Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 13 (2017) 573–578

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

Manufacturing Engineering Society International Conference 2017, MESIC 2017, 28-30 June 2017, Vigo (Pontevedra), Spain

Spacing roughness parameters analysis on the EDM of Inconel®600 alloy

A. Torres, I. Puertas, C.J. Luis*

Mechanical, Energetics and Materials Engineering Department, Public University of Navarre, Campus de Arrosadía, s/n, Pamplona 31006, Spain

Abstract

Many research studies may be found regarding the measurement of surface roughness parameters. Most of them are focused on amplitude parameters as they are the most commonly used in industry, while little research has been found on the spacing ones. Spacing roughness parameters measure the horizontal characteristics of the surface deviations. In this present study, the influence of current intensity, pulse time and duty cycle on spacing roughness parameters Sm and Pc has been analyzed. Design of experiments techniques are used in order to both model and predict the most influential factors by using a small number of experiments. Current intensity of 2 A, pulse time of 25 µs and duty cycle of 0.5 are selected as the best machining conditions in order to obtain the lowest surface roughness.

Keywords: Surface Roughness; EDM; Inconel®600; Manufacturing

1. Introduction

Surface roughness is a widely used index of product quality and in most cases a technical requirement for mechanical products. At present, achieving a certain surface quality is of great importance for the functional behavior of a part [1]. According to that, many research studies may be found regarding the measurement of surface

* Corresponding author. Tel.: +34-948-169301; fax: +34-948-169099.
E-mail address: cluis.perez@unavarra.es

10.1016/j.promfg.2017.09.099

roughness parameters [2]. Most of them are focused on amplitude parameters as they are the most commonly used in industry, while little research has been found on the spacing ones. Spacing roughness parameters measure the horizontal characteristics of the surface deviations and are defined in [3] and [4].

In this line, Das et al. [5] made an attempt to find out the optimum EDM process parameters so that surface roughness value was the lowest possible. Sultan et al. [6] tried to model material removal rate, electrode wear rate and surface roughness through response surface methodology in a die sinking EDM process. Kiyak and Çakir [7] studied the influence of EDM parameters on surface roughness for machining an AISI P20 steel. They found that lower current and pulse time as well as relatively higher pulse pause time produces a better surface finish.

In this present study, the influence of current intensity, pulse time and duty cycle on spacing roughness parameters Sm (mean spacing of profile irregularities) and Pc (peak count) has been analyzed. To do that, Design Of Experiments (DOE) techniques are used in order to both model and predict the most influential factors by using a small number of experiments. In this way, the factors selected have been: current intensity (I), pulse time (t_i) and duty cycle as they are considered between researchers that most influence the EDM process. In addition, the study has been performed for positive and negative electrode polarities in order to compare results and decide the most suitable polarity to obtain the desired surface roughness.

2. Methodology and experimental procedure

Experiments were performed on a die-sinking EDM machine, model ONA DATIC D-2030 S with a side jet flushing system, as shown Fig. 1. As a dielectric fluid, mineral oil was selected.

Fig. 1. EDM process.

Moreover, ground sheets of Inconel®600 with 50 mm x 50 mm x 5 mm in dimensions were used as material. The electrodes selected were made of copper infiltrated graphite (C-Cu). All the experiments were conducted for both positive and negative polarity.

In order to obtain the surface roughness values, a profile rugosimeter ALPA RT-70 was used. Roughness measurements were repeated five times and the average of these five measurements was taken.

Furthermore, a factorial design 4^3 with three factors and 4 levels was selected. Design factors and selected values are shown in Table 1. These levels allow different surface quality to be obtained from finish conditions to rough conditions. As can be observed, current intensity values were 2 A, 4 A, 6 A and 8 A, pulse time values were 25 µs, 50 µs, 75 µs and 100 µs and duty cycle values were 0.3, 0.4, 0.5 and 0.6.

Table 1. Design factors and their values.

Design factor	Values			
Current intensity [A]	2	4	6	8
Pulse time [μs]	25	50	75	100
Duty cycle	0.3	0.4	0.5	0.6

3. Results and discussion

After the experimentation and the measurement of the surface roughness, the results obtained are analyzed in this section.

3.1. Results and analysis of Sm

Sm results are analyzed in Table 2 and Table 3 which represent the ANOVA tables for positive and negative polarities, respectively. As can be observed, five effects for positive polarity and four effects for negative polarity have P-values less than 0.05, indicating that they influence Sm variable for a confidence level of 95 %. Moreover, in both cases, current intensity and pulse time are the most significant effects.

Table 2. Analysis of variance for positive polarity of Sm.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
A: Current intensity	10781.00	1	10781.00	149.63	$1.88\cdot10^{-17}$
B: Pulse time	28196.30	1	28196.30	391.35	$6.10\cdot10^{-27}$
C: Duty cycle	280.13	1	280.13	3.89	0.0536
AA	409.05	1	409.05	5.68	0.0206
AC	882.39	1	882.39	12.25	0.0009
BB	236.39	1	236.39	3.28	0.0755
BC	571.93	1	571.93	7.94	0.0067
Total Error	4034.75	56	72.05		
Total (corr.)	45392.00	63			

Table 3. Analysis of variance for negative polarity of Sm.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
A: Current intensity	23259.60	1	23259.60	140.46	$5.18\cdot10^{-17}$
B: Pulse time	11720.10	1	11720.10	70.77	$1.43\cdot10^{-11}$
C: Duty cycle	205.12	1	205.12	1.24	0.2704
AA	749.39	1	749.39	4.53	0.0377
AB	4444.22	1	4444.22	26.84	$3.01\cdot10^{-6}$
BB	236.39	1	236.39	1.43	0.2371
Total error	9439.22	57	165.60		
Total (corr.)	50054.00	63			

In addition, these results are represented graphically in the main effects plot given by Fig. 2 and Fig. 3. As can be observed, Sm tends to increase if current intensity and pulse time increase. According to that, it was found that experiments whose values of Sm were the lowest, were performed at the lowest value of current intensity (2 A) and low values of pulse time (25 µs and 50 µs). In the case of positive polarity Sm was 60.60 µm whereas for negative polarity it was 76.20 µm.

However, as these factors increase, Sm also increases, as can be found in experiments with the highest Sm value whose values of current intensity and pulse time increased up to 8 A and 100 µs. In this case, Sm values were 168.40 µm and 195.80 µm, respectively, for positive and negative polarities. Moreover, as shown, it should be noted that the results obtained with negative polarity are slightly higher than those obtained with positive polarity. Therefore, when a good surface finish is required, the use of positive polarity is recommended.

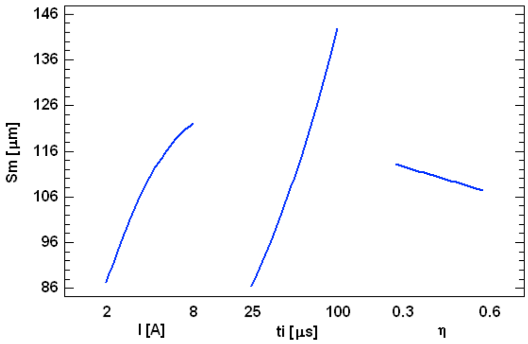

Fig. 2. Main effects plot for Sm with positive polarity.

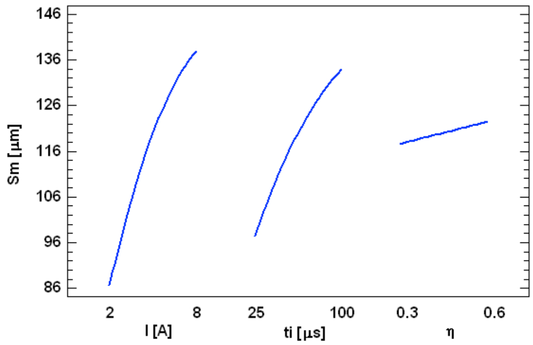

Fig. 3. Main effects plot for Sm with negative polarity.

In the case of Sm and positive polarity, R^2 and R^2_{adj} values are 91.11 % and 90.00 % while for negative polarity the values of R^2 and R^2_{adj} are 81.14 % and 79.16 %. The equations of the adjusted model for Sm are given in Eq. (1) for positive polarity, and in Eq. (2), for the negative one.

$$Sm = 45.4875 + 5.4411 * I + 0.7970 * t_i - 33.1875 * \eta - 0.6320 * I^2 + 14.8525 * I * \eta + 0.0031 * t_i^2 - 0.9566 * t_i * \eta \tag{1}$$

$$Sm = 48.2006 + 8.7472 * I + 0.2019 * t_i + 16.0125 * \eta - 0.8555 * I^2 + 0.1333 * I * t_i - 0.0031 * t_i^2 \tag{2}$$

3.2. Results and analysis of Pc

Table 4 and Table 5 depict ANOVA tables for Pc and for positive and negative polarities, respectively. In the case of positive polarity, pulse time, current intensity, the quadratic effect of current intensity, the interaction effect between current intensity and pulse time and, finally, the interaction effect between current intensity and duty cycle, have significant effect in Sm. Also, in the case of negative polarity, four effects are statistically significant. These effects are: current intensity, pulse time, the interaction effect between current intensity and pulse time and, the quadratic effect of current intensity.

Table 4. Analysis of variance for positive polarity of Pc.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
A: Current intensity	10832.20	1	10832.20	204.47	$3.56\cdot10^{-20}$
B: Pulse time	18963.60	1	18963.60	357.96	$9.60\cdot10^{-26}$
C: Duty cycle	196.88	1	196.88	3.72	0.0591
AA	1415.64	1	1415.64	26.72	$3.38\cdot10^{-6}$
AB	1366.41	1	1366.41	25.79	$4.68\cdot10^{-6}$
AC	866.41	1	866.41	16.35	0.0002
BB	143.40	1	143.40	2.71	0.1056
BC	70.31	1	70.31	1.33	0.2543
Total Error	2913.74	55	52.98		
Total (corr.)	36768.50	63			

Table 5. Analysis of variance for negative polarity of Pc.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
A: Current intensity	13652.90	1	13652.90	168.45	$1.16\cdot10^{-18}$
B: Pulse time	4308.58	1	4308.58	53.16	$1.04\cdot10^{-9}$
AA	1464.98	1	1464.98	18.07	0.0001
AB	1675.67	1	1675.67	20.67	$2.89\cdot10^{-5}$
BB	128.26	1	128.26	1.58	0.2135
BC	188.65	1	188.65	2.33	0.1326
Total error	4619.97	57	81.05		
Total (corr.)	26039.00	63			

Pc variable results are shown in Fig. 4 and Fig. 5, which represent the main effects plot for positive and negative polarities, respectively. As can be observed, results indicate that current intensity and pulse time are the two factors that most influence Pc for both polarities. In addition, their influence is the opposite to the one found in Sm. That is, Sm tends to increase when these factors are increased whereas Pc decreases. Low energy conditions are associated with small and numerous craters on the surface, hence low values of Sm and high values of Pc.

According to the previous example, Pc values of experiments with the highest values of Sm were 164.80 cm^{-1} and 131.40 cm^{-1}. In the case of experiments with the lowest values of Sm, the values of Pc decreased down to 74.40 cm^{-1} and 63.80 cm^{-1}.

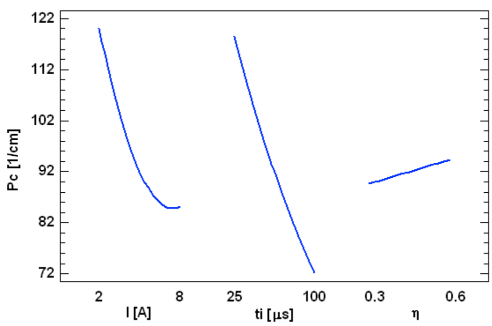

Fig. 4. Main effects plot for Pc with positive polarity.

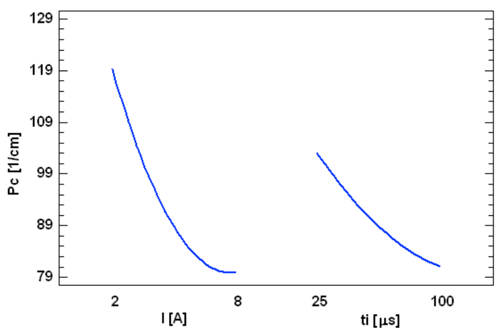

Fig. 5. Main effects plot for Pc with negative polarity.

In the case of Pc and positive polarity, R^2 and R^2_{adj} values are 92.08 % and 90.92 % while for negative polarity the values of R^2 and R^2_{adj} are 82.26 % and 80.39 %. The equations of the adjusted model for Pc and for both polarities are given in Eq. (3) and Eq. (4).

$$Pc = 190.6590 - 15.5737 * I - 1.4358 * t_i + 68.3125 * \eta + 1.1758 * I^2 + 0.0739 * I * t_i - 14.7175 * I * \eta + 0.0024 * t_i^2 + 0.3354 * t_i * \eta \quad (3)$$

$$Pc = 168.5020 - 13.3759 * I - 0.4146 * t_i - 34.3375 * \eta + 1.1961 * I^2 - 0.0819 * I * t_i + 0.0023 * t_i^2 + 0.5494 * t_i * \eta \quad (4)$$

4. Conclusions

In this study, the influence of EDM electrical parameters such as current intensity, pulse time and duty cycle on spacing roughness parameters Sm and Pc while machining an Inconel®600 alloy has been investigated. From this study, the following conclusions may be drawn:

ANOVA results show that current intensity and pulse time are the most influencing parameters that significantly affect the spacing roughness parameters at a confidence level of 95 %. In addition, their influence is the opposite: Sm tends to increase when these factors are increased whereas Pc decreases. Low energy conditions are associated with small and numerous craters on the surface, hence low values of Sm and high values of Pc.

Positive polarity is found to be the most suitable polarity when a very good surface finish is required to be obtained. In this case, the lowest values of both current intensity and pulse time should be selected.

Current intensity of 2 A, pulse time of 25 μs, duty cycle of 0.5 and positive electrode polarity are selected as the best machining conditions in order to obtain the lowest surface roughness. In this case, the optimized values of Sm and Pc are 60.60 μm and 164.80 cm^{-1}, respectively.

References

[1] P.G. Benardos, G.C. Vosniakos, Int. J. Mach. Tool Manuf. 43 (2003) 833-844.
[2] M. Kiyak, O. Çakir, J. Mater. Process. Technol. 191 (2007) 141-144.
[3] UNE-EN ISO 4287:1999, Especificación geométrica de productos (GPS).Calidad superficial: Método del perfil. Términos, definiciones y parámetros del estado superficial. AENOR, Madrid 1999.
[4] UNE-EN ISO 4287:1999/A1: 2010, Especificación geométrica de productos (GPS). Calidad superficial: Método del perfil. Términos, definiciones y parámetros del estado superficial. Modificación 1: Número de picos. AENOR, Madrid 2010.
[5] M.K. Das, K. Kumar, T.K. Barman, P. Sahoo, Proc. Eng. 64 (2013) 446-455.
[6] T. Sultan, A. Kumar, R.D. Gupta, Int. J. Manuf. Eng. (2014) doi:10.1155/2014/259129.
[7] M. Kiyak, O. Çakir, J. Mater. Process. Technol. 191 (2007) 141-144.