

# MACHINING SPEED EVALUATION AT ELECTRICAL DISCHARGE DRILLING WITH TUBULAR TOOL ELECTRODE

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**ABSTRACT:** The electrical discharge drilling could be applied in order to obtain cavities in workpieces made of materials difficult to be machined by classical machining methods. Distinct factors exert influence on the drilling speed. An experimental research was designed and developed by considering the depth of the cavity achieved by means of a tubular tool electrode. One used a machining scheme involving the achieving of the work movement by test piece to the tubular tool electrode clamped on the machine tool table. In this way, the influence exerted by the spurious electrical discharges facilitated by the presence in the work gap of the metallic particles detached from the two electrodes can be diminished. Empirical mathematical models were determined by mathematical processing of the experimental results and using specialized software. The empirical mathematical models proved a high influence exerted on the drilling speed by the peak current intensity.

**KEY WORDS:** electrical discharge drilling, tubular tool electrode, drilling speed, influence factors, empirical mathematical model.

## 1. INTRODUCTION

The electrical discharge machining could be defined as a machining method in which the material removal from workpiece develops as a consequence of the electrical discharges occurred between the closest asperities existing on the active surface of tool electrode and the surface to be machined of the workpiece. Since there exist also at least a work movement achieved by the tool electrode or by the workpiece, a simple or a more complex surface is gradually generated on the workpiece. One must mention that the electrical discharges determine also a material removal process from the tool electrode and this represents the tool electrode wear. In order to ensure a high machining accuracy, especially when the machined surface reproduces in certain extend the active surface of tool electrode, the selection of machining parameters must be made so that the tool electrode wear is minim.

The electrical discharge machining is included in the larger group of non-traditional machining methods and this means that it is applied when the hardness of the workpiece metallic material is too high or the surface to be obtained is too complex; in such situations, the application of the so-called classical machining methods is not possible or their application is not efficient.

There are two main groups of electrical discharge machining processes; one of them is based on the use of massive tool electrode and such processes are included in the group of *ram electrical discharge*

*machining processes*. The second group of electrical discharge machining processes uses a wire tool electrode, found in continuous travelling movement from an unwinding reel to a winding reel. These processes are applied when ruled surfaces must be obtained and the machining process develops on the entire thickness of the plate type workpiece.

As in case of other machining processes, if one takes into consideration only the ram electrical discharge machining process, one can notice that the main parameters of technological interest are the material removal rate, the tool electrode wear, the machining accuracy, the roughness of the machined surface and the thickness of the surface layer affected by the machining process. Due to the fact that the electrical discharge machining process is based on thermal phenomena, it is expected a change of the workpiece material properties in a surface layer having a certain thickness.

In order to evaluate the material removal rate, as indicator, usually the specialists consider the quantity of material removed by the machining process from workpiece, in a certain time unit. Generally speaking, one appreciates that the maximum material removal rate  $Q$  that can be obtained by ram electrical discharge machining is actually of about  $1000 \text{ mm}^3/\text{min}$ .

However, from practical point of view, one can notice that sometimes the speed  $v$  of tool electrode tool in workpiece could be more significant and, in

such a case, the drilling speed  $v$  could be taken into consideration.

Such a parameter of technological interest could be used in case of electrical discharge drilling, but it can be also used when external surface are obtained by ram electrical discharge machining.

In some previous researches, the results obtained in connection with the tool electrode wear, the material removal rate (evaluated as the quantity of material removed from workpiece in a certain process duration) and machining speed were addressed [4, 7]; in this case, our objective was the evaluation of the material removal rate by means of the drilling speed.

Over the years, the machining speed specific to the ram electrical discharge machining was a research objective of the researchers. Thus, Wang et al. succeeded to achieve a compound machining of titanium alloy using high speed EDM milling and arc machining which is characterized by a material removal rate of  $21494 \text{ mm}^3/\text{min}$  and a relative electrode wear ratio of 1.7 %. They developed an experimental research aiming to highlight the influence exerted by electrode polarity, peak voltage, peak current and radius of overcut on the material removal rate and relative electrode wear ratio [8].

Shen et al. [6] proposed a high speed dry electrical discharge machining method able to ensure a material removal rate of  $5152 \text{ mm}^3/\text{min}$ , which means an increase of the material removal rate of about 2-3 times in comparison with the known dry electrical discharge machining processes of test pieces made of AISI 304 stainless steel. The researches were also focused on the structure of re-solidified layer, surface morphology, elementary

composition and phase of the studied test pieces.

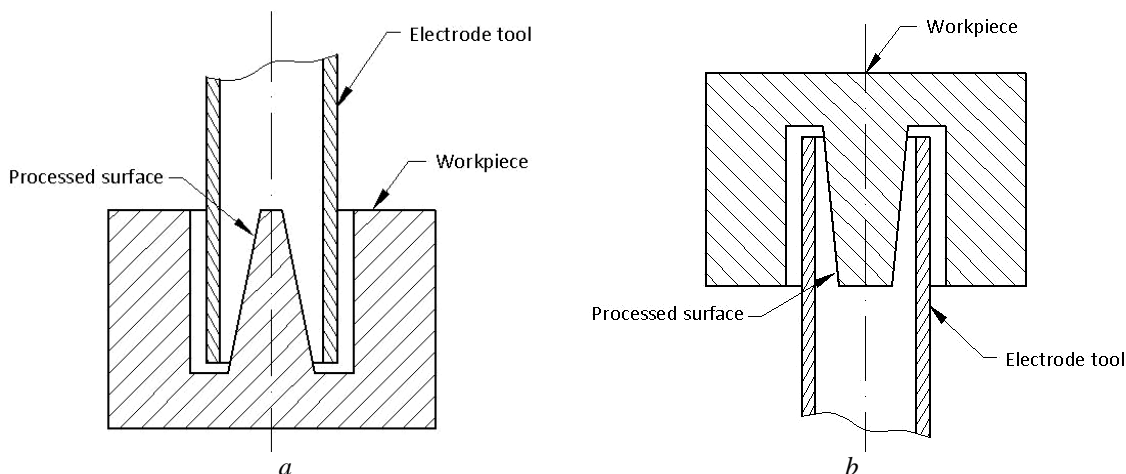
Kao et al. [3] used the Taguchi method and grey relational analysis in order to optimize the electrical discharge machining process of Ti-6Al-4V alloy. One of the considered performance characteristics was the material removal rate; as input factors, they took into consideration the discharge current, open voltage, pulse duration and duty factor [3].

Han et al. proposed a high speed electrical discharge milling with moving arcs, connecting a copper electrode rotating rapidly and the workpiece to a direct current supply, in order to generate a moving electric arc. They noticed that a high material removal rate can be achieved by applying this machining method [2].

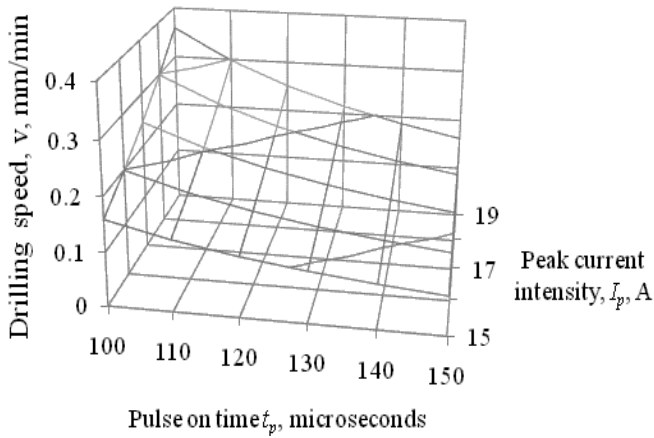
The objective of the research presented in this paper was to obtain an image concerning the influence exerted by some process input factors on the drilling speed, in case of electrical discharge machining.

## 2. THEORETICAL PREMISES

One took into consideration the separation by ram electrical discharge machining of cylindrical parts from a plate type workpiece presenting two parallel surfaces (fig. 1). Such surfaces could be obtained by applying a machining schema involving a machining movement achieved by the tubular tool electrode along a vertical direction, from up to down (fig. 1, a). This machining method was not ensuring an acceptable shape accuracy due to the spurious electrical discharges determined by presence in the work gap of the metallic particles detached from the two electrodes (finally, a conical shape of the external surface was obtaining, instead of a cylindrical one); a machining schema based on the vertical work movement achieved by the workpiece



**Figure 1.** Machining schemas applicable in order to obtain external cylindrical surfaces by ram electrical discharge machining: *a* – tool electrode achieves the machining movements from up to down; *b* – the workpiece electrode achieves the machining movement form up to down [5]



**Figure 3.** Influence exerted by pulse on time  $t_p$  and peak current intensity  $I_p$  on the drilling speed ( $t_b=40 \mu\text{s}$ )

electrode from up to down [4, 5, 7] was adopted (fig. 1, b).

In the final period of the machining process, when the machined part must be separated from workpiece, it is possible to notice a gradual inclination of the part and, during the aspects specific to the electrical discharge machining process, the machining accuracy could be significant affected; in order to obtain correct cylindrical surfaces, the machining process was stopped at a distance of some tenths of millimetres from the superior surface of the workpiece. Subsequently, the parts could be separated by means of a classical plane grinding operation.

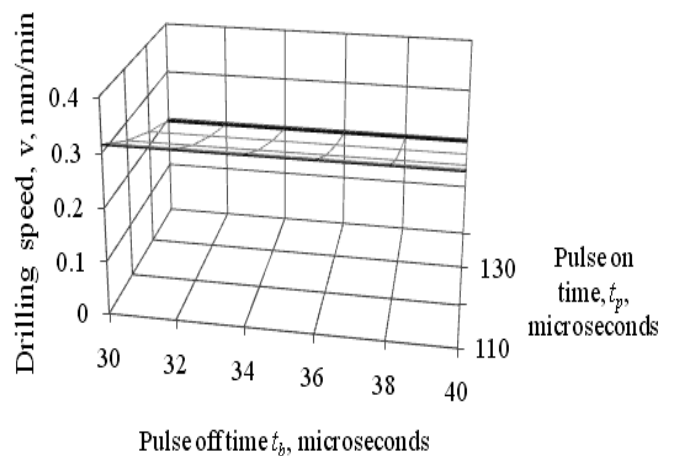
### 3. EXPERIMENTAL CONDITIONS

Within a larger experimental research concerning the obtaining of external cylindrical parts by ram electrical discharge machining, one of the research objectives was to highlight the influence of some process input factors on the drilling speed  $v$ .

The experiments were developed on a numerical

controlled ram electrical discharge machining type Sodick AD3L, in accordance with the requests specific to a full factorial experiment with three independent variables at two levels. Tubular tool electrodes made of copper were clamped in the Erowa device attached to the work head of the machining tool. The test piece was made of high speed steel HS 18-4-1, including 0.659 % C, 17.7 % W, 4.04 % Cr, 1.19 % V, 1.28 % Mo etc. The thickness of the plate type test piece was of 10 mm.

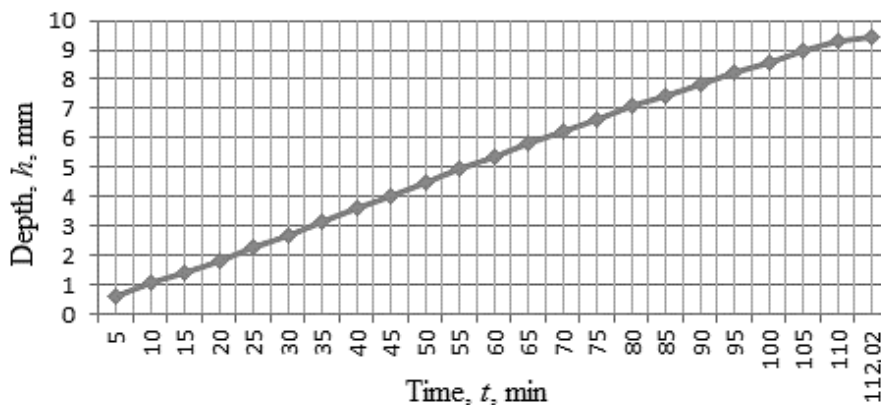
The machining schema presented in figure 1, b was materialized, in order to diminish the negative influence of the spurious electrical discharges generated by the metallic particles detached from the two electrodes involved in the machining process; in



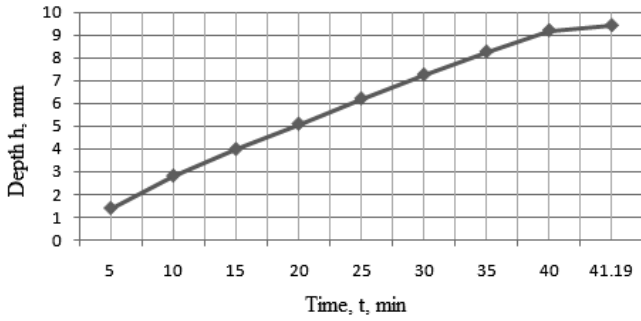
**Figure 2.** Influence exerted by pulse on time  $t_p$  and pulse off time  $t_b$  on the drilling speed ( $I_p=19.3 \text{ A}$ )

the case of such a machining schema, the metallic particles are more easily removed just under the action of their weights.

As input variables, one took into consideration the pulse on time  $t_p$ , pulse off time  $t_b$  and peak current intensity  $I_p$ . The selection of the input factors value was made by taking into consideration the



**Figure 2.** Evolution of the depth of cavity obtained by electrical discharge drilling ( $t_p=140 \mu\text{s}$ ,  $t_b=30 \mu\text{s}$ ,  $I_p=15.3 \text{ A}$ )



**Figure 2.** Evolution of the depth of cavity obtained by electrical discharge drilling ( $t_p=140 \mu s$ ,  $t_b=40 \mu s$ ,  $I_p=19.3 A$ )

recommendations formulated by the machine tool manufacturer for the established work conditions. The values of the input factors were  $t_p=140$  and  $190 \mu m$ ,  $t_b=30$  and  $40 \mu m$ ,  $I_p=15.3$  and  $19.3 \mu m$ .

As above mentioned, in order to avoid the possible negative influence of the machined part inclination in the final stage of machining process, when the part is detached from the plate type workpiece, the machining process was stopped when the depth of the machined cavity was reaching a value of 9.5 mm; this value was set up on the machining equipment. In this way, machining process durations were of 27.26 min (the minimum value) to 112.02 min (maximum value).

One took into consideration the digital information offered by the machining equipment about the length of the work stroke developed up the moment when the machined cavity had a depth of about 9.5 mm.

The information concerning the length of the work stroke developed by the machine tool work head and highlighted by the machine tool digital subsystem could have a difference in comparison with the real depth of the cavity machined in the test piece, due to the wear process able to affect the length of the tool electrode, but the experimental research showed that this difference is relatively low and it could be neglected. One read also the process duration, highlighted also by the digital subassembly of electrical discharge machining equipment.

The drilling speed was determined as a ratio between the length of the tool workpiece stroke and the process duration necessary to obtain a depth of machined cavity of about 9.5 mm.

By means of the digital subsystem of the machine tool, at each 5 minutes of the machining process, there was determined the length of the machine tool work head stroke, in order to obtain an image concerning the evolution in time of the machined cavity depth.

#### 4. EXPERIMENTAL RESULTS AND THEIR MATHEMATICAL PROCESSING

The experimental results were mathematically processed by considering also the values of the input factors specific to each experiment. A software based on the method of least squares was used [1]; the software has the possibility to establish which is the most convenient mathematical relation to the experimental results among some mathematical relations, by taking into consideration the so-called value  $S_G$  Gauss's criterion. Thus, the following polynomial type empirical mathematical model was determined:

$$v = 0.0513 - 0.00265t_p - 0.00079t_b + 0.0345I_p, \quad (1)$$

for which  $S_G=8.101668 * 10^{-4}$ . Since usually in the manufacturing technology the power type relations are preferred, by means of the same software [1], such an empirical mathematical relation was also determined:

$$v = 0.117t_p^{-1.952}t_b^{-0.00401}I_p^{3.429} \quad (2)$$

for which  $S_G=9.2177*10^{-4}$

In accordance with these mathematical models, one can mention that when the pulse on time  $t_p$  and pulse off time  $t_b$ , increase, the drilling speed  $v$  decreases, while the increase of the peak current intensity  $I_p$  has as result an increase of the drilling speed  $v$ .

One can also notice that the most significant influence on the drilling speed  $v$  is exerted, as expected, by the peak current intensity  $I_p$ , whose coefficient in the relation (1) and exponent in the relation (2) has the maximum absolute value. Indeed, the increase of the peak current intensity determines a more intense electrical discharge, the heating of a higher quantity of the workpiece material and, as a consequence, the removal of a higher quantity of material from the workpiece and this means that a higher drilling speed is possible. In a paper published in 2014, whose subject was referring to the material removal rate  $Q$ , by taking into consideration the same machining conditions, the following empirical mathematical model [7] was determined:

$$Q = 0.0117t_p^{-1.908}t_b^{0.0356}I_p^{3.439} \quad (3)$$

One can see the similitude of the values corresponding to the coefficient and exponents from the relation (3) with those included in the relation (2) and this fact confirms the validity of the empirical model constituted by the relation (2). One can mention that in the case of relation (3), the

evaluation was made by means of weighting the test piece before and after each experiment, while in the case of the relation (3), the depth of the cavity obtained by electrical discharge machining was measured.

On the base of the relation (2), the graphical representation from figures 2 and 3 were elaborated, in order to obtain a graphical representation concerning the influence exerted by two of the input factors on the drilling speed  $v$ . One can notice the influence very low exerted by the pulse off time  $t_b$  on the drilling speed  $v$ ; one can appreciate that practically, the pulse off time  $t_b$  did not affect the value of the drilling speed  $v$ , for the considered experimental conditions. Other aspect considered as a result of the experimental research was the possibility of obtaining information concerning the evolution of the machined cavity depth  $h$  as a consequence of the drilling process. The two diagrams from figures 4 and 5 were elaborated on the base of the experimental measurements. Initially, there was taken into consideration decrease of the drilling speed  $v$  once the tool electrode advances in the test piece material, but the diagrams from figures 4 and 5 show that such a result could occur for higher cavity depths. In the case of the presented experiments, the depth of cavity increases approximately linearly at the increase of the drilling process duration.

## 5. CONCLUSIONS

One of the applications of the electrical discharge machining refers to the obtaining external cylindrical surfaces by applying machining schemes similar to those corresponding to the drilling. In order to diminish the negative influence of the spurious electrical pulses facilitated by the presence in the work gap, for a longer time, of the metallic particles detached from the two electrodes, a machining scheme characterized by achieving the work movement by the test piece, from up to down, to the tubular tool electrode placed on the machine tool table was selected. The experimental research was developed in accordance with the request of a factorial experiment with three independent variables at two levels. The experimental results were processed by means of specialized software and empirical models were determined. The empirical mathematical models and the graphical representation elaborated on the base of a power type relation confirmed the higher influence exerted by the peak current intensity  $I_p$  and practically the lack of an influence exerted by the pulse off time  $t_b$ , for the considered experimental conditions. In the

future, there is the intention to extend the experimental research, by taking into consideration other materials for test pieces and to apply an optimization method, in order to determine the most convenient conditions for the electrical discharge drilling.

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