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Surface Roughness Prediction Model for Machining O1 Die Steel Through EDM

Jai Prakash[1*], Ashish Agarwal[2], Vipin[3]

([1]Department of Production Engineering, G.B.P.I.T, Okhla, Delhi, INDIA
[2]Department of Mechanical Engineering, SOET IGNOU, Delhi, INDIA
[3]Department of Mechanical Engineering, DTU, Delhi, INDIA)

*Email:*jaiprakash2971@gmail.com

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Abstract :The objective of this paper is to generate a mathematical model in order to minimize the value of surface roughness (Ra) through EDM by constructing an objective function consisting of combination of process parameters. Taguchi orthogonal design method of experiments with three process parameters viz., current, pulse-on-rate, pulse-off-rate were used to generate 25 numbers of experiments L_{25} at five levels. Experiments were carried out in Electronica S50 (CNC) EDM. Data obtained for performance measurement was subjected regression analysis using ANOVA. Equation was obtained for the surface roughness as a function of current, pulse-on rate, pulse-off-rate.It is found that discharge current, pulse-on-rate, and pulse-off-rate have significant effect on the Ra. Higher values of current and pulse-on-rate increased surface roughness. Lower current, lower pulse-on-rate and relatively higher pulse-off-rate produced a better surface finish.

Keywords:Surface Roughness(Ra), Pulse-on rate (Ton), Pulse-off rate (Toff), current (I).

1. INTRODUCTION

EDM is a non-traditional manufacturing process. It is generally employed for machining hard electrically conductive materials by means of a series of repeated electrical discharges. Electrical energy is used to generate variable intensity spark between pre-determined gaps between workpiece and the electrode. This process results in the erosion of materials from the workpiece. It is important to note that the discrete gaps are prescribed through the designed mathematical model. EDM process is used to machine brittle, hard, difficult-to-machine materials and high strength temperature resistant alloys. As compared to traditional machining process, EDM usually take shorter time to produce piece of desired shape and closer dimensional tolerances. Since, no physical contact takes place between the electrode and workpiece, the process is well-suited for making precision dies, punches and plastics moulds.

M.Kiyak and O.Cakir; studied of the influences of EDM parameters on surface roughness for machining of 40CrMnNiMo864 tool steel (AISI P20). It was observed that surface roughness of workpiece and electrode were influenced by pulse current and pulse time. Pradhan M.K and Biswas C.K; made a response model using RSM with experimental data. The significant coefficients are obtained by performing analysis of variance. Yusuf Keskin et.al; performed experiment to identify parameters which affect surface roughness. Kun Ling et.al; observed that the surface roughness of the workpiece has improved by the addition of Al powder in the dielectric.Vikas et al.; optimized the value of the surface roughness for EN41 material by using Grey-Taguchi method. Y.H.Guu et.al.;deduced that surface roughness are proportional to the power input. Angelos P. Markopoulos et.al. used ANNs models to predict the surface roughness in EDM.K. M. Patel et.al. presented an experimental investigation of the influence of parametric setting on machining performance during EDM of $Al_2O_3/SiC_w/TiC$ ceramic composite. The surface roughness prediction model has been optimized using a trust region method. M.M. Rahman et al., developed a mathematical model for surface finish using response surface method (RSM) and evaluated an optimum machining setting in favour of surface finish. Murat Kiyak et. al.; to investigated and analyzed the effects of discharge energy density on the responses. I.Puertas et.al. carried out their study in cemented carbide 94WC–6Co to predict optimal machining conditions for finishing stages. M.K. Pradhan et.al. used response surface methodology (RSM) to investigate the effect of four controllable input variables namely: discharge current, pulse duration, pulse off time and gap voltage on surface roughness (Ra).

Review of Literature reveals an urgent need for predicting Ra in advance of machining stage for proper planning and execution of manufacturing activities related to EDM specially in case of O1 die steel which is widely used in manufacturing dies, punches and Plastics moulds. Therefore the present work is intended to develop a mathematical model in determining the Ra due to Machining done by EDM.
The experiments have been undertaken with O1 OHNS steel utilizing the copper electrode to generate the experimental data. The data so obtained have been use to predict the model of Ra in EDM process. Parametric investigation has been further carried out to understand the behaviour of various parameters on the Ra in EDM process.

2. EXPERIMENTAL SETUP

The experiments for the present case have been conducted on Spark erosion machine (Electronica S50 CNC) installed at G.B.Pant Engineering College, New Delhi. as shown in Fig.1. Ra was measured in micron with the help of Form Talysurf. The workpiece was O1 OHNS steel having hardness 62 HRC and Chemical composition C: 0.95%, Mn: 1.15%, Cr: 0.50%, V: 0.20% and rest Fe having hardness 62 HRC. Cylindrical electrode made from electrolytic copper of diameter 10 mm was used

Fig. 1: Electronica EDM (S50 CNC)

3. EXPERIMENTAL DESIGN AND CONDITION

Taguchi design method has been applied for designing the experimental procedure using five level orthogonal array design matrix. A three factor and five level setup was chosen with a total of twenty-five experiments were conducted and hence the OA L_{25} was chosen
The experiments were carried at room temperature. All the experiments were performed with EDM oil as a dielectric. The levels of independent variables and coding identifications are presented in Table 1.

Table 1:The levels of independent variables and coding identifications

Level	1	2	3	4	5
Factors					
Current(Amp)	1	1.5	2	3	6
Pulse on time	5	10	20	50	100
Pulse off time	16	20	20	20	26

The experiments were carried at room temperature. Based on Taguchi design matrix 25 experiments were carried out. Table 2 shows the experimental conditions together with the measured Ra values

Table 2 Experimental conditions together with the measured Ra values

Experiment No.	Taguchi Array L25(5^3) Factors: 3 Numbers of Experiments = 25			Parameters			Ra in micron
	Factor A	Factor B	Factor C	T on	Toff	Current I	
1	1	1	1	5	16	1	2
2	1	2	2	10	16	1	2.2
3	1	3	3	20	16	1	2.5
4	1	4	4	50	16	1	2.7
5	1	5	5	100	16	1	2.9
6	2	1	2	5	20	1.5	2
7	2	2	3	10	20	1.5	2.4
8	2	3	4	20	20	1.5	2.8
9	2	4	5	50	20	1.5	3
10	2	5	1	100	20	1.5	3.2
11	3	1	3	5	20	2	2.2
12	3	2	4	10	20	2	2.6
13	3	3	5	20	20	2	3
14	3	4	1	50	20	2	3.4
15	3	5	2	100	20	2	3.6
16	4	1	4	5	20	3	3.7
17	4	2	5	10	20	3	3.8
18	4	3	1	20	20	3	4.5
19	4	4	2	50	20	3	4.7
20	4	5	3	100	20	3	5.7
21	5	1	5	5	26	6	4.4
22	5	2	1	10	26	6	4.9
23	5	3	2	20	26	6	5.6
24	5	4	3	50	26	6	6
25	5	5	4	100	26	6	6.7

4. RESULT AND DISCUSSION

This analysis of the observed data has been carried out to develop parametric equations using regression analysis. The mathematical model used in this process is represented by:

$Y = \emptyset(I, Ton, Toff)$ (1)

In non- linear form, equation 1 becomes

$$Y = C\, I^{n1} Ton^{n2} Toff^{n3} \quad (2)$$

Where Y is the machining response,
φ is the response function,
and I, Ton, Toff are machining variables.
Where C is Machining Constant

Surface finish (Ra)

The model for Ra is formulated as:
$Ra = C\, I^{n1} Ton^{n2} Toff^{n3}$ (3)
Applying logarithm to equation: 3
$\log Ra = \log C + n1 \log I + n2 \log Ton + n3\, Log\, Toff$ (4)

First order Model

The regression analysis using Minitab software the 1st order model for surface finish is shown in the table 3 .

Table 3 : Regression analysis for surface finish vs. I, T-on, T-off for 1st Order model

Predictor	Coef	SE Coef	T	P
Constant	1.604	0.2668	6.01	0
Log Ton	0.14338	0.0114	12.58	0
Log Toff	-1.1738	0.2176	-5.39	0
Log I	0.76892	0.05459	14.09	0

S = 0.0266353 R-Sq = 97.4% R-Sq(adj) = 97.1%

The regression equation based on 1st order model for Surface finish (Ra) is:
LogRa=1.60+0.143LogTon-1.17LogToff + 0.769LogI(5)

Regression Analysis of Variance for Ra

The basic regression line concept, Data= Fit+ Residual.
Data = $(y_i - \bar{y}) = (\hat{y}_i - \bar{y}) + (y_i - \hat{y}_i)$(6)
Where $\bar{y}$ = sum of dependent variable

$\hat{y}_i$ = fitted value of i-th dependent variable
y_i = observed value of i-th dependent variable

Total sum of squares= Regression sum of squares + Residual sum of squares

$$SS_T = SS_R + SS_{Res}$$
$$\sum_{i=0}^{n}(y_i - \bar{y})^2 = \sum_{i=0}^{n}(\hat{y}_i - \bar{y})^2 + \sum_{i=0}^{n}(y_i - \hat{y}_i)^2 \quad (7)$$

Where n = Number of Experiments

Table 4 Analysis of Variance for Ra using 1st order model

Source	DF	SS	MS	F	P
Regression	3	0.56717	0.18906	266.49	0
Residual Error	21	0.0149	0.00071		
Total	24	0.58206			
Source	DF	Seq SS			
Log Ton	1	0.11229			
Log Toff	1	0.31411			
Log I	1	0.14076			

Test of statistic

$$F = \frac{MS_R}{MS_{Res}} = {0.567}/{0.582} = 266.49$$

Coefficient of determination

$$R^2 = \frac{SS_R}{SS_T} = 1 - \frac{SS_{Res}}{SS_T} =$$
$${0.567}/{0.974} = 0.9744 \; i.e. \; 97.44\ \%$$

The F-statistic = 266.49 highlights that there is evidence against the null hypothesis. The p-value for the F-test statistic is 0.000, providing strong evidence against the null hypothesis.

The squared multiple correlation R^2 = 97.44% indicates the variability. The higher value of R^2 states that the model fits the data.
Surface roughness (Ra) with the usage of Equation (5) has been transformed as

$$Ra = \frac{0.2041\ X\ Ton^{0.143} X I^{0.769}}{Toff^{1.17}} \quad (8)$$

It is also evident from the equation (8) that the current and T-on is a dominant factor, followed by T-off because of the respective values of exponents.

Second-order model

The first-order model was sufficient to deduce that the equation is valid, but in order to confirm validity second-order model was postulated to extend the variables range in obtaining the relationship between the Ra and the machining variables ie current, Ton, Toff.

The regression equation for Ra is

Log Ra = - 43.8 - 0.084 Log Ton + 69.7 Log Toff - 0.674 Log I- 0.0416 Log Ton * Log Ton - 27.6 Log Toff *Log Toff + 2.30 Log I* Log I + 0.277 Log Ton * Log Toff - 0.0618 Log I * Log Ton (9)

Analysis of Variance for Ra using 2nd order regression model is displayed in table 5

Table 5: Analysis of varience for Ra 2nd order model

Source	DF	SS	MS	F	P
Regression	8	0.577421	0.072178	248.73	0
Residual Error	16	0.004643	0.00029		
Total	24	0.582064			
Source	DF	Seq SS			
Log Ton	1	0.112293			
Log Toff	1	0.314109			
Log I	1	0.140764			
Log Ton * Log Ton	1	0.001291			
Log Toff *Log Toff	1	0.000283			
Log I* Log I	1	0.008426			
Log Ton * Log Toff	1	0.000057			
Log I * Log Ton	1	0.000199			

The analysis of variance as shown in Tables 5 indicates that the ratio of lack of fit to pure error i.e. F-statistics is 248.73, whilst the P-statistics is 0.000. These values show the same trend and thereby confirming the validity of first-order model. Ra based on 1st order model and 2nd order model were used to compare Normal probability, Histogram, residual fits, order of data plots.

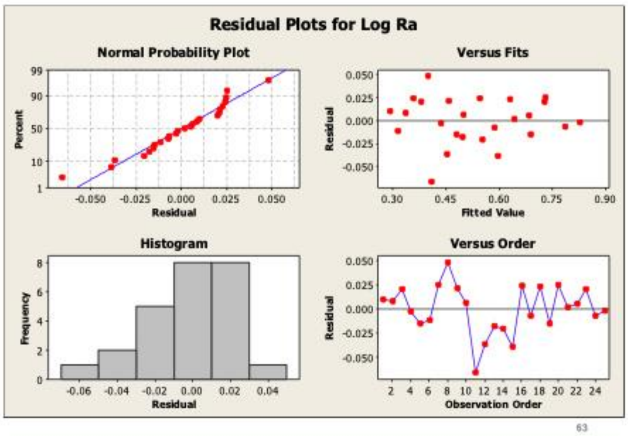

Figure 2: Residuals plot for Ra using first order model

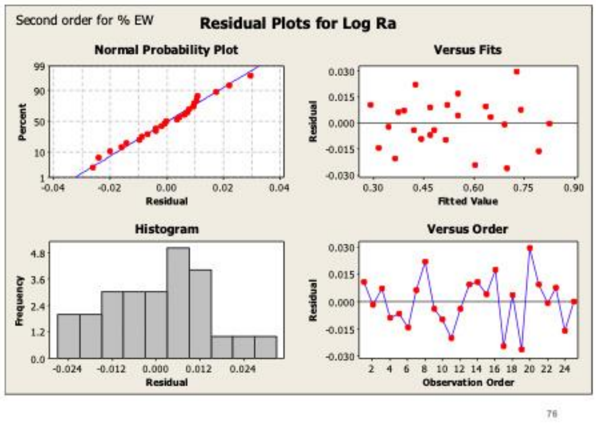

Figure 3: Residuals plot for Ra using Second order model

5. CONCLUSIONS

1. The model indicates that discharge current, pulse-on-rate, and pulse-off-rate have significant effect on the Ra. Higher values of current and pulse-on-rate increased surface roughness. Lower current, lower pulse-on-rate and relatively higher pulse-off-rate produced a better surface finish
2. Residual versus observation order in 1st order model in figure 2 lies between -0.050 to 0.050 and in case of 2nd order model as shown in figure 3 lies between -0.03 to 0.03 indicating that there are systematic effects in the data due to time or collection order
3. The histogram plot for 1st order model in figure 2 the process capabilities lies between -0.06 to 0.04 and in case of 2nd order model as shown in figure 3 it lies between -0.024 to 0.024 proving that the data are not skewed and not outliers exist
4. The Residuals vs fitted values in the figure 2 lies between -0.050 to 0.050 and in figure 3 lies between -0.030 to 0.030 which indicate that the variance is constant and nonlinear relationship exists as well as no outliers exists in the data
5. The Normal probability plot in both the figure 2 and the figure 3 indicates that the data are normally distributed except in first and last experiment and the variables are influencing the response. Outliers don't exist in the data, because standard residue is between -0.050 to 0.050 in 1st order model and -0.035 to 0.03 in the 2nd order model.
6. These residual plots will facilitate to predict beforehand the Ra at any zone of experimental domain. These plots may also be used for comparing various Ra to predict the machining parameters.

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