ELECTRODE TOOL WEAR AT ELECTRICAL DISCHARGE MACHINING OF SMALL DIAMETER EXTERNAL CYLINDRICAL SURFACES

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ABSTRACT: In a world where minimizing tendency is everywhere, the necessity of obtaining surfaces of small dimensions, but with similar properties and reliability as those with regular dimensions is evident. Electrical discharge machining of small diameter external cylindrical surfaces meets the minimizing tendency in industry and offers a series of outstanding advantages comparing to classical machining methods. Applying a machining pattern that uses a plate electrode having 8 sets of holes with 4 distinct diameters each, experimental tests had been done, in order to analyze and model the evolution of tool electrode wear. The wear of the tool electrode is the result of the machining process and it can be both controlled and estimated using input parameters. In this paper, a series of parameters with impact on tool electrode wear is analyzed and empirical mathematic models were determined in order to highlight certain process input factors influence on tool electrode wear degree.
KEY WORDS: electrical discharge machining, tool electrode wear, experimental research, empirical mathematical model, influence factors

1. INTRODUCTION

During the last century, materials machining technology has suffered distinct changes due the necessity to keep up with recently discovered materials. The high hardness is a very good example of impossibility of using classical machining technologies such as turning, drilling and threading or in the best case the results of using them are unsatisfactory.

Because of this type of necessities, the nonconventional machining technologies have appeared [6]. These technologies can be easily defined as those technologies developed and continuously improved in the last 50 years using machining methods aiming productivity improvement, process simplifying and increased quality of obtained surfaces.

Among other technologies such as laser beam machining, plasma beam machining or ultrasonic machining, the electrical discharge machining is part of the nonconventional technologies that convert electrical energy into other types of energy (mechanical, thermal energy, chemical energy etc.) [1, 3, 4, 7].

Electrical discharge machining uses erosive effects of electrical discharges in impulse applied in order to machine electrical conductive materials. The electrical discharges are periodically generated between the tool electrode and the workpiece, having the goal to melt, to vaporize, to solidify and to remove the material in excess from the workpiece.

The tool electrode and the workpiece are isolated from each other using a dielectric liquid which has the following functions: isolating, cooling and removing of the eroded material.

Electrical discharge machining applications are very various, being used mainly where the classical procedures are impossible to be used or the results of using them are not satisfactory: low tolerances, complex geometries, high hardness etc.

From diesel injectors' holes micro machining to several tone molds manufacturing, the advantages of this machining technology are very popular in industry, determining a high level interest in process continuous improvement and in increasing its productivity.

Classical machining procedures are not eliminated by nonconventional technologies appearance, and, in many situations, they are used together, in the so called hybrid machining methods.

There are two types of electrical discharge machining equipment:

- Equipment of machining with massive tool electrode, having the following features:
  - reproducing a negative shape of tool electrode active zone geometry into workpiece;
  - lack of physical contact between electrode and workpiece;
  - eroding both tool electrode and workpiece at each electrical discharge, with a variable ratio depending on

several factors: electrical discharge current intensity, tool electrode and workpiece materials and the distance between the previous mentioned elements.

- Wire electrical discharge machining equipment, having the following features:
  - using a wire tool electrode to cut a preset contour from a workpiece made of electroconductive material;
  - excellent cutting accuracy, often needed in case of molds and piercers cutting;
  - electrical discharges eroding both the part and the wire;

Workpiece material properties and dimensions
Tool electrode material properties and dimensions
Position of the tool electrode and workpiece
Electrical parameters (current intensity of electrical discharges, voltage)
Pulse on time (duration of one electrical discharge)
Pulse off time (brake duration between two successive electrical discharges)
Dielectric fluid characteristics
Washing type
Exterior temperature

Figure 1. Factors able to affect the results of electrical discharge machining process

  - ensuring a wire tool electrode inclination to obtain more complex cuttings and profiles.

There are certain output parameters that are of a high interest in the research depicted in this paper: material removing rate, machined surface roughness, exterior cylindrical surface cylindricity, tool electrode wear ratio, the thickness of the layer affected by the electrical discharges on tool electrode and workpiece etc. All these parameters have been mentioned in figure 2 and they are directly dependent on factors mentioned in figure 1.

Obtaining external cylindrical small diameter external surfaces theme has been addressed mainly due to general tendency of minimizing things (parts, equipment etc). The reasons of minimizing things are basically economical, low dimensions generating raw material lower costs and the similar results for consumed energy, small warehousing areas and last, but not the least, cheap and easy transportation.

Small diameter external cylindrical surfaces could have various uses: producing piercers for plastically deformation based machining processes, obtaining multiple holes, multiple dosage units or even in medical and watches industry.

In order to obtain small diameter external cylindrical surfaces, classical and nonconventional machining methods could be used. Turning is the most usual such a method. It could be used easily when material hardness is not at a high level. If the machining productivity is low, nonconventional methods application is recommended using massive tool electrodes or wire electrode electrical discharge machining.

Either conventional ways or nonconventional/hybrid ways could be chosen; they come with both advantages and disadvantages. Electrical discharge machining proves to be a perfect solution in sensitive situations, when classical solutions do not work efficiently, because of machined material properties, but there is no need to have a very high productivity.

Material remove rate
Surface roughness
Outer cylindrical surfaces cylindricity
Electrode wear rate
Electrode's affected thickness

Figure 2. The most important output parameters of the electrical discharge machining process

The main problem consists in having an electro conductive workpiece material. Due to the fact that during the electrical discharge machining process, the tool electrode is consumed as well, it is to be avoided choosing this procedure for enlarged serial production, in which the parts must fit in low tolerances.

Because very few scientists treated electrical discharge machining of small diameter external cylindrical surfaces, we have chosen this research theme. Even though in studyaspects regarding this type of machining have been addressed in researches [5] in which the authors have used a number of copper tubular electrodes to apply several machining patterns. What is interesting is that the scientists have eliminated certain inactive zones from tool electrodes, for a better circulation of dielectric liquid inside the working zone.

Our intention was to analyze the factors that could influence the tool electrode wear during the electrical discharge machining and the ways in which these could be manipulated in order to reduce the tool electrode wear. Another treated aspect is the one of obtaining small diameter external cylindrical surfaces, existing a huge potential of improving the process and various application possibilities.

2. TOOL ELECTRODE WEAR PROCESS DURING ELECTRICAL DISCHARGE MACHINING OF SMALL DIAMETER EXTERNAL CYLINDRICAL SURFACE

In this paper, we used the so-called small diameter external cylindrical surfaces. To give an even clearer image on size range, cylindrical surfaces having diameter less than 10 mm have been defined as small diameter cylindrical surfaces. Several machining patterns to be applied in order to obtain this type of surfaces have been identified. Some of them are easily to apply; others could have been physically obtained only by modifying the EDM equipment.

In [5] the authors presented a series of possible solutions for obtaining external cylindrical surfaces. All these analyzed solutions can be evaluated and adopted by taking into consideration the dimensions and the position of small diameter surfaces and the technological possibilities of the electrical discharge machining equipment.

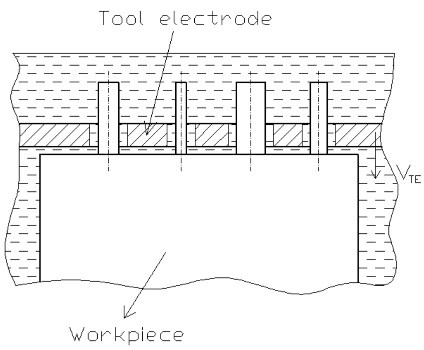


Figure 3. Machining scheme applied in order to obtain small diameter cylindrical surfaces by means of a plate tool electrode

In this paperwork solution showed in figure 5 have been taken into consideration for experimental tests using a copper plate type tool electrode for machining 2 metallic bars manufactured from Rp3 and 1.0503 steel, the last one being considered „reference material". During machining, the tool electrode has been fixed on the tool holding subsystem and the workpiece has been fixed on the machine tool table. The tool electrode motion was placed along the OZ axe.

The wear is defined as the process in which a part modifies progressively its dimensions during service into the system that it is part of.

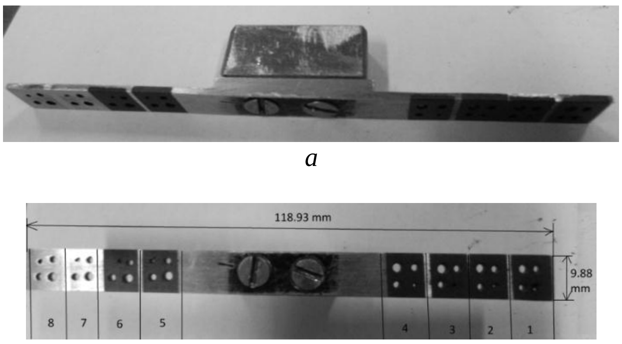
In electrical discharge machining process, the electrical discharges are essentially generated between the closest points of tool electrode active part and workpiece, when the electric field intensity between the above points is higher than that corresponding to the breaking down dielectric local resistance. As consequences of these electric discharges, both the workpiece and tool electrode lose material by melting and vaporizing. The tool electrode lost material is considered as the tool electrode wear. It is important that the tool electrode material has a high resistance to the electrical discharges, in order to maintain long time the dimensions corresponding to its active zone. For this reason, the tool electrode active zone is made of copper or graphite, both being materials able to ensure a high wear resistance in the electrical discharge machining process.

In figure 3, one can see a machining scheme in which a copper plate is used in order to obtain small diameter cylindrical surfaces. In this plate, holes having distinct diameters were achieved, so that as a consequence of a work movement from up to down, achieved by the tool electrode, cylindrical zones are gradually generated on the workpiece placed on the work table of the electrical discharge machining equipment.

It is expected that as a result of the electrical discharges, the active surface of the tool electrode is affected by a wear phenomenon; thus, a certain conical surface could be generated instead of the cylindrical one, but a certain image about the tool electrode wear could be obtained by measuring the tool electrode mass before and after the electrical discharge machining process.

3. EXPERIMENTAL CONDITIONS

In order to experimentally study the tool electrode wear in electrical discharge machining by means of a plate tool electrode, a Sodick AD3L electrical discharge machine was used. The equipment has work movements along 3 axes numerically controlled. Certain parameters of machine software



a

b

Figure 4. Tool electrode used in the experimental research (*a*) and the aspect of the tool electrode active surface after the electrical discharge machining process (*b*)

Table 1. Experimental conditions and results

Exp. no.	**Pulse on time, tp, µs**	**Pulse off time, tb, µs**	**Peak current intensity, Ip, A**	**Tool electrode mass before experiment, g**	**Tool electrode mass after experiment, g**	**Mass difference, Δm_{TE}, g**	**Process duration**	**Wear rate, *W*, g/min**
Col. no. 1	2	3	4	5	6	7	8	9
1	230	40	8.6	61.3581	61.3600	-0.0019	6	-0.0003
2	230	40	6.4	61.3600	61.3591	0.0009	6	0.0002
3	230	50	8.6	61.3591	61.3587	0.0003	6	0.0001
4	230	50	6.4	61.3587	61.3583	0.0004	6	0.0001
5	180	40	9.6	61.3583	61.3574	0.0009	6	0.0002
6	180	40	6.4	61.3574	61.3556	0.0018	6	0.0003
7	180	50	8.6	61.3556	61.3510	0.0046	6	0.0008
8	180	50	6.4	61.3510	61.3639	-0.0129	6	-0.0022

have been modified; therefore there was no need to make any physical adjustments. The tool electrode had a shape as one can see in figure 4. Practically, a copper plate was assembled by means of two screws to a parallelipipedic part which facilitates the tool electrode clamping in an Erowa ER-010793 type device. At its turn, the Erowa device is attached to the work head of the electrical discharge machining equipment. The tool has 8 active zones, in each of them four holes having distinct diameters (0.84 mm, 1.4 mm, 1.56 mm and 2 mm) were previously achieved.

As a test piece material, a medium carbon steel (containing 0.45 % C) was preferred.

As independent variables, one took into consideration the pulse in time t_p, pulse off time t_b and the average peak current intensity I_p; the values corresponding to these sizes were included in table 1. As initial values, those recommended by the software of the electrical discharge machine was considered. One thought a factorial experiment at two levels; as second level for the independent variables, one selected values having a difference of about 25 % in comparison with the values recommended by the machining equipment software.

The values of the considered input factors were included in the columns no. 2, 3 and 4 from the table 1.

4. EXPERIMENTAL RESULTS AND THEIR USE

Both, the test piece and the tool electrode were weighted before and after each experiment, in order to obtain information about the evolution of the tool electrode wear. After each experiment, the tool electrode was carefully washed and dried, in order to remove the dielectric liquid or other particles possible to be adhered to it. An analytical balance type Radwag Partner AS 60/220/C/2 was used for weighting; there were made three mass measurements and in the mathematical processing of the experimental results the average value of the mass were considered. The tool electrode mass before experiment was inscribed in the column no. 5 from table 1 and the tool electrode mass after experiment was included in column no. 6; in this way, in the column no. 7 the differences between the tool electrode mass before and after each experiment was mentioned. Taking into consideration the established duration of 6 minutes for each experiment, there was the possibility to evaluate the tool electrode wear ratio, which was included in column no. 9.

The experimental results were processed by means of specialized software based on the method of least squares. As result, empirical mathematical models were determined.

As one can see, in the cases of two experiments, the mass after application of the electrical discharge machining process was higher than the initial mass and this could be considered as a result of a deposition process, by which solid particles found in dielectric liquid adhered to the tool electrode, determining an increase of its mass. Appreciating that in such a case the tool electrode was not evident, in the mathematical processing these results were not taken into consideration.

The specialized software [2] is able to select the most adequate function for a set of experimental results, by taking into consideration the so-called Gauss's criterion; in our case, such a function is a linear polynomial:

$$W = 0.000968 - 0.0000079 9 t_p + 0.0000249 t_b + \\ - 0.0000227 I_p \quad (1)$$

for which the Gauss's criterion has the value S_G=3.583333·10^{-8}.

If one is interested in determining a power type function, by means of the same specialized software the following empirical mathematical model could be determined:

$$W = 115848\, t_p^{-5.067} t_b^{1.551} I_p^{-0.685}, \quad (2)$$

the Gauss's criterion having, in this case, the value S_G=4.145787·10^{-8}.

The above written functions show that the most significant influence is exerted on the tool electrode ratio by the pulse on time t_b, since in the equation (1) it has the highest value among the coefficients attached to the independent variables, while in the relation (2), the highest value of the exponents corresponds also to the variable t_p. A certain contradiction could be noticed in the case of influence exerted by the average peak current intensity, whose increase determines a decrease of

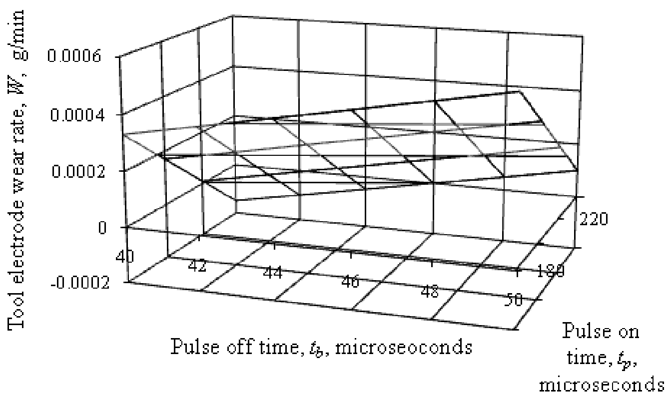


Figure 5. Machining scheme applied in order to obtain small diameter cylindrical surfaces by means of a plate tool electrode

the tool electrode wear ratio (the exponent attached to the variable I_p being negative); it is possible that this situation could be generated by the adherence of distinct particles found in the dielectric liquid to the tool electrode and this adherence could affect the evaluation of the tool electrode wear.

In order to graphically illustrate the influence exerted by the process input factors t_p and t_b, the diagram from figure 5 was elaborated.

5. CONCLUSIONS

There is sometimes the necessity to obtain small diameter cylindrical holes by electrical discharge machining and, if the workpiece material has a low machinability by classical machining methods, the electrical discharge machining could be applied. In the specialty literature, distinct electrical machining methods applicable in order to obtain small cylindrical surfaces are showed. Within the research presented in this paper, an electrical discharge machining method based on the use of a plate type tool electrode was applied. This tool electrode has a set of cylindrical holes which facilitate the generation of small diameter external surfaces on the workpiece. The experimental results were processed by means of specialized software and empirical mathematical models were determined. These empirical models highlights the influence exerted by the pulse on time, pulse off time and peak current intensity on the tool electrode wear ratio. In the future, other experimental researches will be developed, by taking into consideration the influence exerted by the workpiece material and other machining conditions on the tool electrode wear ratio.

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