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Effect and Optimization of various Machine Process Parameters on the Surface Roughness in EDM for an EN41 Material using Grey-Taguchi

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Abstract

The article presents an idea about the effect of the various input process parameters like Pulse ON time, Pulse OFF time, Discharge Current and Voltage over the Surface Roughness for an EN41 material. Here, 5 different output parameters concerned with surface roughness like R_a, R_q, R_{sk}, R_{ku} and R_{sm} are taken and optimized accordingly, using the Grey-Taguchi method. The Grey-Taguchi method used in the article considers an L_{27} orthogonal array, which uses a different combination of the 4-input parameters to obtain an optimized value of the surface roughness for EN41 material. The 5 different output values of the surface roughness are calibrated into a single value (i.e. Grade) by calculating their normalized, Δ and ξ values .On the basis of their Grade, the S/N ratio is obtained and accordingly the ANOVA table is generated. It was found that the Current had larger impact over the Surface Roughness value, followed by the Voltage. The experimental results thus, obtained were compared with the theoretical results and they were found very close to one another.

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Keywords: EN41; EDM; Surface Roughness;Grey-Taguchi.

1. INTRODUCTION

The existence of the increased competition among the different countries to meet the technological advances and the creation of the new and different military equipments, led to the creation of different hard materials which were

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difficult to machine. To meet these growing advances, it was very much necessary to create certain machining equipments, which can be easily used to machine such materials. This very requirement was met during the 2nd world war, as indicated by E. C. Jameson (2001), by the USSR and USA individually, by the development of the Electro-Discharge machine (EDM). The EDM machine since then has got continuously modified to control the amount and the direction of sparks produced from the EDM machine. The EDM machine consists of a closed chamber, where the continuous spark is used to machine the work-piece material in the presence of a suitable dielectric medium, usually Paraffin oil. The work-piece i.e. EN41 material is of positive polarity, while the tool i.e. copper is of negative polarity.

The Surface Roughness plays a very important role for any manufacturing work in order to identify the extent of the surface finish with reference to time and cost. A number of experimental works has been carried out till date for the investigation of the effect of the different parameters over the surface roughness value for different materials. B.Jabbaripour et al (2012) carried out an investigation over the effect of pulse current, pulse on time and open circuit voltage over the surface roughness for Ti-6Al-4V alloy material. They found out that the Pulse current and the Pulse On time had larger significance over the surface roughness. Another investigation was carried out by M.K. Das et al (2013) to find out the effect of different input parameters over the MRR and surface Roughness in EDM using the WPCA approach. It was found out that the Current followed by the Voltage had larger impact over the multi-optimization of MRR and surface roughness. Another approach regarding the surface roughness optimization was carried out by S Aravind Krishnan et al (2012) to optimize MRR and Surface roughness in wire Electrical discharge turning operation using artificial neural network approach. Pulse of time, spark gap, servo feed, flushing pressure and Rotational speed were selected as the input parameters to optimize the surface roughness and MRR simultaneously. Similar work was carried out by Adeel Ikram et al (2013), where surface roughness, kerf and MRR were optimized simultaneously using Taguchi design in wire electrical discharge machining for tool steel D2. Wire feed velocity, pressure, pulse on time, pulse off time, open voltage, servo voltage and wire tension were taken as the input parameters to optimize the multi output parameters. It was found that the pulse on time had a larger effect over the multi-output optimization. Many other experimental works related with this field was carried in the recent years. Manish Vishwakarma et al (2012) carried out the effect of 5-different input parameters like input current, pulse time, duty cycle, gap voltage and flushing pressure over the surface roughness for an EN19 material. They found out that the flushing pressure had least affect over the output parameters. The other parameters had significant effect. U. Esme et al (2009) also carried out an experiment for the optimization of surface roughness. He considered pulse duration, wire speed, voltage and flushing parameters as the input parameters for obtaining the effect over the surface roughness in EDM for AISI 4340 material. He used both the Artificial neural network approach and the Taguchi design of experiment for the process.

Nomenclature

C1	Pulse-On time
C2	Pulse-Off time
C3	Discharge Current
C4	Voltage
R_a	Arithmetic average of absolute values
R_q	Root Mean Squared
R_{sk}	Skewness
R_{ku}	Kurtosis
$X_i(s)$	Normalized Formula for Surface Roughness based on Lower the better condition
Δ	Absolute difference
ξ	Grey relational coefficient

2. EXPERIMENTAL DETAILS

The entire experiment was carried out in a CNC Die sinking EDM (EMT 43 – Electronica Machine Tools) machine, which used paraffin oil as the dielectric medium. Moreover, a rectangular shaped tool made of copper material of size 25 X 25 mm size was taken to perform the experiment. Copper because of its high electrical conductivity was considered as most suitable material for carrying out the experiment. The work-piece on which the surface roughness was calculated was a cylindrical EN41 material of dimension φ25mm X 15mm. The chemical composition of the work-piece i.e. EN41 material and the tool material i.e. Copper was obtained by EDX (JSM 63901v, Resolution=3nm at 30kV at high vacuum mode and 4nm at 40 kV low vacuum mode).

Here, the 4-input parameters i.e. Pulse ON time, Pulse OFF time, Current and Voltage were considered and coded as C1,C2,C3 and C4 with each of these input variables having 3 values ,termed as the levels (shown in Table 1). On the basis of these different values for the input parameters, the design of experiments table was constructed and accordingly the experimentation was conducted.

Table 1: Input parameters along with their levels and Codes

Input-Parameters	Coding	Level		
		1	2	3
Pulse ON Time(T_{on})	C1	200	300	400
Pulse OFF time (T_{off})	C2	2300	2200	2100
Discharge current (I_p)	C3	8	16	24
Gap voltage (V)	C4	40	60	80

After the machining operation, the surface roughness was carried out using a stylus type profilometer, called Talysurf (Taylor Hobson, 3+) to find out the surface roughness for the EN41 material. A traverse speed of 1mm/sec, cut off length of 0.8 mm and an evaluation length of 8 mm were set for the stylus to work. A set of 3-different readings were calculated for the different values of the surface roughness and the average of these values were obtained.

3. RESULTS AND DISCUSSION

3.1 Grey Taguchi Approach

The Grey Taguchi Approach is generally an advanced form of the Taguchi method, which emphasizes on the optimization of more than one output parameters, rather than optimizing a single output parameter as in case of the Taguchi method. The Taguchi method developed by Genichi Taguchi (1990) was the most important statistical tool for the optimization of the single output parameter. It considers a set of different number of input parameters, may it be an L_{27} orthogonal array or an L_9 orthogonal array depending upon the degree of accuracy needed. The number of experiments chosen in the article is a L_{27} orthogonal array comprising of the different combinations of the input parameters. The Taguchi design of experiment, as described by Jiju Antony (2001) and P. J. Ross (1996), finds a larger use than any other traditional modern method as it captures the variability of the different results, rather than finding out the average. Moreover, the result of S/N ratio (Montgomery (2001)) is least effected by any outside disturbances. A set of 5-output parameters of the surface roughness, namely R_a, R_q, R_{sk}, R_{ku} and R_{sm} are considered and converted into a single output parameter, called the Grade. The calculation of the grade requires the calculation of the normalized, Δ and Grey relational coefficient (ξ) values for each of the 5-output parameters of the surface roughness. The average of the grey relational coefficient (ξ) values for each of the 5-output parameters of the surface roughness gives the value of the grade of the entire output parameters. Based on the grade calculated, the corresponding S/N ratio is obtained through the Minitab 16 software.

$$\text{S/N ratio} = -10 \log \left(\frac{1}{n} \sum_{i=1}^{n} y2 \right) \tag{1}$$

$$Xi(s) = \frac{\max\ Yi\,(s) - Yi(s)}{\max\ Yi(s) - \min Yi(s)}, \tag{2}$$

where, Max $Y_i(s)$ is the maximum value of the Y_i for the S_{th} response and Min $Y_i(s)$ is the minimum value for the S_{th} response. Here, the value of ' i' varies from 1 to 27.

$$\Delta = 1\text{- Normalized value of the surface Roughness} \tag{3}$$

And,

$$\xi = \frac{\Delta\min + \psi\Delta\max}{\Delta oi(s) + \psi\Delta\max}, \tag{4}$$

Where, Δ_{min} and Δ_{max} are the minimum and maximum values of the absolute differences,
While, the Δ_{oi} is the absolute difference between $\Delta_o(S)$ to $\Delta_i(S)$. ψ is the distinguishing coefficient, whose value varies from 0 to 1 and is generally considered to weaken the effect of larger value of Δ_{max} .In the present article, it is taken to be 0.5.

Table 2: Experimental Results

Exp no	R_a	R_q	R_{sk}	R_{ku}	R_{sm}	Grade	S/N ratio	Rank
1	9.41	11.2	0.26	2.47	0.24	0.76873	2.284527	3
2	11.6	14.13	0.3	3.02	0.25	0.600165	4.434587	11
3	11.65	13.97	0.5	3.08	0.25	0.570001	4.882495	16
4	8.49	10.6	0.39	3.2	0.22	0.749423	2.505462	4
5	14.43	17.17	0.45	2.33	0.26	0.58702	4.626949	13
6	11.41	14.17	0.73	4.1	0.29	0.48456	6.293051	24
7	10.53	12.93	0.59	3.18	0.21	0.638558	3.895999	6
8	10.71	12.97	0.37	4.48	0.23	0.585037	4.656338	14
00	13.77	16.8	0.78	3.66	0.27	0.450888	6.918635	27
10	10.67	12.57	0.2	2.51	0.27	0.695892	3.149166	5
11	14.63	17.33	0.21	2.39	0.25	0.62209	4.122932	8
12	15.8	18.77	0.18	2.67	0.3	0.544326	5.282819	19
13	9.87	12.27	0.03	2.7	0.23	0.792093	2.024472	1
14	14.57	17.43	0.54	2.71	0.24	0.538836	5.370867	20
15	13.27	16.27	0.48	3.01	0.26	0.524299	5.608427	21
16	9.46	12.13	0.66	3.7	0.24	0.607931	4.322909	9
17	16.27	19.2	0.21	2.97	0.3	0.504456	5.943534	23
18	15.9	19.43	-0.07	2.86	0.28	0.569306	4.893086	17
19	10.23	12.77	0.23	2.83	0.19	0.769382	2.277155	2
20	15.23	17.97	-0.13	2.5	0.3	0.589228	4.594331	12
21	14.97	18.57	0.54	3.06	0.23	0.51009	5.847067	22
22	11.17	13.67	0.32	3.04	0.26	0.600513	4.429547	10
23	19.6	23.67	0.48	2.95	0.24	0.46413	6.667215	26
24	13.3	16.67	0.31	3.08	0.25	0.547189	5.237258	18
25	11.07	13.6	0.44	3.62	0.2	0.633428	3.966053	7
26	16.2	19.73	0.3	3.01	0.32	0.472642	6.509363	25
27	16	19	0.2	3.13	0.21	0.577771	4.764879	15

The grade in the table 2 signifies the closeness of the combination of the different parameters close to the optimal parameter. The value of the grade is calculated as:

$$\text{Grade}=\gamma_i = \frac{1}{n}\sum \xi_i(S), \text{ from 1 to n} \quad (5)$$

Now, the response table is obtained using the Minitab 16 software (Minitab User Manual Release 13.2, 2001), where the rank of each of the input parameters is signified. The rank of the input parameter signifies the impact of the input parameters over the surface roughness value. From the table, it can be easily seen that the Input current had larger impact over the surface roughness followed by T_{off} and voltage respectively. While, the delta value is the difference between the highest average for each factor and the lower average for the same factor. The Response table for the mean of the mean of Grey relational grade is shown below in table 3.

Table 3: Response Table for Grey relational grade

Level	C1	C2	C3	C4
1	0.6038	0.5600	0.6951	0.5885
2	0.5999	0.5876	0.5515	0.5703
3	0.5738	0.6300	0.5309	0.6187
Delta	0.0300	0.0700	0.1642	0.0484
Rank	4	2	1	3

Now, the different plots were obtained using the Minitab 16 software indicating the effect of each of the input parameters individually on the surface roughness values. The curve showing larger amount of inclination is the most significant curve, while the curve being horizontal to the mean line has less significant effect over the surface roughness. From the figure 1, it can be easily find out that the discharge current graph shows a larger inclination and hence is most significant, followed by the Pulse off time graph. Moreover, the interaction plots (figure 2) are plotted and their significance is obtained by seeing the interaction between the different curves. If the curve are not parallel and crosses each other, then a powerful interaction occurs and vice-versa. Here, the effect of the interaction is very small. The optimal value of surface roughness was found out at-[C1]3 [C2]1 [C3]3 [C4]2.

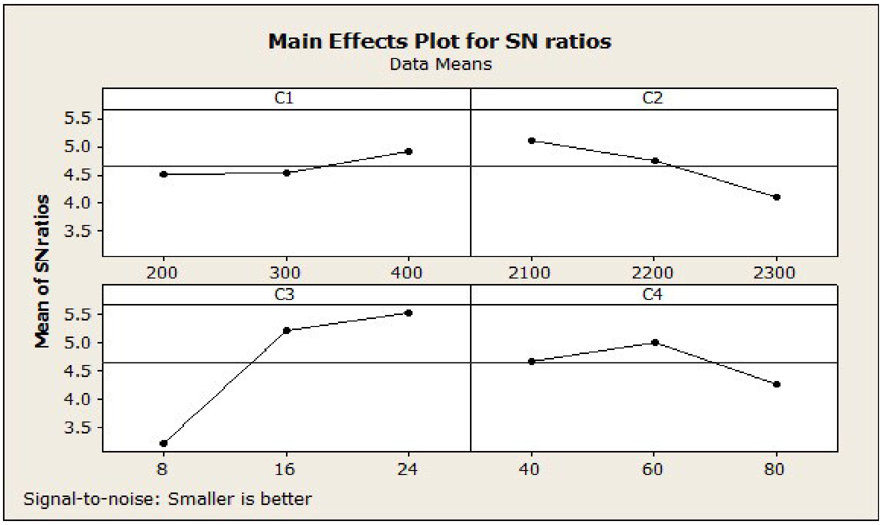

Fig 1: Main effect plot for S/N ratio

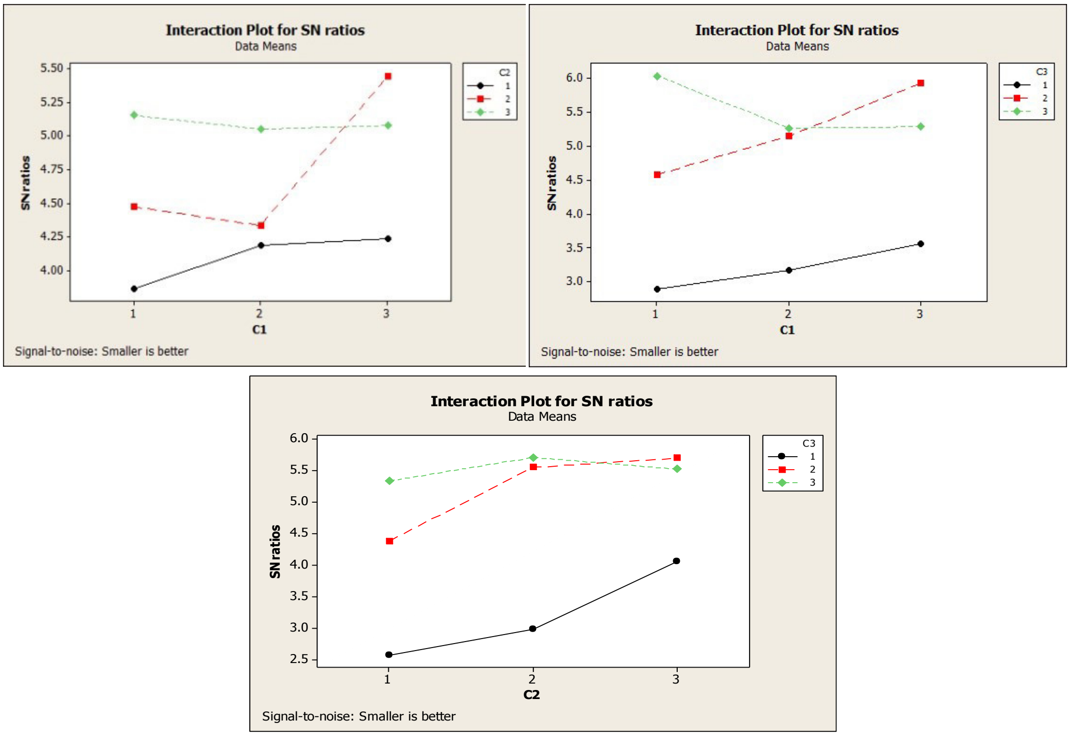

Fig 2: Interaction plot for S/N ratio

Now, the Analysis of Variance, also called the ANOVA table (Table 4) was generated to obtain the percentage contribution of the different parameters individually and along with their interaction over the Surface Roughness value. The F-ratio, also called the variance ratio was obtained from the Minitab 16 software. The F-ratio shows the effect of the process parameter over the surface roughness value. A higher value of the F-ratio signifies a larger impact and hence a larger contribution over the Surface roughness value. It was found out that the Input current had a larger impact over the Surface roughness value followed by the Pulse off time. The ANOVA table was generated at 95% confidence level.

Table 4: ANOVA table for Mean of Grey relational grade

Source	DF	Seq SS	Adj SS	Adj MS	F	% Contribution
C1	2	0.004789	0.004789	0.002394	0.87	2.40
C2	2	0.022374	0.022374	0.011187	4.08	11.23
C3	2	0.143982	0.143982	0.071991	26.26	72.30
C4	2	0.010750	0.010750	0.005375	1.96	5.40
C1*C2	4	0.008005	0.008005	0.002001	0.73	2.01
C1*C3	4	0.013169	0.013169	0.003292	1.20	3.30
C2*C3	4	0.013369	0.013369	0.003342	1.22	3.36
Error	6	0.016448	0.016448	0.002741		
Total	26	0.232886				100

Significant at 95 % confidence level (F0.05,2,6=5.14)
(F0.05,4,6=4.53)

4. CONFIRMATION TABLE :

A Confirmation table, as depicted in table 5, was obtained to compare the Experimental results with the predicted results. The predicted results were obtained by the formula:

$$\gamma = \gamma_m + \sum_{i=1}^{0}(\gamma i - \gamma m) \quad (6)$$

Where, γ is the optimal level of process parameter, γ_i is the mean value of S/N ratio and γ_m is the total mean S/N ratio and O is the number of main design parameter. From the table below, it can be easily seen that the experimental and the predicted values are very close to one another.

Table 5: Confirmation table

	Initial Parameter Combination	Optimal Parameter Combination	
Level	[C1]2 [C2]2 [C3]2 [C4]2	[C1]3 [C2]1 [C3]3 [C4]2	
Parameter		Experimental	Predicted
R_a	9.40	14.97	
R_q	11.23	18.57	
R_{sk}	0.26	0.54	
R_{ku}	2.48	3.06	
R_{sm}	0.21	0.23	
Grade	0.48613	0.51009	0.6675
Improvement of grey relational grade=0.18137			

5. CONCLUSION :

Thus, the present article concludes the effect of the different input parameters like Pulse ON time, Pulse OFF time, Discharge Current and Voltage over the surface roughness for an EN41 material. It was found out that the discharge current had a larger impact over the surface roughness parameter. The effect of the other parameters was significantly less and can be ignored. The interaction plots also showed negligible effect over the Surface Roughness value. The entire result was calculated at 95 % confidence level and the experimental value so obtained was found very close to the predicted value and hence, the entire work is validated.

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