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Optimization of The Surface Roughness During The Electrical Discharge Machining of Tool Steel Alloy DIN 1.2080

Abdullatif Mehemed Gohman[1], Imad Mokhtar Mosrati[2,*], Abdurahim A. Sakeb[3], Wannes Abraheem Shabeesh[4]

[1]Mechanical and Industrial Engineering Department, Faculty of Engineering, Azzaytuna University, ben_guhman@azu.edu.ly
[2]Mechanical and Industrial Engineering Department, Faculty of Engineering, Azzaytuna University, imadmokhtar@yahoo.com
[3]Mechanical and Industrial Engineering Department, Faculty of Engineering, Azzaytuna University, abdurahimsakeb@gmail.com
[4]Higher Institute of Engineering Technology, Zliten,wanissh@yahoo.com

ABSTRACT

This study used an experimental methodology to improve the input parameters and outputs of the electrical discharge manufacturing process for the purpose of improving the metal surface roughness (Ra) as a measure of the process performance during machining of DIN 1.2080 alloy steel. Tagushi method is utilized as design and optimization approach. Four input parameters are considered, which are electrode diameter (D), discharge current (Ip), pulse on time (Ton) and the operating factor (η). Signal to noise ratio is used as an analytical tool. Through the final results of the adopted optimization methodology, the optimum values of the inputs were obtained as follows: electrode diameter at level1 (15mm), discharge current at level1 (9A), pulse on time at level2 (1200µs) and duty factor at level2 (0.8), the value of the surface roughness decreases by 2.05 times at the optimized process parameters than the initial process parameters, whereas it is decreased from 6.30 µm to 3.07 µm. Taking into consideration the standard (smaller is better). The results of the main effect diagram indicated that the factors: electrode diameter, and discharge current were the most important parameters influencing the surface roughness, followed by pulse on time, and duty factor.

Keywords:
Electrical discharge machining process.
Tagushi design and optimization method
Surface roughness.

*Corresponding Author Email: imadmokhtar@yahoo.com

1. INTRODUCTION

Electrical discharge machining (EDM) referred as spark machining, it is a non-traditional manufacturing process between a tool called electrode and the workpiece in the presence of a dielectric fluid. Nowadays, EDM is widely used in the industrial field to produce high complicated parts such as in automotive and aerospace.

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This process is done by applying high-frequency current to the sample, which melts the material, the electrode does not touch the workpiece, but potential current is discharged through a dielectric fluid across a very small gap. "The spark is reported to be up to 12000°C, this process is used when the workpiece material is hard, and the shape is not easy to machine using traditional manufacturing processes" [1]. Applying optimal parameters setting is very important before starting the EDM machining process to get the best results of the surface roughness; this reduces the production cost and developing the product's quality. The basic principle of the electric discharge machining, that material is removed from the workpiece through melting and vaporization of material, sparks are generated between electrode and sample, high temperatures are formed due to the sparks occur between the two surfaces. Workpiece material melts and vaporizes and it is carried away from the gap by the dielectric flow.

In this way several sparks occur until the tool surface shape is formed in the workpiece as shown in figure 1. Finally, the tool shape is formed on the workpiece [2]. There are a lot of applications of EDM in the industry like automotive industry, such as: cylinders, gears, and many other engine parts are obtained from EDM technology [3].

The important process parameters which influence the responses are: electrical parameters (generator power supply produces the pulse current at the machining gap [4]. Voltage (V) that depends on the electrode gap. pulse-on time (Ton) It is the time during which actual machining takes place and it is measured in µs. Reference [5] investigated the effect of the electrical parameters on EDM outputs, and developed a significant regression model, it is found that pulse on time and discharge current have a significant effect on EDM responses. Also there are non- electrical parameters affect the EDM process, such as: electrode material must be good electrical conductors. Commonly used materials include graphite, copper, copper-graphite alloys. All EDM electrode materials must possess certain properties in order to perform economically in a given application [6]. Another important non electrical factor is dielectric fluid, It is applied at machining medium for cooling and to remove the melting material away from machining zone.

Responses of the EDM process are the performance measures used to evaluate the efficiency of the process, this article investigated and optimized the surface roughness Ra as performance response using Tagushi approach. Ideal surface roughness may be specified in various ways, but the common method is the 2D arithmetic average method, Ra (µm), The Ra value is obtained by averaging the height of the surface above and below the center line, some scratches by the tool are gnereted. however 3D method could be used as well. Refer to [7] a study to optimize the process parameters in machining of 6061Al metal using wire electrical discharge machining was introduced, four input process parameters, voltage, pulse-on time, pulse-off time, and wire feed rate, were picked as factors to study the surface roughness. It is discovered that the voltage and wire feed rate are highly significant factors and pulse off time is not significantly.

In [8] surface roughness Ra model was built up for the parameters of current and electrode type. It is found the current has very significant impact on roughness.

The changes of product surface during the EDM process have been studied by many researchers, The thermal effect may also cause cracks and stresses in the top surface. EDM has great advantages, the most important one is ability of machining complicated product shapes, regardless of material strength and hardness, but reducing Ra is a big challenge [9].

Taguchi design and optimization method is known as a widely used tool for the improvement of quality, compared to classical experimental design, taguchi method makes the design of the experiments to achieve the desired product quality. The Taguchi method uses signal-to-noise ratio (S/N) to turn the trials result data into a value of the characteristics to analyze them. The S/N reflects both the average and the variety of the quality characteristics. The standard S/N ratios generally used as follows: larger-the-better, smaller-the-better and nominal-the-best. The optimal setting in this article is the parameter combination, which has the smallest S/N ratio, in this study, smaller-the-better way is used to optimize Ra.

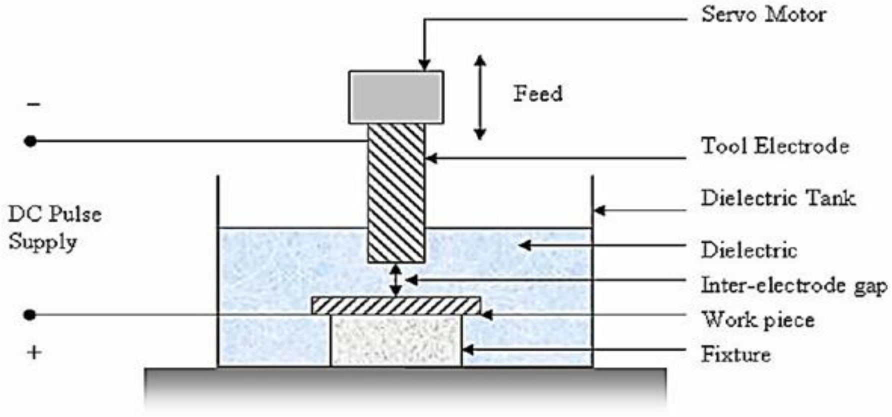

Figure 1. EDM Process

2. Materials and Methods

In this study the experimental work was performed, the experimental setup, selection of the workpiece material, and design of experimental process are selected. Surface roughness is measured using ALPA-SMRT20 device. A series of experiments on the EDM machine for tool steel (DIN 1.2080) was conducted to study and examine the effects of the input machining parameters; current Ip, pulse on time Ton, duty factor η, and electrode diameter D on the output variable Surface Roughness Ra. Charmilles Roboform FORM 2-LC EDM die sinking machine was used for experiments as shown in figure 2.

Figure 2. Charmilles Roboform 2-LC Electrical Discharge Machine.

The workpiece material used in this study was tool steel (DIN1.2080) alloy, chemical composition is shown in table 1. A Three shafts (Ø 25 mm x 31 mm length), (Ø 20 mm x 31 mm length) and (Ø 15 mm x 31 mm length), with nine pieces for each shaft were used.

Table1. Chemical Composition.

Elements	C	Si	Mn	Cr	Mo	V	Ni
Composition	2.2	0.42	0.32	12.25	0.03	1	0.3

The electrode materials used in this research were copper, three shaft bars at different diameters are used, (Ø 30 mm x 71 mm length), (Ø 20 mm x 71 mm length) and (Ø 15 mm x 71 mm length)**.** The dielectric fluid has been used is mineral kerosene. The surface roughness Ra is measured to evaluate machining performance as shown in figure 3.

Figure 3. Surface Roughness Device.

The Taguchi and signal to noise ratio approach is used to design the experiments and to establish optimum process settings. Analysis of variance ANOVA is performed to analyze the effect of input parameters on the surface roughness, minitab software is utilized for this purpose. Four input parameters are chosen in this study: electrode diameter, current, pulse on time, and duty factor, each parameter has three levels, as shown in table2.

Table 2. Control Factors and Their levels.

Controllable Factors	Factors Designation	Levels		
		Level 1	Level 2	Level 3
Electrode Diameter	D	15	20	25
Current	Ip	9	16	25
Pulse on time	Ton	300	1200	2400
Duty Factor	η	0.65	0.8	0.9

In this work, an L9 orthogonal array is used, the experimental layout for the machining factors are shown in table 3. The experimental setting is shown in table 4.

Table 3. Experimental layout using an L9 standard orthogonal array.

Experiment No.	Factor A Electrode Diameter	Factor B Current	Factor C Pulse on	Factor D Duty Factor
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

An EDM machine (FORM 2-LC) was used in this study, experiments were run, machining time for each run in the experiments was 45 minutes and each experiment is repeated three times, the surface roughness was measured in each experiment

Table 4. Experimental setting

Experiment No.	A Electrode Diameter	B Current	C Pulse on Time	D Duty Factor
1	15	9	300	0.65
2	15	16	1200	0.80
3	15	25	2400	0.90
4	20	9	1200	0.90
5	20	16	2400	0.65
6	20	25	300	0.80
7	25	9	2400	0.80
8	25	16	300	0.90
9	25	25	1200	0.65

3. RESULTS

After finishing all experiments, Ra was measured in each run, table 5 shows the results.

Development of the surface roughness (Ra) regression model: through the obtained data, the model for surface roughness (Ra) was developed using linear regression. The surface roughness was the dependent variable, the independent variables are electrode diameter, pulse on time, current, and duty factor. The data were analyzed by minitab 16 software. The adequacy of model has been checked using correlation coefficients (R^2). Developed model can be used to predict values of surface roughness. A regression analysis is applying the least squares method to the experimental data to obtain the coefficients of the model, the following equation (1) is attained for surface roughness Ra.

$$Ra = -0.645 + 0.317Di + 0.4411\ Ip - 0.000567\ Ton + 0.98\eta \quad (1)$$

Correlation coefficient R2 =96.6%, R2(adj) =93.1%, S = 0.906388

Table 5. Results for surface roughness (Ra)

Run No	Sample No	Ra (µm)	Average Ra (µm)
1	A1	3.3	3.32
	B1	3.2	
	C1	3.5	
2	A2	4.8	4.96
	B2	5.1	
	C2	5	
3	A3	9.5	9.53
	B3	9.4	

	C3	9.7	
4	A4	3.4	3.54
	B4	3.6	
	C4	3.6	
5	A5	6.3	6.30
	B5	6.9	
	C5	5.8	
6	A6	10.5	10.5
	B6	10.4	
	C6	10.6	
7	A7	4.7	4.56
	B7	4.4	
	C7	4.6	
8	A8	10.3	10.21
	B8	10.1	
	C8	10.3	
9	A9	12.4	12.56
	B9	12.6	
	C9	12.7	

ANOVA is useful for identifying the level of significance of the developed model. If the p-value of a term appears less than 0.05 (for 95% confidence level) then it is concluded that the model is significant. The result of ANOVA is shown in table 6. From Anova table regression is significant because p-value is less than 0.05. The regression model presented high determination coefficient (R^2= 96.6%) which indicates goodness and high significance of the model.

Table 6. Analysis of variance for Ra model.

Source	DF	SS	MSS	F	P	Remarks
Regression	4	92.474	23.119	28.14	0.003	Significant
Residual Error	4	3.286	0.822			
Total	8	95.760				

Optimization of surface roughness (Ra): To optimize the process parameters and the output response, the experimental results are transferred to signal-to-noise ratio (S/N ratio), to measure the quality characteristics deviating from the desired values. Signal-to-noise ratio for surface roughness (Ra) is calculated with consideration of smaller-is-better (SB) characteristics according to equation (2). Experimental results and their corresponding S/N ratio are shown in table 7. The S/N ratio for each level of process parameters was calculated, the optimal combination of process parameters for the response has been predicted.

The formula for the smaller-is-better S/N ratio using base 10 log is:

$$S/N = -10*\log(\Sigma(Y2)/n) \qquad (2)$$

Where Y = responses for the given factor level combination and n = number of responses in the factor level combination.

Table 7. Experimental Results and S/N for Ra.

Run No	Ra (µm)	S/N Ra
1	3.32	-10.4228
2	4.96	-13.9096
3	9.53	-19.5819
4	3.54	-10.9801
5	6.30	-15.9868
6	10.57	-20.4815
7	4.56	-13.1793
8	10.21	-20.1805
9	12.56	-21.9798

The mean S/N response table for surface roughness is shown in table 8.

Figure 4 shows the main effects on surface roughness, it is clear that the parameters: discharge current and electrode diameter have a significant effect, pulse on time and duty factor are found to be less significant. Optimal results could be got from the main effect plot, selecting the smallest levels of S/N ratio values. Therefore, based on the S/N analysis, the optimal process parameters for the surface roughness are as follows: electrode diameter at level1 (15mm), discharge current at level1 (9A), pulse on time at level2 (1200µs) and duty factor at level2 (0.8) i.e Di1-Ip1-Ton2-η2.

Table 8. Mean S/N ratio for Ra.

Symbol	Process parameters	Mean S/N ratio				
		Level 1	Level 2	Level 3	Max-Min	Rank
Di	Electrode Diameter	**-14.64**	-15.82	-18.45	3.81	2
Ip	Discharge Current	**-11.53**	-16.69	-20.68	9.15	1
Ton	Pulse on	-17.03	**-15.62**	-16.25	1.41	3
η	Duty Factor	-16.13	**-15.86**	-16.91	1.06	4
					Total mean S/N ratio = -16.3002	

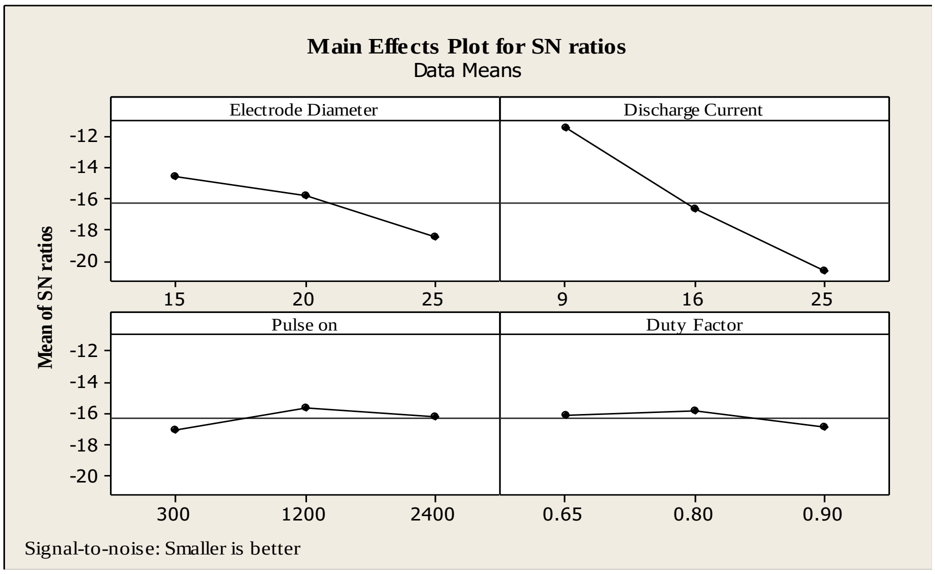

Figure 4. Main effect plot for S/N ratio Ra.

Conformation experiment has been carried out to verify the improvement of the response using the optimal combination of the process parameters. Results of conformation experiment using the optimum process parameters and initial process parameters are shown in table 9. Good agreement was found between predicted and experimental values. The improvement of S/N ratio from the initial process parameters to the optimal process parameters is 6.224 dB. Based on the results of the confirmation test, the surface roughness is decreased by 2.05 times.

Table 9. Results of confirmation experiment for Ra.

Level/Response	Initial process parameters	Optimal Process Parameters	
		Prediction	Experimental
Level	Di2-Ip2-Ton3-η1	Di1-Ip1-Ton2-η2	Di1-Ip1-Ton2-η2
Surface Roughness [µm]	6.30	2.74	3.07
S/N Ratio [dB]	-15.9868	-8.7447	-9.7427
Improvement of S/N Ratio		6.244	

4. CONCLUSIONS

Taguchi's design and optimization methodology are utilized for minimizing the surface roughness during EDM machining of DIN 1.2080. From the study results, it is concluded that: based on ANOVA analysis, the developed regression model is statistically significant. According to the S/N analysis and the main effect plot, current and electrode diameter have the greatest effect on surface roughness, pulse on time and duty factor has less effect, the optimal process parameters are as follows: electrode diameter at level1 (15mm), discharge current at level1 (9A), pulse on time at level2 (1200µs) and duty factor at level2 (0.8) i.e Di1-Ip1-Ton2-η2. Where the value of the surface roughness is decreased 2.05 times at the optimized process parameters than the initial process parameters, whereas it is decreased from 6.30 µm to 3.07 µm.

5. REFERENCES

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تحسين خشونة السطح اثناء التشغيل بالتفريغ الكهربائي لسبيكة صلب الفولاذ (DIN1.2080)

عبداللطيف قحمان[1,*]، عماد المصراتي[2]، عبدالرحيم ساكيب[3]، ونيس شابيش[4]

[1] جامعة الزيتونة، كلية الهندسة، قسم الهندسة الميكانيكية والصناعية، ليبيا، *ben_guhman@azu.edu.ly*
[2] جامعة الزيتونة، كلية الهندسة، قسم الهندسة الميكانيكية والصناعية، ليبيا، *imadmokhtar@yahoo.com*
[3] جامعة الزيتونة، كلية الهندسة، قسم الهندسة الميكانيكية والصناعية، ليبيا، *abdurahimsakeb@gmail.com*
[4]المعهد العالي للتقنية الهندسية زليتن ، ليبيا ،*Wanissh@yahoo.com*

الملخص

استخدمت هذه الدراسة منهجية تجريبية لتحسين مدخلات ومخرجات عملية التصنيع بالتفريغ الكهربائي لغرض تحسين خشونة السطح المعدني (Ra) كمقياس لأداء العملية أثناء تشغيل سبائك الصلب نوع DIN 1.2080. تم استخدام طريقة تاقوشي للتصميم والتحسين. أربع مدخلات تم اخدها في الاعتبار، وهي قطر الالكترود (D) ، تيار التفريغ (Ip) ، زمن النبض (T) وعامل التشغيل (η). تم استخدام نسبة الإشارة إلى الضوضاء كأداة تحليلية. من خلال النتائج النهائية لمنهجية التحسين المعتمدة. تم الحصول على القيم المثلى للمدخلات على النحو التالي: قطر الالكترود عند المستوى 1 (15 مم) ، تيار التفريغ عند المستوى 1 (A9) ، زمن النبض عند المستوى 2 (µs1200) وعامل التشغيل عند المستوى 2 (0.8). تقل قيمة خشونة السطح بمقدار 2.05 مرة عند القيم المحسنة للمدخلات عن القيم الأولية ، حيث انها انخفضت من 6.30 ميكرومتر إلى 3.07 ميكرومتر. أشارمخطط التأثير الرئيسي إلى أن العوامل: قطر الالكترود، وتيار التفريغ كانا من أهم العوامل المؤثرة على خشونة السطح ، يليها زمن النبض، وعامل التشغيل.

الكلمات الدالة :
عملية التصنيع بالتفريغ الكهربائي.
طريقة تاقوتشي للتصميم والتحسين.
خشونة السطح.

[*]البريد الإلكتروني للباحث المراسل: ben_guhman@azu.edu.ly