

MATERIAL REMOVAL RATE AT ELECTRICAL DISCHARGE MACHINING OF SMALL DIAMETER EXTERNAL CYLINDRICAL SURFACES

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ABSTRACT: The industrial practice needs sometimes small diameter external cylindrical surfaces obtained in workpieces made of difficult to cut materials. Such surfaces could be obtained by electrical discharge machining. An analysis of some machining schemes able to ensure obtaining external cylindrical surfaces was developed. An experimental investigation was designed and materialized on the base of a machining scheme which uses a plate electrode having small holes previously performed by drilling and a ram electrical discharge machine. The tool electrode achieved an up-down work motion. The experiments were developed in accordance with the principles valid in the case of a complete factorial experiment, on the test piece made of high speed steel. The experimental results highlighted the influence exerted by some experimental factors on material removal rate. The power type empirical mathematical function shows the influence exerted by pulse time, pulse off time and peak current intensity on the material removal rate.

KEY WORDS: electrical discharge machining, external cylindrical surfaces, plate tool electrode, material removal rate, high speed steel

1. INTRODUCTION

The non-conventional technologies are considered by most people as machining methods performed in laboratory conditions, to which a small number of people have access and with no application in current manufacturing processes. In reality, the non-conventional technologies have very wide application areas and we can simply define them as those machining methods developed and step by step improved during the last 50 years, aiming to productivity improvement and increase of machined surfaces quality.

The nonconventional machining methods are based on conversion of electrical energy into another type of energy: mechanical, thermal, light.

It is preferable to use these technologies in those situations where the conventional machining methods do not succeed or cannot be applied, like: parts with tight tolerances (active parts for molds, injectors), workpieces materials characterized by high hardness, workpieces with special geometries, micro holes, deburring of workpieces made of materials with special properties. In such situations, it is absolutely necessary to apply nonconventional machining methods, in order to satisfy all quality requirements mentioned in documentation or in execution drawings. Usually, such technologies are

completely automatic, so that the quality of product is ensured from designing stage, without any or with a minimum human factor to be involved. Sometimes, these modern technologies request complex equipment, outstanding working environments (high pressure, vacuum or ionization special environments) [5]. All these special requirements could involve expensive equipment, fact which is found in the final cost of processing.

Nonconventional machining processes can be analyzed according to the type of used energy in four major categories: mechanical, electro-chemical, chemical, thermo-electrical. In various research projects or papers, one often found some other classification methods. In the study elaborated by Sabou [5], the author divides unconventional machining processes in:

- machining with micro splinters (EDM, electrochemical, abrasion processing, compound processing);
- machining using accelerated electron beam;
- plasma beam machining;
- cutting (using laser/ accelerated electron beam/plasma);
- welding (using laser/ accelerated electron beam) etc.

The electrical discharge machining (EDM) is a thermo-electrical process, developed for machining electroconductive materials; it uses erosive effects of electrical discharges in pulse, periodically primed between workpiece surface and an electrode active surface, with the final goal to remove the excess material from workpiece. The tool electrode and workpiece are connected to terminals of a power source and they are submerged in dielectric liquid (usually mineral oils, kerosene, paraffin and distilled water). Dielectric liquid is an electrical insulator that prevents the rapid appearance of electrical discharges. Many people consider the words "insulated" and "dielectric" synonymous. Interesting information about it is found in [3], where it is presented as a word invented by William Whewell, in reply to Michael Faraday's inquiry. The two were well-known British researchers during the 18th century, the word proposed by Faraday being "bound" of electricity and magnetism. William Whewell invented a term combining two words: "dia", which in Greek means "through", and "electric", but felt that it is much easier to pronounce "dielectric". For a correct and complete analysis of roles that must be fulfilled by the dielectric liquid, three distinct information sources have been compared: [1, 4, 6]. After analyzing the mentioned studies, the following roles had been identified:

- role of insulator;
- cooling role;
- role of cooling the eroded material and turning it into small solid spheres;
- role of removing eroded material from machining area;
- ionization role. One found this role only in one of the studies [1]. After the end of electrical discharge, the path of the spark must be immediately deionised or extinguished, so that next discharge is able to take place. The dielectric is charged to contract the path of the spark, in order to get a high energy density, which increases the discharge efficiency. In our opinion, this ionization role is very important and it was omitted by other authors or maybe it was considered as a part of insulating role.

Initially, electrical discharge machining was facilitating copying the shape of tool working surface into the workpiece. Nowadays, electrical discharge machining is ranked as fourth most popular machining method, after milling, turning and grinding [5].

One could consider that the EDM appeared as a response to the need of machining metallic parts

with better mechanical and thermal characteristics. Being used rather rarely in the past, EDM process is nowadays applied with great results in very wide application areas, from extracting broken screws to machining very complex molds, achieving diesel fuel injector spray holes or turbine blades for the aerospace industry. The main advantage of EDM is that the workpiece material hardness is not

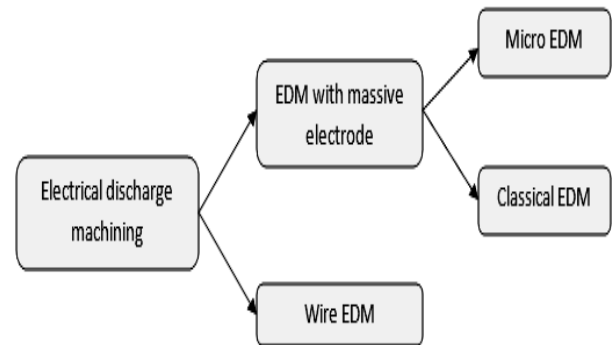


Figure 1. Electrical discharge machining processes

important, the requested condition being that the processed material is electroconductive [7].

As nothing is perfect, the electrical discharge machining has its *disadvantages*, some of them being noticed by us during experimental tests. One of them is the lower productivity in some machining schemes, usually when finishing conditions must be ensured. Even this kind of machining process is studied for years, there are still a lot of things to be improved and maybe in the future the process will be more accurate and the productivity will increase. Another disadvantage is that the tool electrode shape is affected by electrical discharges during machining; in this way, machining conditions depends on the tolerances that the beneficiary wants to obtain. Practically, the tool cannot be used for another machining.

The low productivity involves also a high cost of machining, which is an interest aspect in mass production, where the time and the financial elements are very important aspects.

Electrical discharge machining processes can be classified as one can see in figure 1.

Nowadays, the "micro" word has become very popular, thanks to the size reduction trend in wide areas of products, from electronics to military and medical equipment; thus, micro-EDM has accumulated a significant percentage of research attention.

Small diameter external cylindrical surfaces can be used in various domains and applications, like micropunches used in the machining processes based on plastic deformation, multiple micro holes drilling, multiple unit dosage and slideways for small parts etc.

There are both, classical and non-conventional machining methods that can be used in order to

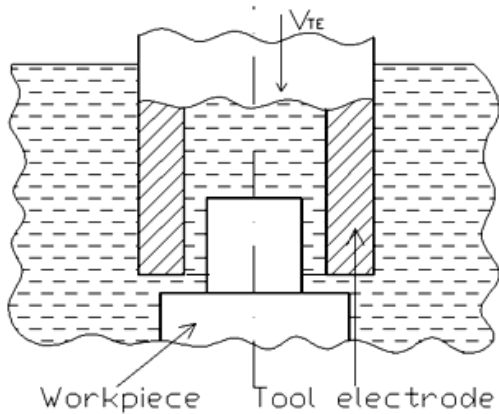


Figure 2. Obtaining external cylindrical surfaces by means of a tubular tool electrode

obtain small diameter external cylindrical surfaces. Turning could be one of the ways of obtaining small diameter external cylindrical surfaces, especially when the material hardness is not too high.

If the machinability of workpiece material is low, some nonconventional machining methods could be applied and the so-called *ram electrical discharge machining* and *wire electrical discharge machining* could be included in this group. Of course, all these machining methods have their specific advantages or disadvantages and they have also their limits.

Essentially, there are two situations when small diameter external cylindrical surfaces can be obtained by electrical discharge machining: when the material of the workpiece has high hardness or the surface to be machined is complex and characterized eventually by high requests of surface roughness and accuracy.

Another advantage specific to electrical discharge machining would be that it is not necessary to have a lot of working space around machining area where the tool electrode must act. This aspect was highlighted in a study presented in [8], where the authors describe a set of experiments developed by using a tubular tool electrode whose external cylindrical surface was affected by detaching a part of the inactive zone. Usually, at micro-machining, the space problem is important and a good solution for solve it would be ram electrical discharge machining.

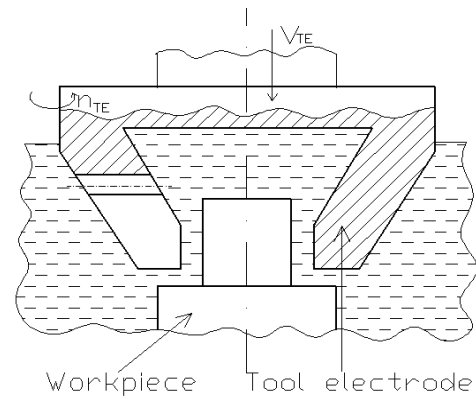


Figure 3. Obtaining small diameter cylindrical surfaces by using an up-down rectilinear work motion achieved by the workpiece

The topic of obtaining external cylindrical surfaces was studied and presented in some papers, but not too much information can be found. As above mentioned, in [8] the problem of machining of small diameter cylindrical surfaces was treated and some machining schemes have been identified.

Various solutions able to facilitate the obtaining of a cylindrical external surface on a ram electrical discharge machine have been analyzed.

Wang et al. described in [9] the process used by them in order to obtain multiple cylindrical microelectrodes. They had used an EDM machine tool and applied electrochemical etching for processing tool electrode and after that they used the

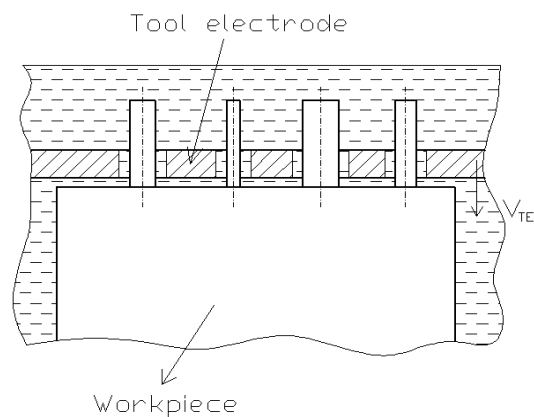


Figure 4. Obtaining cylindrical tool electrode by means of a rotating tool electrode with an internal conical surface

resulted micro tool to perform small holes by EDM. In this way, the researchers succeeded to increase the material removal rate of electrical discharge drilling of micro-holes.

2. PREMISES FOR OBTAINING SMALL DIAMETER EXTERNAL CYLINDRICAL SURFACES

Five possible solutions that can be used in order to obtain small diameter external cylindrical surfaces

using electrical discharge machining are presented in figures 2, 3, 4, 5 and 6.

Essentially, on the current machining equipment, the ram electrical discharge machining is based on the relative motions achieved by the tool electrode and/or by the workpiece within a Cartesian coordinate system [8]. External cylindrical surfaces like that presented in figure 2 can be obtained using a hollow cylindrical working electrode. The tool electrode might have various dimensions, with thick

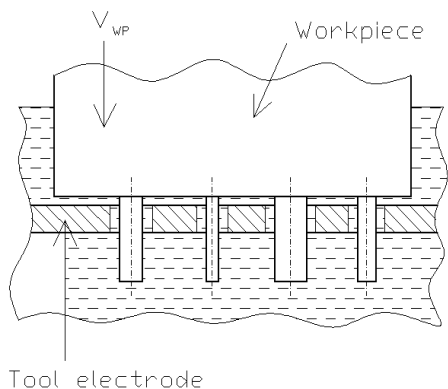


Figure 5. Obtaining small diameter external cylindrical surfaces by means of a plate tool electrode having small diameter holes

or thin walls, cropped or not in some active areas, in order to facilitate the entrance of the dielectric liquid. The tool electrode moves vertically, along the O_z axis.

In figure 3, a possible solution based on the above presented one and that can be used when it is necessary to avoid obtaining a conical profile instead of cylindrical one is shown. Such a problem (connicity) could appear when the tool electrode has cylindrical shape and in the upper side of the workpiece more electrical discharges develop, due to the presence of the metallic particles detached from

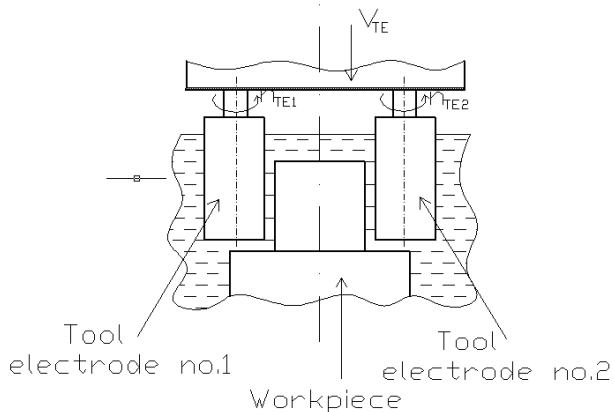


Figure 7. Obtaining small diameter cylindrical surfaces by means of a plate tool electrode having an up-down workpiece rectilinear motion

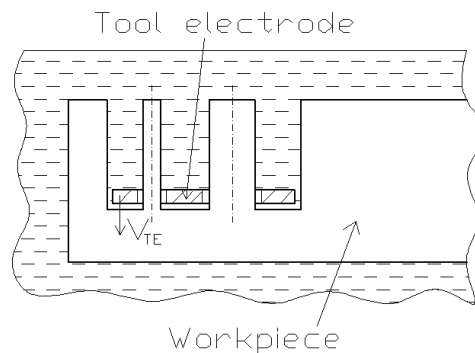


Figure 6. Obtaining external cylindrical surface by using two tool electrodes found in revolution motions

electrodes and found in the evacuation motion from the work zone. The tool electrode could have a rotation movement with a rotation speed n_{TE} around its axis, in order to obtain an improved circularity of the external cylindrical surface.

A machining scheme like that presented in figure 4 can be used to create many exterior cylindrical surfaces in a single machining process. A plate tool electrode having a number of holes is used in order to obtain small diameter external cylindrical surfaces. The diameters of external cylindrical surfaces thus generated will have values in accordance with to the diameters of holes existing in tool electrode. The work gap has a very high influence in this process, because the diameter of machined surface represents the difference between the hole's initial diameter and the double size of the work gap. In this example, the direction of tool electrode motion with a rectilinear speed v_{TE} was considered as from up to down.

In figure 5, the same principle as in the previous one is applied, with an exception that could have a high impact: the workpiece is the one that has a vertical work motion (with a rectilinear speed v_{WP}), and not the tool electrode. In this way, the tool electrode could be clutched on a magnetic table and, as in the previous case, it must contain open-ended holes. Theoretically, in this situation, the resulted surfaces should have a higher quality, due to the fact that the melted metal can be easily taken off by dielectric liquid from the active area. The open-ended holes and the position of the workpiece allow to the particles detached from electrodes to go down without generating spurious electrical discharges between sticking walls of the holes and tool electrode surfaces. In figure 6, a possible machining scheme with two rotating electrodes is drawn to attention. This machining schema is developed on the base of that presented in figure 2.d from [8]. Using two electrodes having a rotation motion around their symmetry axis and a second rotation

motion around the symmetry axis of the surface to be obtained, a better productivity and/or a better surface quality could be obtained.

3. EXPERIMENTAL RESEARCH REGARDING OBTAINING SMALL DIAMETER CYLINDRICAL EXTERNAL SURFACES

Usually, there are differences between theoretical situations and the real ones; thus, a ram electrical discharge machining type Sodick AD3L able to have controlled rectilinear motions along 3 axes has been used to analyze in laboratory conditions the applicability of some technical theoretical considerations previously described.

The equipment was available for experiments by courtesy of “Gheorghe Asachi” Technical University, Iași and contains a numerical control subsystem and an automatic tool changing device.

8 machining experiments were made, in accordance with the requests of a complete factorial experiment and using the machining scheme presented in figure 7. The chosen machining scheme involved a tool electrode made from electrotechnical copper with 8

similar sets of four cylindrical holes each (whose diameters were of 1.56 mm, 2 mm, 0.84 mm and 1.4 mm), positioned as one can see in figure 8. The test piece was made of high speed steel (containing 0.659 % C, 4.04 % Cr, 1.28 % Mo, 1.19 % V, 17.7 % W). In order to determine the quantity of material detached from the test piece, after each experimental test, one used a Partner AS 60/220/C/2 analytical balance.

An EROWA ER-010793 device was used in order to clamp the tool electrode which has an active work zone shaped as a plate (fig. 8, a). Depending on the shapes of the tool electrode and workpiece, projected machining area and requested roughness, the numerical control subsystem recommends some operating parameters. In this case, we kept constant all recommended parameters excepting pulse time t_p , pause duration t_b and peak current intensity I_p . Only these last three parameters have been changed during the experimental tests and the erosion process has been stopped after duration of 25 minutes. The test piece was weighed before and after every experiment, in order to obtain information about the

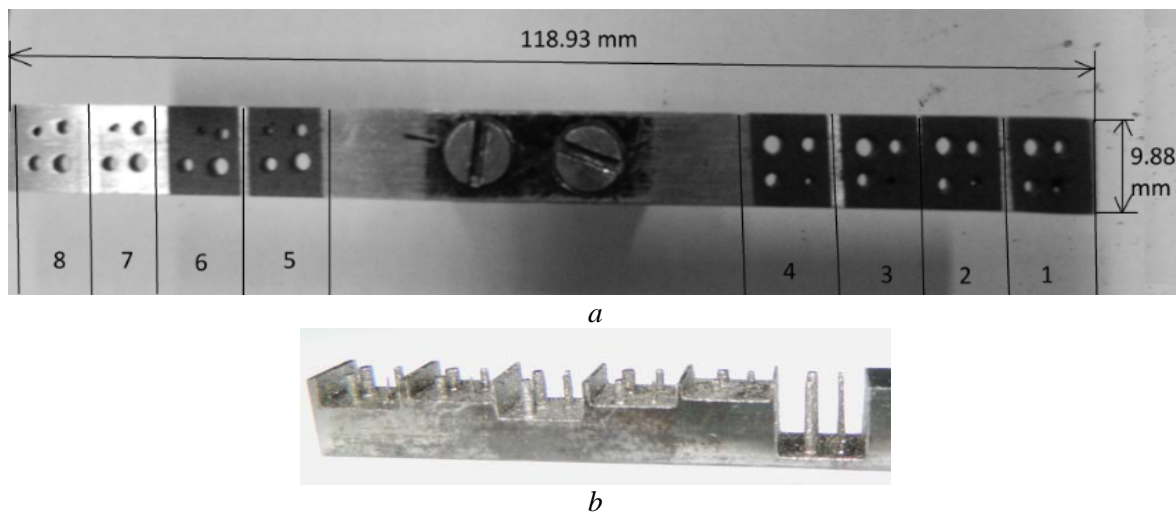


Figure 8. Copper tool electrode used within experimental tests (a) and image of the test piece (b)

Table 1. Experimental results

Experiment no.	Pulse time t_p , μs	Pulse off time t_b , μs	Peak current intensity, I_p , A	Test piece mass before experiment, g	Test piece mass after experiment, g	Mass differences, Δm_{TP}	Material removal rate Q , g/min
1	230	40	8.6	67.9078	65.3642	2.5436	0.1017
2	230	40	6.4	65.3642	63.6424	1.7218	0.0689
3	230	50	8.6	63.6424	60.4610	3.1814	0.1273
4	230	50	6.4	60.4610	58.6331	1.8279	0.0731
5	180	40	8.6	57.4271	51.6038	5.8233	0.2329
6	180	40	6.4	51.6038	49.0695	2.5343	0.1014
7	180	50	8.6	49.0695	44.5437	4.5258	0.1810
8	180	50	6.4	44.5437	42.3458	2.1979	0.0879

evolution of the material removal rate. The experimental results obtained in case of test pieces made of high speed steel are presented in table 1. The experimental results were processed by using specialized software based on the method of least squares [2]; thus, the following empirical mathematical model was determined:

$$Q = 34.430 t_p^{-1.785} t_b^{-0.124} I_p^{2.113} \quad (1)$$

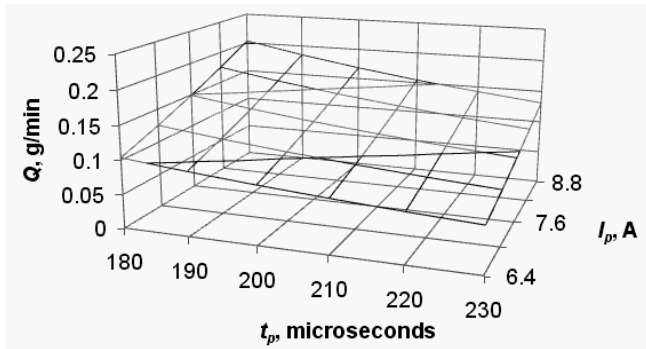


Figure 9. Influence exerted by the pulse time t_p and peak current intensity I_p on the material removal rate Q (pulse off time $t_b=40 \mu s$).

On the basis of the empirical relation (1), the graphical representation from figure 9 was elaborated.

As one can see, both the power type empirical relation and the graphical representation show that the material removal rate decreases when the pulse time t_p increases and diminishes at the increase of the peak current intensity I_p . The empirical model highlights that the most important factor able to exert influence on the material removal rate Q is the peak current intensity I_p , whose exponent has the maximum absolute value, in comparison with the values of the exponents attached to the other input factors (pulse time t_p and pulse off time t_b).

4. CONCLUSIONS

The electrical discharge machining uses erosive effects of electrical discharges in pulse, periodically developed between workpiece surface and tool electrode active surface, in order to remove the excess material from workpiece. There are various machining methods, both classical and non-conventional and which are able to facilitate the obtaining of external cylindrical surfaces. If the workpiece material hardness is high, one of the nonconventional machining methods applicable for obtaining small diameter external surfaces is the electrical discharge machining. An analysis of some distinct electrical discharge machining schemes aiming to obtain external cylindrical surfaces was developed. For experimental research, a machining

scheme based on the use of an up-down vertical linear motion achieved by the plate tool electrode was preferred. By measuring the weight of the test piece before and after each experiment, some information concerning the material removal rate was obtained. The experimental results were mathematical processed by means of software based on the method of least squares and a power type function empirical mathematical model was determined. In the future, there is the intention to develop new theoretical and experimental researches concerning the obtaining of small diameter holes, inclusively in case of some distinct test pieces materials.

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