12	2/30	1/2.452	2/9	2/2500	27	23	19	23
16	2/80	2/12	2/30	2/5.394	1/2	1/1750	43	40	37	40

included; the column no. 11 contains the average value of wire tool electrode wear w_{TE}, which is considered as offering a general image about the wire tool electrode wear (for each experiment).

The values corresponding to the two experimental levels were established by taking into consideration the values offered by the machining equipment; these values were also presented in table 1.

The experimental results were processed by means of specialized software (Crețu, 1992) and the following empirical mathematical model was considered as the most adequate to the experimental results:

$$w_{TE} = 4.886 + \frac{690.198}{h} + \frac{36.302}{t_p} + \frac{101.579}{t_b} \quad \frac{93.849}{F_t} \quad \frac{53.680}{i_p} + \frac{107187.4}{v_t}, \qquad (3)$$

for this relation the Gauss's criterion having the value $S_G = 81.04915$.

Since in machine building frequently the power type empirical models are preferred, by means of the same software (Crețu, 1992), an empirical mathematical model of such a type was determined:

$$w_{TE} = 7958666 h^{\ 0.298} t_p^{\ 0.169} t_b^{\ 0.129} F_t^{0.530} i_p^{\ 0.334} v_T^{\ 1.511}, \qquad (4)$$

the Gauss's criterion having the value S_G=127.9905.

On the base of the empirical mathematical model (3), the graphical representations from figures 3 and 4 were elaborated; these diagrams highlights the influence exerted by the most important input factors on the wire tool electrode wear w_{TE}.

The analysis of the power type empirical model corresponding to the relationship (4) shows that the most important influence factor able to affect the wire tool electrode wear is the travelling speed v_t, since in the above mentioned relation the exponent attached to v_t has the maximum absolute value. If one takes into consideration the order of the influences exerted by the studied factors on the wire tool electrode wear, on can notice that on the base of the absolute values of exponents attached to distinct sizes, the following order is valid: v_t, F_t, i_p, h, tp, t_b (the absolute values of the exponents being 1.511>0.530>0.334>0.298>0.169>0.129). As expected, the wire tool electrode wear increases when the current intensity increases also; one noticed that a higher travelling speed v_t contributes to a diminishing of the wire tool electrode wear, due to the shorter presence of a certain zone of wire tool electrode in the work zone.

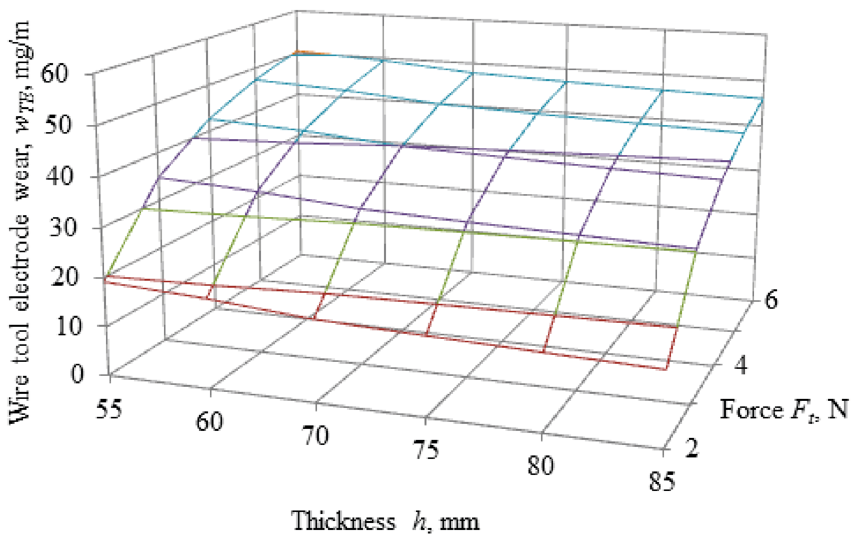

Figure 3: Influence exerted by test piece thickness *h* and tensile force F_t on wire tool electrode wear w_{TE}

4 CONCLUSIONS

The wire tool electrode wear is an important parameter of technological interest in wire electrical discharge machining process, due to its influence on the machining accuracy. In order to highlight the influence exerted by some distinct factors on the wire tool electrode wear, a factorial experiment was designed and applied. As input factors, test piece thickness, pulse on time, pulse off time, tensile

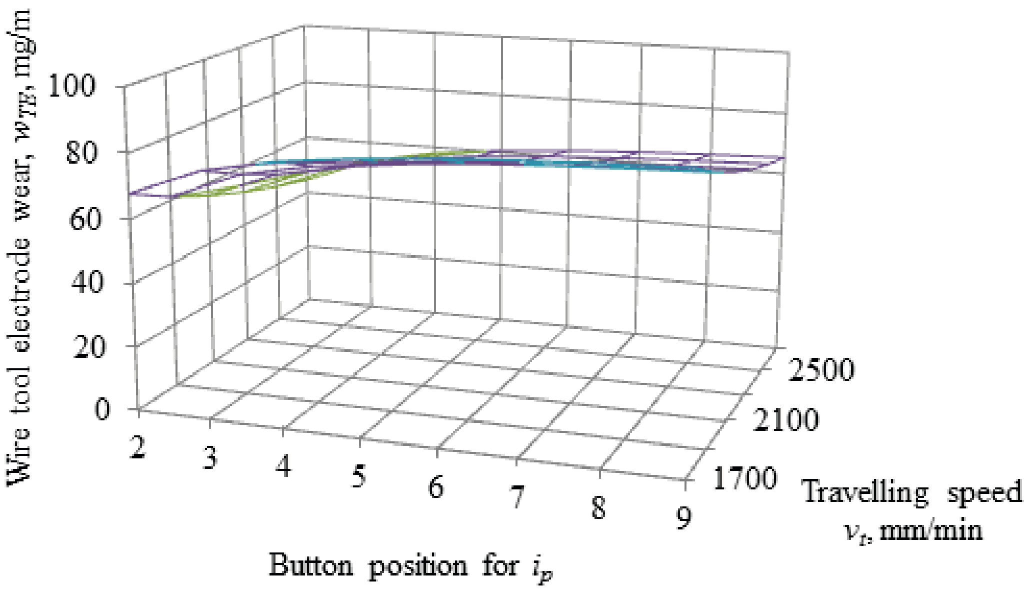

Figure 4: Influence exerted by current intensity i_p and travelling speed v_t on wire tool electrode wear w_{TE}

force, current intensity and travelling speed were considered.

The wire tool electrode wear was evaluated as a ratio between the tool electrode mass decrease and the length of the same electrode. Empirical mathematical models were determined and graphical representations were elaborated, in order to show how the main input factors exert influence on the wire tool electrode wear.

In the future, there is the intention to extend the experimental research by taking into consideration the voltage applied to the two electrodes involved in process.

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