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Optimisation of MRR in EDM Process

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Abstract : *This paper stresses upon the material removal rate in the EDM Process. The various process parameters such as current, diameter of electrode, pulse rate, various levels have been taken into consideration to determine the material removal rate. Experimental data was obtained. The same data was put to Regression analysis to obtain the equation of material removal rate. Equation of material removal rate was in forms of logarithms. The equation obtained was put for parametric investigations.*

Keywords : *MRR, Optimisation, EDM, EN-31*

I. INTRODUCTION

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EDM is non-traditional manufacturing process. It is used to remove material from electrically conductive materials by means of a series of repeated electrical discharges. The electrical energy is used to generate spark between the gap of workpiece and electrode which therein erode materials from the workpiece. 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 workpiece of desired shape and closer dimensional tolerances. Since, no physical contact takes place between the electrode and workpiece, this process is used for making precision dies and moulds.

Researchers such as Tosun and Ozler [2004] have worked on optimization of EDM process parameters with multiple performance characteristics. Many researchers like Mandal et al. [2007], Kesheng and Mahdavinejad [2008] used fuzzy analysis of single machining pulses to optimize the EDM parameters and used real number between 0 and 1 to compute the magnitude of the system. GAO [2008]; optimized machining parameters using artificial neural network and genetic algorithm. Shabgard [2009]; developed a mathematical model for relating MRR, TWR and surface roughness to machining parameters (current, pulse-on, voltage). Thillaivanan [2010]; proposed Taguchi parameter design method and artificial neural network to optimized operating parameters for EDM process. Iqbal and Khan [2010] study to establish a analysis of surface integrity, micro cracks, recast layer thickness and material migration by combining both electrical and non-electrical process parameters, etc. Vipin et al [2010] have developed computational modeling to predict the metal removal rate. Experimental data has been used to develop the models with the aid of regression analysis. Ranganath et al [2014] have investigated the effects of various EDM parameters to yield the response in terms of MRR.

Going through the Literature it was felt that there is an urgent need to predict Metal removal rate in advance of machining stage for proper planning and execution of manufacturing activities related to EDM. Therefore the present work is intended to develop a model to determine the Metal removal rate due to Machining done by EDM.

The experiments have been undertaken with EN-31 steel utilizing the copper electrode to generate the experimental data. The data so obtained have been use to predict the model of material removal rate (MRR) in EDM process. Parameteric investigation has been further carried out to understand the behaviour of various parameters on the material removal rate (MRR) in EDM process.

II. EXPERIMENTAL SETUP

The experiments for the present case have been conducted on Spark erosion machine (Electronica S50 CNC) as shown in Fig.1. MRR is based on the material removes in grams by EDM. The composition of the work which was EN-31 steel has chemical composition as C: 1.02%, Mn: 0.54%, Cr: 1.40%, Si: 0.30% and rest Fe and electrode material was Copper.

Fig. 1: EDM machine Electronica S50 CNC

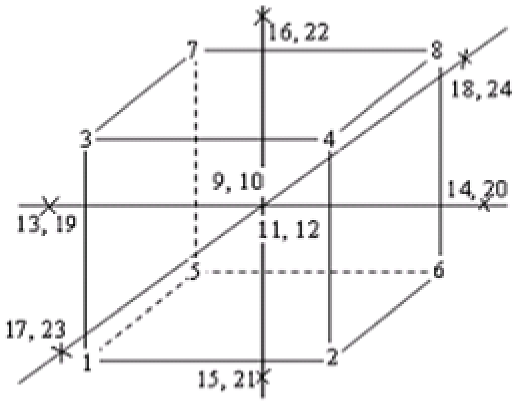

Fig. 2 Representation of 2^3Central design

Experimental design and conditions

The first-order model was developed by an experimental design consisting of 12 experiments. Twelve experiments constitute Eight experiments (2^3 factorial designs) and Four experiments (an added centre point repeated four times) as shown in Fig.2. This was done to predict the independent parameters as used in the Equation. The blocks provide the confidence interval of the parameters and help in the analysis of variance.

A second-order model is developed by adding six augment points to the factorial design. Depending on the capacity of the machine, an augment length of ±1 was chosen. The augment points consist of three levels for each of the independent variables denoted by -1, 0, 1. These six experiments were repeated twice to develop the second-order model. The resulting 12 or 24 experiments form the central composite design Fig. 2 shows 2^3 designs.

III. EXPERIMENTAL CONDITIONS AND RESULTS

All the experiments were run with kerosene dielectric. The levels of independent variables and coding identifications are presented in Table 1. Table 2 shows the experimental conditions together with the measured MRR values.

Table 1: Levels of independent variables

Level	V Low	Low	Medium	High	V High
Coding	-2	-1	0	1	2
Electrode diameter (mm) D	6	8	10	12	14
Current (A) I	4	6	8	10	12
Pulse time (µs) P	5	6	7	8	9

Table 2 Experimental conditions and results of EDM test

Trial No.	Coding			Electrode diameter (mm) D	Current (A) I	Pulse rate (µs) R	MRR (gms)
	x_1	x_2	x_3				
1	-1	-1	-1	8	6	6	0.754
2	1	-1	-1	12	6	6	0.447
3	-1	1	-1	8	10	6	0.773
4	1	1	-1	12	10	6	0.752
5	-1	-1	1	8	6	8	0.346
6	1	-1	1	12	6	8	0.589
7	-1	1	1	8	10	8	0.638
8	1	1	1	12	10	8	0.621
9	0	0	0	10	8	7	0.595
10	0	0	0	10	8	7	0.658
11	0	0	0	10	8	7	0.645
12	0	0	0	10	8	7	0.641
13	-2	0	0	6	8	7	0.574
14	2	0	0	14	8	7	0.655
15	0	-2	0	10	4	7	0.303
16	0	2	0	10	12	7	0.895
17	0	0	-2	10	8	5	0.967
18	0	0	2	10	8	9	0.995
19	-2	0	0	6	8	7	0.575
20	2	0	0	14	8	7	0.655
21	0	-2	0	10	4	7	0.305
22	0	2	0	10	12	7	0.89
23	0	0	-2	10	8	5	0.966
24	0	0	2	10	8	9	0.956

III. QUANTITATIVE METHODS

Regression Analysis: log MRR versus log D, log I, log R

First-order model

The predicted MRR model for the first 12 block is:

$$\log MRR = -0.092 - 0.019 \log D + 0.601 \log I - 0.762 \log R \quad (1)$$

Table 3: Analysis of variance for 12 tests

Source	DF	SS	MS	F	P
Regression	3	0.053715	0.017905	2.59	0.126
Residual Error	8	0.055368	0.006921		
Lack of Fit	5	0.054269	0.010854	29.63	0.009
Pure Error	3	0.001099	0.000366		
Total	11	0.109083			

The analysis of variance is shown in Table 3. The ratio of lack of fit to pure error i.e F-statistics is 29.63, whilst the P-statistics is 0.009. Therefore, the model is adequate for determination of MRR prediction. So the MRR with the usage of Equation (1) has been transformed as

$$MRR = \frac{0.8091 * I^{0.601}}{D^{0.019} * R^{0.762}} \qquad (2)$$

It is also evident from the equation obtained that the pulse rate is a dominant factor, followed by current and electrode diameter because of the respective values of exponents.

Equation 2 have been used to develop metal removal rate contours respectively in the electrode diameter - current plane for pulse rate 6μs as shown in Fig. 3. These contours facilitate to predict beforehand the metal removal rate at any zone of the experimental domain. One can also use these contours for comparing various MRR to predict the machining parameters.

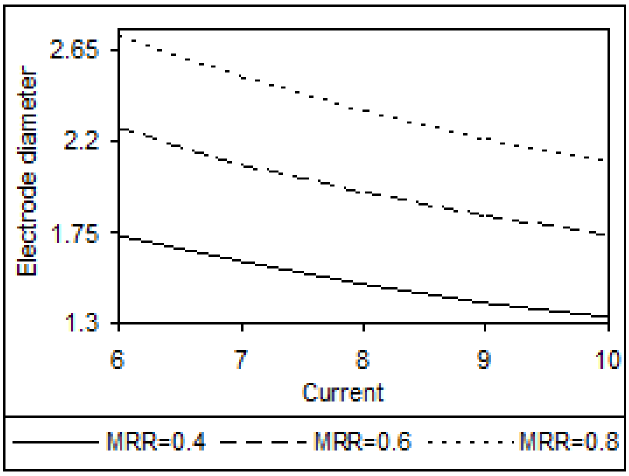

Fig. 3**:** Dual response contours of first- order MRR in the electrode diameter-current plane for pulse rate 6 μs

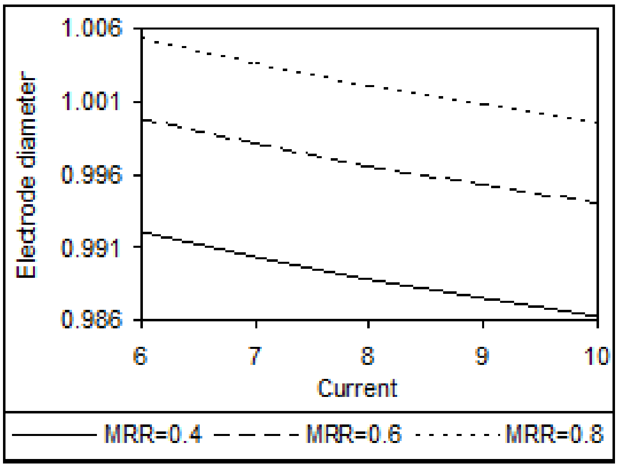

Fig. 4 Dual response contours of second- order MRR in the electrode diameter-current plane for pulse rate 6 μs

Second-order model

Even though the first-order model was found to be adequate, the second-order model was postulated to extend the variables range in obtaining the relationship between the MRR and the machining independent variables. The model was based on the central composite design with added augment points to the nucleus of the design. The distance of the augment points was 1 unit.

The model equation is given by:

$$\log MRR = 15.4 - 7.87 \log D + 0.99 \log I - 29.6 \log R$$
$$- 0.70 \log D * \log D - 0.923 \log I * \log I + 9.95 \log R * \log R$$
$$- 0.10 \log D * \log I + 11.2 \log D * \log R + 1.84 \log I * \log R$$
………………(3)

The analysis of variance as shown in Tables 4 indicates that the ratio of lack of fit to pure error i.e. F-statistics is 95.41, whilst the P-statistics is 0.000. The contours show the same trend and thereby confirm that the first-order model is adequate for the present context. Figure 4 is a plot of the dual response of metal removal rate.

Table 4: Analysis of variance for second-order model.

Source	DF	SS	MS	F	P
Regression	9	0.433625	0.048181	9.93	0.000
Residual Error	14	0.067897	0.004850		
Lack of Fit	5	0.066640	0.013328	95.41	0.000
Pure Error	9	0.001257	0.000140		
Total	23	0.501522			

IV. CONCLUSION

(1) The material removal rate equation shows that the pulse rate is the main influencing factor, followed by current and electrode diameter in the operation model.
(2) Dual-response contours provide useful information about the maximum attainable material removal rate as a function of all three independent variables.
(3) For a particular MRR, Electrode diameter decreases with the increase in the current supplied.

(4) For a particular Electrode diameter, MRR increases with the increase in the current supplied.

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