

## OBTAINING EXTERNAL CYLINDRICAL SURFACES USING A TOOL ELECTRODE TYPE PLATE WITH HOLES

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**ABSTRACT:** External cylindrical surfaces could be obtained in workpieces made of electro conductive materials both by classical machining methods and nonconventional machining methods. One of such nonconventional machining methods is the electrical discharge machining method. If it is necessary to obtain small diameter external cylindrical surfaces, a method based on the use of a plate type tool electrode with holes of adequate diameters could be applied. Practically, as a consequence of the common linear work movement, the workpiece material is gradually removed and only the material corresponding to the hole is not affected by the process of material removal, constituting gradually a cylindrical column. The theoretical analysis of the process developed in such conditions showed that various factors could affect the depth of tool electrode penetration into the test piece material. Experimental researches aiming to highlight the influence exerted by some process input factors (pulse on time, pulse off time, peak current intensity, and process duration) on the height of columns generated by electrical discharge machining were designed and materialized. By mathematical processing of the experimental results, empirical mathematical models were determined. These models showed that the penetration depth increases when the peak current intensity and process duration increase and diminishes when the pulse on time and pulse off time increase.

**KEYWORDS:** electrical discharge machining, external cylindrical surfaces, plate type electrode, experimental research, empirical mathematical models.

### 1. INTRODUCTION

The electrical discharge machining could be defined as a machining method based on the developing of electrical discharges between the closest asperities existing on the tool electrode active surfaces and on the workpiece surface to be machined. As a consequence of the electrical discharges, small quantities of material from the tool electrode and workpieces are removed from the asperities peaks, so that gradually a new surface is generated [2, 7, 10].

External cylindrical surfaces could be obtained by electrical discharge machining in some distinct ways. Thus, a higher machining accuracy could be reached by using the so-called *wire electrical discharge machining*. In such a case, a travelling wire tool electrode is used to separate an external cylindrical surface from a plate workpiece, if strictly coordinated movements are achieved by the table supporting the workpiece or / and by the wire tool electrode.

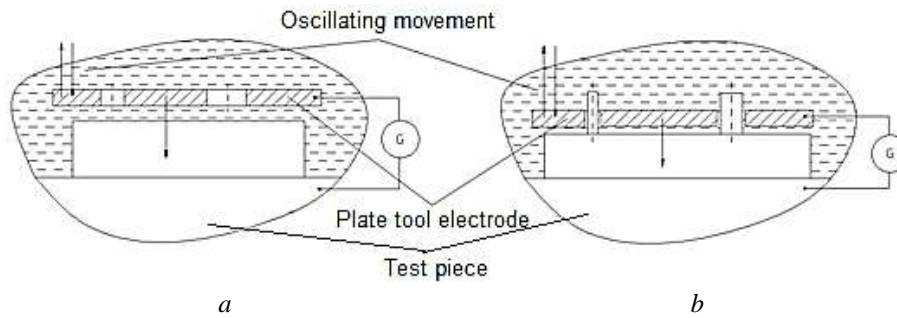
On the ram electrical discharge machine tools, cylindrical surfaces could be obtained by rotating the workpiece and, moving radially a tool electrode having a rectilinear active zone or even moving a

tool electrode along a linear generatrix of the cylindrical surface to be obtained.

Small diameter external cylindrical surfaces could be also obtained by moving a tool electrode whose active zone materializes a circle along a rectilinear line. The above-mentioned circle could be obtained using a plate tool electrode, in which holes with diameter established in accordance with the diameter of the surface to be obtained are used. The workpiece material is thus removed by the common rectilinear work movement of the tool electrode. Only the workpiece material corresponding to the hole from the plate tool electrode is not affected by the material removal as a consequence of the machining process and gradually a cylindrical column is thus generated.

Over the years, the researchers investigated some of the characteristics of the various electrical discharge machining techniques able to contribute to the obtaining of external cylindrical surfaces.

Thus, Deneș and Grecu used a wire electrical discharge machine to generate a cylindrical surface or generally speaking revolutions surfaces using the rotation of the workpiece, while the wire tool electrode has a tangential direction to the circle



**Figure 2.** Scheme of obtaining external cylindrical surfaces by electrical discharge machining and using a plate tool electrode with holes: *a* – situation before machining; *b* – situation when column type surfaces were generated by electrical discharge machining process

corresponding to the cross section through the revolution part to be obtained [2]. A device adapted on the wire electrical discharge machine must ensure also a relative movement of the wire tool electrode along a trajectory corresponding to the axial section to the revolution surface to be obtained.

Gil et al. addressed the problem of high-aspect ratio micro-pin manufacturing by means of an electrical discharge milling process [3]. They highlighted the possibilities of obtaining small diameter cylindrical surfaces by electrical discharge machining using a rotating workpiece and a wire tool electrode, a disc tool electrode (within a cylindrical electrical discharge grinding process) and a parallelepipedic tool electrode whose active rectilinear zone is placed in a plan perpendicular on the workpiece rotation axis.

Guu and Hocheng investigated a way of obtaining external cylindrical surfaces using a parallelepipedic tool electrode which has a cylindrical surface, while the tool electrode achieves a radial movement to the workpiece rotation axis [4]. They appreciated that this rotary electrical discharge machining process could ensure a higher material removal rate and improve the conditions for gap flushing, compared with the so-called classical electrical discharge machining method.

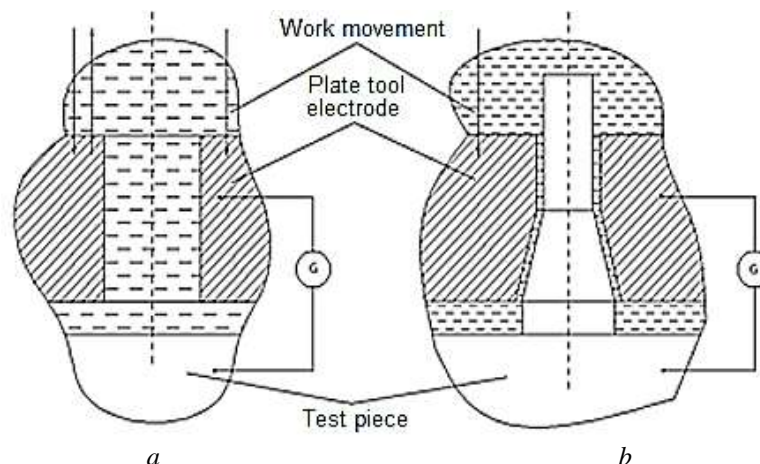
A process of cylindrical wire electrical turning was studied by Haddad et al. [5]. A device able to hold the rotating test pieces was adapted on wire electrical discharge machining using yet a computer numerical control subsystem. They used a mixed full factorial experiment, to highlight the influence exerted by some process input factors on the surface roughness and roundness of the surfaces resulted by using the wire electrical discharge turning process. The problem of using the Taguchi method in approaching the cylindrical wire electrical discharge turning process was taken also in consideration by Haddad et al. [6].

Some aspects concerning the material removal rate and the tool electrode were addressed in papers published by Stoica et al. [8, 9] and Slătineanu et al. [7].

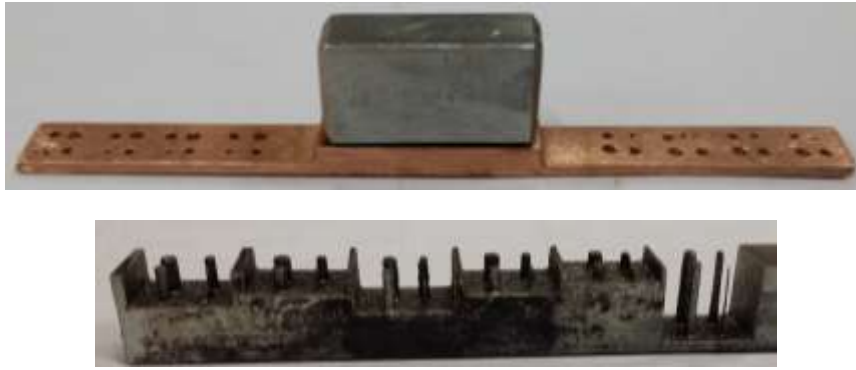
The objective of the research presented in this paper was to highlight some aspects concerning the height of the cylindrical columns generated when using a plate tool electrode having holes with diameters in correspondence with the diameters of the external cylindrical surfaces to be obtained.

## 2. THEORETICAL CONSIDERATIONS

The machining scheme taken into consideration is presented in figure 1.



**Figure 1.** Evolution of a wear process able to affect the shape of the tool electrode active zone: *a* – before starting the electrical discharge machining process; *b* – after a certain period of using the tool electrode



**Figure 3.** Image of the tool electrode and aspects of the type columns external cylindrical surfaces obtained as a result of the experimental research

A plate tool electrode having holes with distinct diameters (0.84 mm, 1.4 mm, 1.56 mm and 2 mm) was proposed to be used; this tool electrode achieves a vertical linear motion to the workpiece. Both tool electrode and test piece are connected in the electric circuit of the electric pulse generator *G*. As a material for the tool electrode the electro technical copper was used, while the test piece material could be a high speed steel. The material removal process as a consequence of the electrical discharges initiated between the test piece and tool electrode surfaces will gradually contribute to the generation of some cylindrical surfaces corresponding to columns attached to the workpiece (fig. 1, b).

A machining process in which both the tool electrode and test piece were immersed in the work dielectric fluid was considered. As known, in order to facilitate the work gap flushing, usually the tool electrode achieves a vertical oscillation movement; in this way, a certain circulation of the work dielectric fluid is ensured, by discharge and absorption phenomena.

Various techniques could be applied to evaluate the material removal rate in the case of such a machining scheme. If the test piece is weighted before and after the electrical discharge machining process and taking into consideration the test duration, the material removal rate could be calculated.

It is expected that the gradual penetration of the plate tool electrode in the test piece could ensure a higher machining speed at the beginning of the electrical discharge machining process, due to an easier circulation of the work dielectric fluid in the machining gap.

Distinct factors could exert influence on the process of obtaining external cylindrical surfaces by means of such an electrical discharge machining process.

These factors could be grouped in the following way:

*a) The chemical composition of the test piece material.* If this material includes elements characterized by high melting and vaporizing temperatures, a relative low machining speed could be expected. It is important to mention that not only the melting and vaporizing temperature are able to affect the machinability by ram electrical discharge machining, but also some other thermal properties of the test piece material could significantly affect the material removal rate;

*b) The characteristics (amplitude, frequency) of the oscillation movements achieved by the tool electrode.* It is expected that for certain values of these characteristics, a higher machining speed could be obtained, due to a possible accelerated removal from the work gap of the particles detached by the electrical discharges from the test piece and tool electrode;

*c) The tool electrode material.* As known, there are tool electrode materials able to have a high resistance to the electrical discharges.

It is expected that during the electrical discharge machining process, the shape of the active surface corresponding to the tool electrode could be affected by a wear process and, probably, an internal conical surface could appear (fig. 2), changing the work conditions in comparison with those corresponding to the initial state of tool electrode surfaces, when a wear process did not appear. If the initial plane active surface of the plate tool electrode is substituted by a region where a conical surface appeared, some changes could be signaled in the values of the vertical work movement speed.

### 3. EXPERIMENTAL CONDITIONS

To test the possibilities of obtaining small diameter external surfaces using a plate type tool electrode

which has holes of distinct diameters, an experimental research was proposed and developed.

A copper tool electrode including many active zones was used. Holes with distinct diameters (0.84 mm, 1.4 mm, 1.56 mm and 2 mm) were achieved in each tool electrode active zone. A parallelepipedic component of the tool electrode was used to place and clamp the tool electrode in the EROWA tool electrode holder.

The experiments were achieved on a ram electrical discharge machine type Sodick AD3L (Japan). Test pieces shaped as parallelepipedic bars were previously prepared. The test pieces were made of a high speed steel containing 0.75 % carbon, 4.10 % chrome, 17.5 % tungsten, 1.2 % vanadium, and 5 % cobalt taking into consideration that in a quenched state, such a material has a high hardness and can be difficultly machined by classical machining methods.

Subsequently, a set of experiments were planned to be materialized, to highlight the influence exerted by some process input factors on the results of technological interest [8, 9]. The experiments were initially planned in accordance with the rules specific to a full factorial experiment, with three independent variables at two levels. One considered that in the interval of independent variables variation, the output parameter will have a monotone variation, allowing the use of only two experimental levels for the independent variables. Within each experiment, the possibility of measuring the distance of tool electrode penetration into the test piece at certain time intervals appeared. The Sodick AD3L type electrical discharge machine has a control panel on which the distance of tool electrode descent is highlighted. The experimental results determined by reading the information existing on the machine tool control panel were included in the table 1.

#### 4. EXPERIMENTAL RESULTS AND THEIR ANALYSIS

The experimental results presented in table 1 were mathematically processed using a specialized software [1], based on the method of last squares. One could mention that this software offers five types of mathematical empirical models, namely polynomial of first and second degree, power type function, exponential function and hyperbolic function. The adequate mathematical empirical model could be selected on the base of the so-called Gauss's criterion; this criterion takes into consideration the sum of squares of differences between the ordinates corresponding to the experimental points and points determined by means of the proposed empirical model. The lower is the

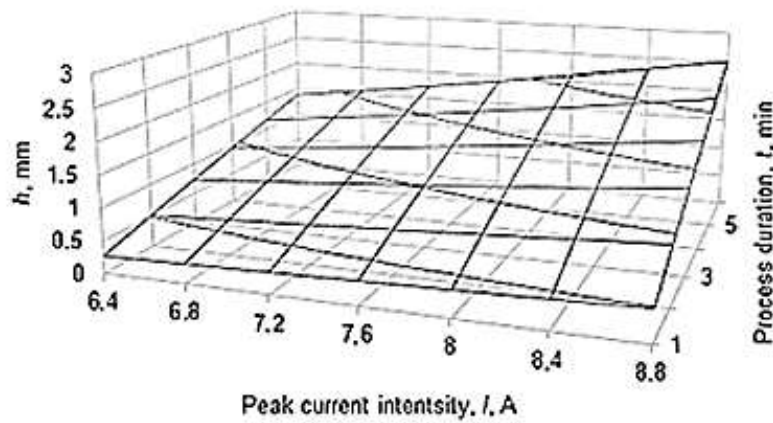
**Table 1.** Experimental results obtained in the case of test piece made of high speed steel

| Current number | Pulse on time, $t_p$ , $\mu s$ | Pulse off time, $t_b$ , $\mu s$ | Peak current intensity, $I$ , A | Process duration, $t$ , min | Height of column, $h$ , mm |
|----------------|--------------------------------|---------------------------------|---------------------------------|-----------------------------|----------------------------|
| 1              | 230                            | 40                              | 8.6                             | 2                           | 0.85                       |
| 2              |                                |                                 |                                 | 3                           | 1.20                       |
| 3              |                                |                                 |                                 | 4                           | 1.56                       |
| 4              |                                |                                 |                                 | 6                           | 2.51                       |
| 5              | 230                            | 40                              | 6.4                             | 1                           | 0.20                       |
| 6              |                                |                                 |                                 | 2                           | 0.43                       |
| 7              |                                |                                 |                                 | 3                           | 0.64                       |
| 8              |                                |                                 |                                 | 4                           | 0.84                       |
| 9              |                                |                                 |                                 | 5                           | 1.01                       |
| 10             |                                |                                 |                                 | 6                           | 1.19                       |
| 11             | 230                            | 50                              | 8.6                             | 1                           | 0.47                       |
| 12             |                                |                                 |                                 | 2                           | 0.93                       |
| 13             |                                |                                 |                                 | 3                           | 1.37                       |
| 14             |                                |                                 |                                 | 4                           | 1.81                       |
| 15             |                                |                                 |                                 | 5                           | 2.32                       |
| 16             |                                |                                 |                                 | 6                           | 2.69                       |
| 17             | 230                            | 50                              | 6.4                             | 1                           | 0.29                       |
| 18             |                                |                                 |                                 | 2                           | 0.49                       |
| 19             |                                |                                 |                                 | 3                           | 0.70                       |
| 20             |                                |                                 |                                 | 4                           | 0.89                       |
| 21             |                                |                                 |                                 | 5                           | 1.08                       |
| 22             |                                |                                 |                                 | 6                           | 1.23                       |
| 23             | 180                            | 40                              | 8.6                             | 1                           | 0.41                       |
| 24             |                                |                                 |                                 | 3                           | 1.31                       |
| 25             |                                |                                 |                                 | 4                           | 1.76                       |
| 26             |                                |                                 |                                 | 5                           | 2.22                       |
| 27             |                                |                                 |                                 | 6                           | 2.69                       |
| 28             |                                |                                 |                                 | 180                         | 40                         |
| 29             | 2                              | 0.69                            |                                 |                             |                            |
| 30             | 3                              | 0.89                            |                                 |                             |                            |
| 31             | 4                              | 1.16                            |                                 |                             |                            |
| 32             | 5                              | 1.42                            |                                 |                             |                            |
| 33             | 6                              | 1.59                            |                                 |                             |                            |
| 34             | 180                            | 50                              | 8.6                             | 1                           | 0.47                       |
| 35             |                                |                                 |                                 | 2                           | 0.81                       |
| 36             |                                |                                 |                                 | 3                           | 1.24                       |
| 37             |                                |                                 |                                 | 4                           | 1.59                       |
| 38             |                                |                                 |                                 | 5                           | 2.06                       |
| 39             |                                |                                 |                                 | 6                           | 2.56                       |
| 40             | 180                            | 50                              | 6.4                             | 1                           | 0.29                       |
| 41             |                                |                                 |                                 | 2                           | 0.51                       |
| 42             |                                |                                 |                                 | 3                           | 0.73                       |
| 43             |                                |                                 |                                 | 4                           | 0.99                       |
| 44             |                                |                                 |                                 | 5                           | 1.19                       |
| 45             |                                |                                 |                                 | 6                           | 1.42                       |

value of the Gauss's criterion, the more adequate is the considered empirical mathematical model.

By mathematical processing of the experimental results included in table 1, the following empirical mathematical function was determined:

$$h = 0.129t_p^{-0.482}t_b^{-0.0477}I^{1.882}t^{0.915}, \quad (1)$$



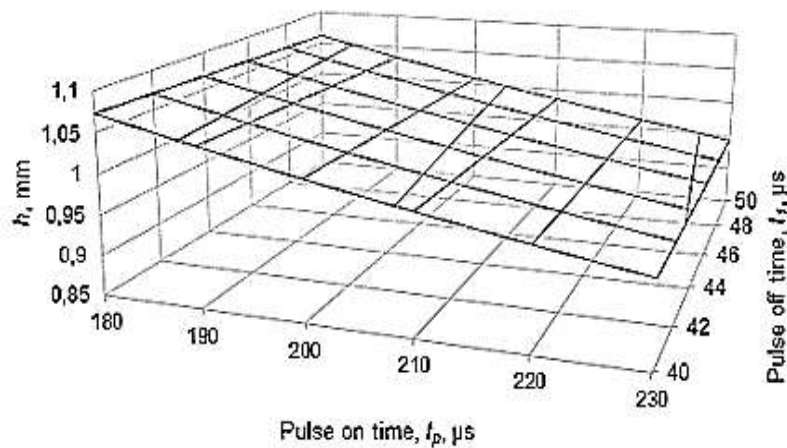
**Figure 5.** Influence exerted by the peak current intensity  $I$  and by the process duration  $t$  on the height of column corresponding to the obtained cylindrical surface ( $t_p=210 \mu\text{s}$ ,  $t_b=45 \mu\text{s}$ )

for which the value of the Gauss's criterion is  $S_G=0.01666352$ .

On the base of the mathematical empirical function (1), the graphical representations from figures 4 and 5 were elaborated.

The analysis of the mathematical empirical models

tool electrode penetration into the test piece material. Thus, one noticed that the most significant influence is exerted by the peak current intensity  $I$ , since in the equation (1), the maximum absolute value corresponds to the exponent attached to this size.



**Figure 4.** Influence exerted pulse on time  $t_p$  and pulse off time  $t_b$  on the height of column corresponding to the obtained cylindrical surface ( $I=7.5 \text{ A}$ ,  $t=3 \text{ min}$ )

and of the graphical representations from figures 4 and 5 allowed the statement of some remarks concerning the influence exerted by the independent variables (process input factors) on the depth  $h$  of

## 5. CONCLUSIONS

External cylindrical surfaces of small diameter could be obtained in workpieces made of electro conductive materials by electrical discharge machining, when classical machining methods could not be applied. A simple technique applied in such a case could be based on the use of a plate type tool electrode, in which holes with adequate diameters are previously achieved. Using the vertical work movement specific to the ram electrical discharge

When the pulse on time  $t_p$  and pulse off time  $t_b$  increase, the height  $h$  decreases, while the increase of the peak current intensity  $I$  and process duration  $t$  determine an increase of the height  $h$ .

machine, column type surfaces could be obtained. An experimental research was designed and materialized to highlight the influence exerted by the pulse on time, pulse off time, peak current intensity and process duration on the height of the column type surfaces obtained on test pieces made of high speed steel. By mathematical processing of the experimental results using a specialized software, empirical mathematical models able to show the influence exerted by the above-mentioned process

input factors were elaborated. In the future, there is the intention to extend the researches in order to correlate the height  $h$  of the column type surfaces

with the machining speed at the electrical discharge machining for the selected machining scheme.

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