

# INFLUENCE OF SOME PROCESS INPUT FACTORS ON THE SURFACE ROUGHNESS AMPLITUDE PARAMETERS AT EDM WHEN USING TUBULAR TOOL ELECTRODES

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**ABSTRACT:** The electrical discharge machining could be used sometimes to improve the roughness of the machined surfaces. The values of the surface roughness parameters are affected by the characteristics of the electrical discharges developed between the closest asperities existing on the active surface of the tool electrode and on the workpiece surface to be machined. An electrical discharge machining scheme based on the use of tubular tool electrodes was applied to detach cylindrical parts from a parallelepipedal workpiece. An experimental research was developed to highlight the influence exerted by the pulse on time, pulse off time and average peak current intensity on some of the surface roughness parameters which take into consideration the amplitude of the asperities corresponding to the machined surface, in the case of a test piece made of high speed steel HS18-1-1-0. Power type mathematical empirical models were determined by mathematical processing of the experimental results and using a specialized software. The analysis of the empirical mathematical models showed that the values of the surface roughness parameters increase when the average peak current intensity increases and slowly decrease when the values of the pulse on time increase also. In our case, one noticed that for the experimental conditions, the pulse off time practically does not affect the values of the considered surface roughness parameters.

**KEY WORDS:** electrical discharge machining, amplitude surface roughness parameters, influence factors, experimental research, power type empirical mathematical models.

## 1. INTRODUCTION

The electrical discharge machining is a nonconventional machining method that is based on the developing of electrical discharges between the closest asperities existing on the active surface of the tool electrode and the surface to be machined of the workpiece [4, 7, 8, 12, 13]. As a direct consequence of these electrical discharges, small quantities of material are removed both from the tool electrode and the workpiece, but the machining conditions are established so that the quantity of material removed from the workpiece exceeds the quantity of material detached from the tool electrode. In fact, the process of removing the material from the tool electrode is an unwanted process because it determines the so-called *wear of the tool electrode*. On the other hand, when the problem of a rough electrical discharge machining process is formulated, a high material removal rate is a convenient aspect.

In the case of the surface finishing by electrical discharge machining, the machining accuracy, the surface roughness and the thickness of the surface

layer affected by the machining process are considered. In other situations, when a single electrical discharge machining process is applied, the industrial practice could be interested both by a high material removal rate and low heights of the surface asperities generated by the machining process.

Generally, the surface roughness is considered as geometrical errors of third and fourth order; if the geometrical errors of first order are the part shape errors, the errors of second order are constituted by the waviness, the errors of third order are the striations and the ribs with periodical or pseudo-periodical character, generated especially as a consequence of the feed movement, the asperities of the fourth order could include the results of material slips, voids, pores and they have an irregular characters, being generated by the inhomogeneity of the workpiece material [1].

For a long time, the prescriptions inscribed on the mechanical drawings took into consideration only the arithmetic mean deviation of the profile (the

parameter  $Ra$ ) and the so-called height  $Rz$  of the profile irregularities in ten points.

In the last decades, the development of the researches in the field of the machined surface roughness showed that the abovementioned parameters ( $Ra$  and  $Rz$ ) do not consider other aspects able to characterize the profile of the machined surface and new surface roughness parameters were defined and measured.

At present, there are the following essential groups of surface roughness parameters: amplitude parameters, amplitude parameters that consider also the average of the ordinates, pitch parameters, hybrid parameters, curves and parameters associated to certain curves. At the same time, the symbol  $Rz$  was attributed to *the maximum height of the profile* and it was defined as the sum of the highest heights of the profile prominences and the highest depths of the spaces that exist between two profile irregularities, within the basic length.

Due to the necessity of obtaining by electro erosion surfaces characterized by low values of the surface roughness parameters, various researches aiming to highlight the influence exerted by process input distinct factors on the values of the surface roughness parameters were designed and performed.

Thus, an experimental investigation concerning the influence exerted by some process input factors on the surface roughness parameter  $Ra$  was developed by Keskin et al. [6] They established and discussed a polynomial empirical mathematical model by considering the spark time and the power.

A polynomial of second degree model was also proposed for the surface roughness parameter  $Ra$  by Patel et al. [9] in the case of test samples made of  $Al_2O_3/SiC_w/TiC$  ceramic composite. They used the response surface methodology, the analysis of variance and the trust region as research methods. A maximum of the surface roughness parameter  $Ra$  was highlighted in the case of the influence exerted by the discharge current.

Salonitis et al. developed a theoretical thermal base model to evaluate the surface roughness as a function of the discharge current, arc voltage or spark duration [10]. The experimental researches proved an average deviation of about 6.1 % in comparison with the results obtained by using the theoretical thermal model.

Jabbaripour et al. investigated the surface roughness, material removal rate and corrosion resistance of the surfaces obtained by powder mixed electrical discharge machining of test pieces made of  $\gamma$ -TiAl when using distinct powders [5]. They noticed that

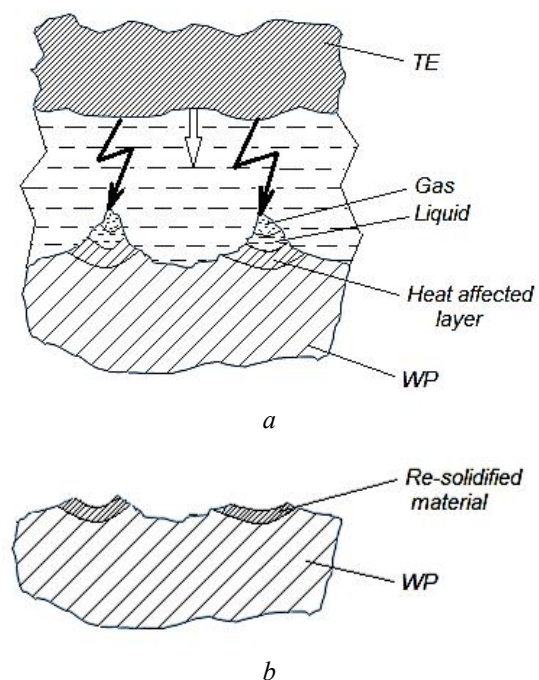
aluminum powder could ensure a diminishing of the size of the surface roughness parameter about 32 % compared with the classical version of the electrical discharge machining.

The objective of this paper was to study the influence exerted by the pulse on time, pulse off time and average peak current intensity of the electrical discharge machining process on some of the current amplitude parameters used to characterize the surface roughness.

## 2. PREMIZES OF GENERATING THE SURFACE ASPERITIES DURING THE ELECTRICAL DISCHARGE MACHINING PROCESS

As above mentioned, the surface obtained by electrical discharge machining is the results of producing electrical discharges between the closest asperities placed on the tool electrode  $TE$  active surface and on the workpiece  $WP$  surface to be machined (fig. 1). The electrical discharges are initiated because of diminishing of the distance between electrodes following the existence of at least work movement.

If each electrical discharge has enough energy to melt and even vaporize the metallic material of the workpiece, after a certain duration of the electrical discharge machining process, the machined surface will be a concatenation of craters previously generated by the electrical discharges. Practically, because of the machining movement achieved usually by the tool electrode to the workpiece, when



**Figure 1.** Generation of a new surface as a consequence of the electrical discharge developing: a – effects of the electrical discharges on the asperities peaks; b – re-solidification of the melted material found in the new craters

the distance between the asperities peaks becomes lower than a certain value, the electrical discharges develop (fig. 1, a). Because of the electrical discharge, a small part of the asperity peak could be affected by a vaporizing effect, another part of the asperity material is melted, and another part constitutes the so-called heat affected zone. The fast increase of the heat and of the vapoured and liquefied metallic material generates an explosion and small quantities of the workpiece material are thrown in the dielectric liquid and removed from the work gap because of the dielectric liquid circulation. Another quantity of the melted material could adhere to the new generated crater, but under the action of the superficial tensions, the thickness of the re-solidified material could be higher in the bottom of the crater and lower in the tops of the new prominences generated by the electrical discharge process. For this reason, the surface roughness could be lower than the theoretically generated surface roughness.

As above mentioned, at present, various parameters could be used to evaluate the roughness of a certain machined surface. In accordance with the content of the standard SR ISO 4287, firstly one could mention that there are parameters calculated from the primary profile (*P*-parameters), parameters calculated from the roughness profile (*R*-parameters), and parameters calculated from the waviness profile (*W*-parameters). Subsequently, only the *R* parameters are considered.

As above mentioned, at present there are various groups of surface roughness parameters [3]:

- *amplitude parameters* (that consider peak and valley): maximum profile peak height *R<sub>p</sub>*, maximum profile valley depth *R<sub>v</sub>*, maximum height of the

profile *R<sub>z</sub>*, mean height of the profile elements *R<sub>c</sub>*, total height of the profile *R<sub>t</sub>*;

- *amplitude parameters that consider the average of the ordinates*: arithmetical mean deviation of the assessed profile) *R<sub>a</sub>*, root mean square deviation of the assessed profile *R<sub>q</sub>*, skewness of the assessed profile *R<sub>sk</sub>*, kurtosis of the assessed profile *R<sub>ku</sub>* etc.);

- *spacing parameters* or *pitch parameters*: mean width of the profile elements *R<sub>sm</sub>* etc.;

- *hybrid parameters*: root mean square slope of the assessed profile *RΔq*, profile slope at mean line  $\gamma$ , mean slope of the profile  $\Delta_a$ , root mean square of the mean slope of the profile *RMS*, average wavelength  $\lambda_a$ , *RMS* wave length  $\lambda_q$ , relative length of the profile *l<sub>o</sub>*, bearing area length *t<sub>p</sub>*, steepness factor of the profile *S<sub>f</sub>*, roughness height uniformity *H<sub>u</sub>*, roughness height skewness *H<sub>s</sub>*, roughness pitch uniformity *P<sub>u</sub>*, roughness pitch skewness *P<sub>s</sub>* etc.;

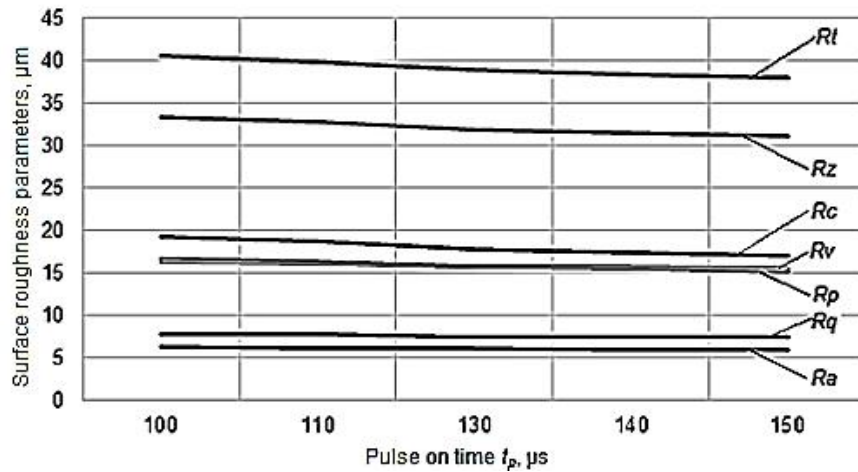
- *curves and related parameters*: material ratio of the profile *Rmr(c)*, material ratio curve of the profile - Abbott Firestone curve, profile section height difference *Rδc*, relative material ratio *Rmr*, profile height amplitude curve etc.

### 3. EXPERIMENTAL CONDITIONS AND RESULTS

To perform a comparison of the way in which the values of some surface roughness parameters are affected by some process input factors in obtaining external cylindrical surfaces by means of tubular tool electrode [11], the results of some experimental tests were used. To diminish the influence exerted by the spurious electrical discharges due to the presence of the metallic particles in the work gap, the machining scheme was based on the placing the test piece on the machine tool head, by means of the

Table 1. Experimental conditions and results

Exp. no.	Process input factors			Surface roughness parameters						
	Pulse on time, <i>t<sub>p</sub></i> , μs	Pulse off time, <i>t<sub>b</sub></i> , μs	Average peak current intensity, <i>I<sub>p</sub></i> , A	<i>R<sub>a</sub></i> , μm	<i>R<sub>p</sub></i> , μm	<i>R<sub>v</sub></i> , μm	<i>R<sub>z</sub></i> , μm	<i>R<sub>c</sub></i> , μm	<i>R<sub>t</sub></i> , μm	<i>R<sub>q</sub></i> , μm
Column no. 1	2	3	4	5	6	7	8	9	10	11
1	110	30	15.3	7.15	15.6	20.8	36.5	20.9	46.6	8.94
2	140	40	15.3	5.45	12.9	17.0	29.9	13.9	39.5	6.91
3	140	30	19.3	8.87	27.7	21.6	49.4	24.1	59.0	11.0
4	110	40	19.3	6.68	17.2	16.0	33.2	19.2	40.4	8.11
5	110	30	19.3	6.69	15.8	15.6	31.5	16.3	36.8	7.93
6	110	40	15.3	5.12	17.8	13.5	31.3	20.1	37.5	6.68
7	140	30	15.3	3.85	10.3	9.80	20.1	12.7	23.2	4.69
8	140	40	19.3	7.87	16.6	17.5	34.1	23.2	40.9	9.29



**Figure 2.** Influence exerted by the pulse time  $t_p$  on the values of the surface roughness parameters (tool electrode made of copper, test piece material: HS18-1-1-0,  $t_b=35 \mu\text{s}$ ,  $I_p=17 \text{ A}$ )

Erowa device used usually to position and clamp the tool electrode. This last component of the machining technological system (tubular tool electrode) was positioned and clamped in a chuck placed, at its turn, on the machine tool table. To perform the electrical discharge machining process, the equipment Sodick AD3L was used; the equipment has a subassembly for computer numerical control of the process.

The test piece was a parallelepipedal bar having a thickness of 10 mm and made of high speed steel HS18-1-1-0. As tool electrodes, tubes made of copper were used. To avoid the possible inclination of the cylindrical part obtained by electrical discharge machining when the part is detached from the workpiece, a work stroke of 9.55 mm was programmed by means of the computer numerical control subsystem. Finally, the parts were separated from the bar test piece applying a grinding operation.

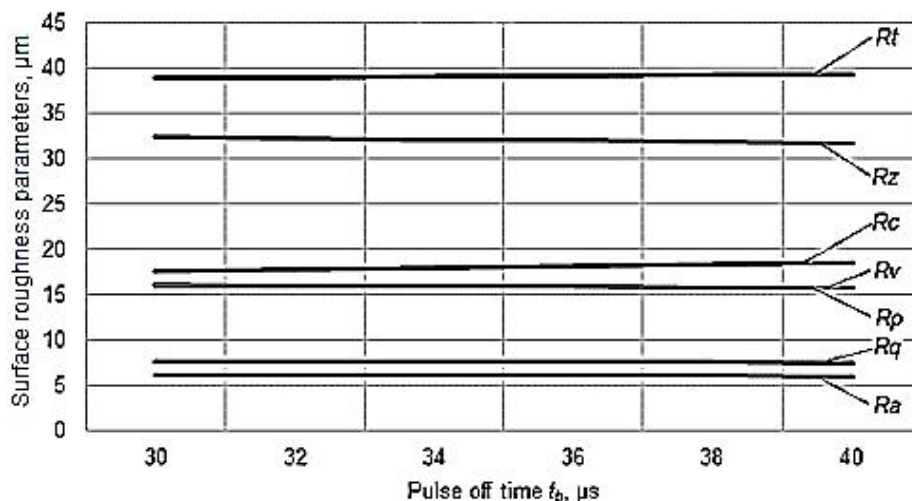
The values of the surface roughness parameters were measured by means of the surface roughness tester

Surtronic S25.

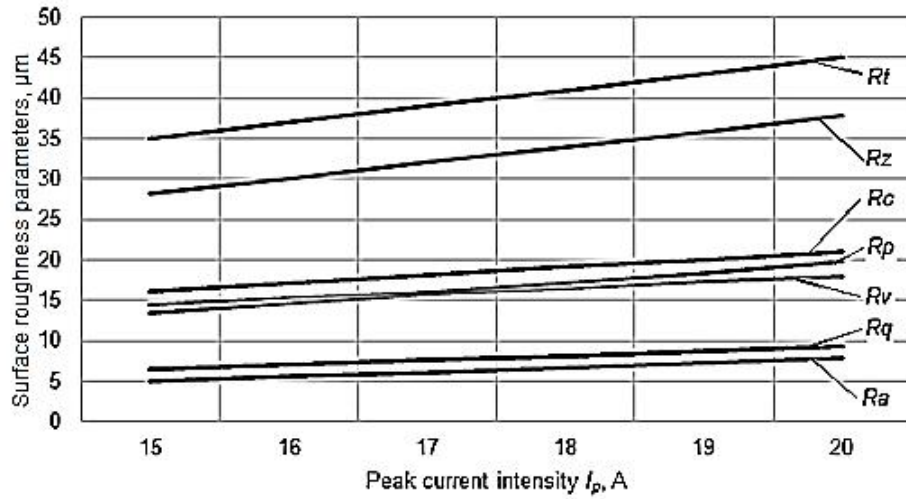
The experiments were developed in accordance with the requirements of a full factorial experiment, with three independent variables (process input factors: pulse on time  $t_p$ , pulse off time  $t_b$  and average peak current intensity  $I_p$ ) at two variation levels.

The values of the process input parameters for each experiment were included in the columns nos. 2, 3 and 4 from the table 1. In the columns nos. 5, 6, 7, 8, 9, 10, and 11, the values of the following 7 surface roughness parameters were inscribed: arithmetical mean deviation  $R_a$  of the assessed profile, the maximum profile peak height  $R_p$ , the maximum profile valley depth  $R_v$ , the maximum height of the profile  $R_z$ , the mean height of the profile elements  $R_c$ , the total height of the profile  $R_t$ , the root mean square deviation  $R_q$  of the assessed profile.

The initial values of the process input parameters were established by taking into consideration the recommendations formulated by the equipment producer; as second level of the process input factors



**Figure 3.** Influence exerted by the pulse time  $t_p$  on the values of the surface roughness parameters (tool electrode made of copper, test piece material: HS18-1-1-0,  $t_p=125 \mu\text{s}$ ,  $I_p=17 \text{ A}$ )



**Figure 4.** Influence exerted by the peak current intensity  $I_p$  on the values of the surface roughness parameters (tool electrode made of copper, test piece material: HS18-1-1-0,  $t_p=125$ ,  $t_b=35$   $\mu$ s)

variation, the values corresponding to a difference of about 25 % to the initial established values were adopted. The experimental results were mathematically processed by means of a specialized software based on the method of the least squares [2]. The software allows selecting of the most adequate empirical mathematical models among 5 functions (polynomial of first and second order, power type function, exponential type function, hyperbolic function) by considering the so-called Gauss's criterion.

Appreciating that the power type function empirical mathematical models could offer a direct image about the intensity of the influence exerted by the process input factors on the sizes of the amplitude parameters used to characterize the roughness of the surfaces obtained by electrical discharge machining and the power type functions are usually preferred to be used in the field of machining processes, the following relations were established:

$$Ra = 0.207t_p^{-0.114}t_b^{-0.0933}I_p^{1.508} \quad (1)$$

$$Rp = 1.373t_p^{-0.218}t_b^{-0.0608}I_p^{1.313} \quad (2)$$

$$Rv = 3.928t_p^{-0.110}t_b^{-0.05878}I_p^{10.755} \quad (3)$$

$$Rz = 5.206t_p^{-0.171}t_b^{-0.0647}I_p^{1.014} \quad (4)$$

$$Rc = 3.220t_p^{-0.297}t_b^{0.153}I_p^{0.924} \quad (5)$$

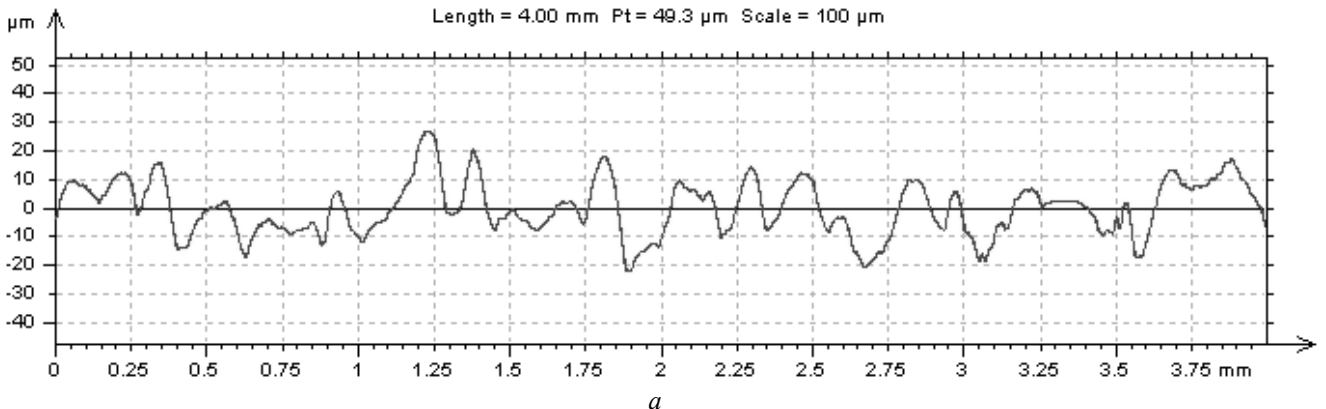
$$Rt = 6.543t_p^{-0.166}t_b^{0.0363}I_p^{0.868} \quad (6)$$

$$Rq = 0.448t_p^{-0.153}t_b^{-0.0437}I_p^{1.315} \quad (7)$$

On the base of the above mentioned mathematical empirical models, the graphical representations from figures 2, 3, and 4 were elaborated. In figure 5, an example of surface profile is presented.

The analysis of the empirical mathematical models corresponding to the equations (1)-(7) and of the graphical representations from figures 2, 3, and 4 shows that some similarities could be highlighted.

Thus, one could notice that in all the empirical mathematical models, the exponent attached to the factor  $t_p$  has a subunit negative value, and this fact shows that when the pulse duration  $t_p$  increases, the values of the surface roughness parameters are



**Figure 5.** Profile of the surface obtained by electrical discharge machining (tool electrode made of copper, test piece material: HS18-1-1-0,  $t_p=140$   $\mu$ s,  $t_b=40$   $\mu$ s,  $I_p=15.3$  A)

affected by a decrease. With one exception (equation (5)), the factor  $t_b$  exerts a low negative influence on the values of the surface roughness amplitude parameters, since the exponents attached to this process input factor are negative and low.

The factor  $I_p$  exerts the maximum influence on the surface roughness parameters. Indeed, in all the other empirical mathematical models, the exponent attached to the average peak current intensity  $I_p$  has the maximum values (compared with the values of the exponents attached to the other two factors,  $t_p$  and  $t_b$ ) and this influence is materialized by an increase of the values of the surface roughness parameters when the factor  $I_p$  increases, too.

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## 4. CONCLUSIONS

An experimental research was developed to highlight the influence exerted by some process input factors on the surface roughness amplitude parameters. One noticed that in the case of all the analysed surface roughness amplitude parameters, an increase of the surface roughness parameter value is determined by the increase of the average peak current intensity and a low decrease of the surface roughness amplitude parameters values is the result of the pulse on time increase. In the future, there is the intention to develop a theoretical model aiming to show the influence of some electrical discharge machining process input factors on the size of the surface roughness parameters.

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