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Optimization of machine process parameters on material removal rate in EDM for EN19 material using RSM

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ABSTRACT **:** *In the present study, response surface methodology was used to investigate the relationships and parametric interactions between the measurable and controllable variables on the material removal rate (MRR) in die sinking EDM of EN19 material. The material is extensively being used for the application in High speed components e.g. gears. For conducting the experiments, four process variables viz. pulse on time, pulse off time, discharge current and gap voltage were considered and electrolytic copper was used as the electrode material. Total 31 experiments were carried out for different combinations of process parameters. The experimental results were analyzed using Response Surface Model (RSM). The significant coefficients were obtained by performing analysis of variance (ANOVA). From the analysis, it was found that pulse off time, discharge current, gap voltage and the interaction terms were significant where as the pulse on time had almost negligible effect towards MRR. This methodology was found to be very effective and the model sufficiency was very satisfactory. Moreover, an attempt has been made to optimize the material removal rate in the studied region. The error between the predicted and experimental MRR value was found to be 1.45% .*

Keywords *: EDM, EN19, MRR, Optimization, RSM.*

I. INTRODUCTION

Electrical Discharge Machining (EDM) removes the material by errosion procedure. Series of constantly repeating electrical discharges emerged between the tool and the work piece in dielectric fluid and remove the material. When current conducting wires approaches each other an arc is generated. On close examination it can be observed that small portion of metal has been eroded. .A. McGeough in his book 'Advanced Methods of Machining' [1] refered that this phenomena was first perceived by Sir Joseph Priestly as early as 1768. B.R. Lazarenko discovered it in 1943, that precision machining can be achieved by EDM [2,3].

Some research attempts have been made for modeling EDM process and investigation of the process performance to recuperate MRR. Semi-empirical models of MRR for various work piece and tool electrode combinations have been presented by Wang and Tsai [4]. Tosun et al. [5] have presented an investigation on the effect and optimization of machining parameters on the kerf (cutting width) and material removal rate (MRR) in wire electrical discharge machining operations. Luis et al. [6] have studied the influence of pulse current, pulse time, duty cycle, open-circuit voltage and dielectric flushing pressure, over the MRR and other response variables on tungsten carbide materials.Kuppan et al. [7] have developed response surface model and shown the influencing parameters on MRR. Chiang [8] has developed mathematical models to see the effects of machining parameters on the performance characteristics of the material removal rate (MRR), electrode wear ratio, and surface roughness in EDM process of ceramic material. Patel et al. [9] have studied the machining characteristics, surface integrity and material removal mechanisms of advanced ceramic composite in EDM. Parashar et al. [10] have carried out statistical and regression analysis of material removal rate (MRR) using design of experiments for WEDM operations. In the current study, material removal rate (MRR) is modeled using RSM in EDM of EN19 material.

II. RESPONSE SURFACE METHODOLOGY

Response surface methodology comprises a group of statistical techniques for empirical model building and model exploitation. It helps the experimenter to find the optimum setting for the input variables that optimizes the predicted response.It also used to improve the robustness of the process and the product.

Response surface methodology (RSM) began with the work of Box and Wilson in the Journal of the Royal Statistical Society. In RSM ideas were developed using linear polynomial models, mainly first-degree and second- degree models, with continuous response variables assumed. It is a mainly combination of

mathematical & statical process and used for modeling and problem analysis & also used for response optimization.
where μ is the expected response, given x, x'=[x_1............x_q], x_1.....x_q are the level of the factors coaded to be (1) -1 & 1 and resposes from different runs are assumed to be independent with constant variance σ2 [13].

III. EXPERIMENT SETUP

Experiments are conducted on die sinking EDM machine (EMT-43 Manufacturer Electronica Machine Tools). Both Electrode and workpiece material identification and composition was confirmed using EDX process (JEOL,JAPAN,JSM-6390LV). The tool electrode (positive polarity) of electrolytic pure copper with 25 mm x25 mm size was used. Work-piece material is EN19 with round cylinder of diameter 25 mm and of thickness 15 mm. Commercial grade EDM oil is used as dielectric fluid. With the help of Design of experiment (DOE) [11, 12] three levels,four parameters & 31 tests are conducted randomly.

Table 1 Process Variables

Variable	Code	Level		
		2	3	4
Pulse on time(μS)	A	300	400	500
Pulse of time(μS)	B	1700	1600	1500
Discharge current (Ip)Amp	C	10	15	20
Voltage (V)	D	30	40	50

ANOVA calculates the F-ratio, which is the ratio between the regression mean square and the mean square error. The F-ratio also called the variance ratio & this is the ratio of variance due to the effect of a factor and variance due to the error term [14]. If the calculated value of F-ratio is higher than the tabulated value of F-ratio for roughness, then the model is adequate at desired α (error term) level to represent the relationship between machining response and the machining parameters .Analysis is done by using MINITAB software[11].

Table 2 Experiments results

Run Order	A	B	C	D	MRR
1	1	-1	-1	1	0.19558
2	1	1	1	1	0.62963
3	1	1	1	-1	0.714583
4	0	2	0	0	0.564103
5	-1	1	1	1	0.66575
6	0	0	0	2	0.32422
7	-2	0	0	0	0.465909
8	0	0	0	0	0.44375
9	0	0	0	0	0.44375
10	0	0	0	0	0.44375
11	0	0	0	0	0.44375
12	0	-2	0	0	0.252051
13	-1	1	-1	-1	0.630952
14	0	0	0	-2	0.555128
15	1	1	-1	1	0.28355
16	1	1	-1	-1	0.45789
17	2	0	0	0	0.38493
18	0	0	-2	0	0.44318
19	-1	-1	-1	1	0.23773
20	-1	1	-1	1	0.40523
21	1	-1	1	1	0.455882

22	-1	-1	1	1	0.453333
23	0	0	0	0	0.44275
24	0	0	2	0	0.88122
25	-1	-1	-1	-1	0.36188
26	0	0	0	0	0.44375
27	0	0	0	0	0.44375
28	-1	1	1	-1	0.775926
29	1	-1	-1	-1	0.29753
30	1	-1	1	-1	0.570833
31	-1	-1	1	-1	0.562475

IV. RESULTS AND DISCUSSION

The results for EN 19 tool steel in EDM are presented in following table. With the help of the results and using RSM technique second order response model is being developed. It is observed from the adequacy test by ANOVA that linear terms, Ton, Toff, Ip, V and interaction terms Toff with Ip & Ip with V and square terms V2 are significant.The fit summary recommended that the quadratic model is statistically significant for analysis of MRR.

Table 3 FOR MRR (BEFORE ELIMINATION)

TERM	COEEFICIENT	SE COEEFICIENT	T	P
Constant	0.443607	0.007822	56.715	0
A	-0.02624	0.004224	-6.212	0
B	0.086349	0.004224	20.442	0
C	0.118923	0.004224	28.153	0
D	-0.06197	0.004224	-14.67	0
A*A	-0.0052	0.00387	-1.344	0.198
B*B	-0.00954	0.00387	-2.464	0.025
C*C	0.053995	0.00387	13.953	0
D*D	-0.00164	0.00387	-0.423	0.678
A*B	-0.01979	0.005174	-3.825	0.001
A*C	0.018418	0.005174	3.56	0.003
A*D	0.004562	0.005174	0.882	0.391
B*C	0.002404	0.005174	0.465	0.648
B*D	-0.01031	0.005174	-1.993	0.064
C*D	0.011684	0.005174	2.258	0.038
R-Sq = 99.08% R-Sq(pred) = 94.69%				
R-Sq(adj) = 98.27%				

ANOVA table after elimination of nonsignificant factors is presented in Table 4.Results for the reduced model indicate that the model is significant ,and lack of fit is non significant (p-value is less than 0.05).After eliminating the non-significant terms, the final response equation for MRR in coded terms is given below:

$$MRR=0.437296-0.02624 \times T_{ON} + 0.086349 \times t_{OFF} + 0.118923 \times I_P - 0.06197 \times V - 0.00888 \times T_{ON}^2 + 0.054652 \times V^2 - 0.01979 \times T_{OFF} \times I_P + 0.01848 \times T_{OFF} \times V + 0.011684 \times I_P \times V \qquad (2)$$

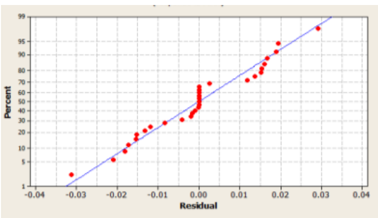

Fig.1 Normal probability plot of residuals

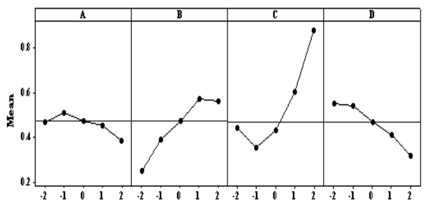

Fig.2 Optimum combination of process parameter

Maximum MRR is 1.16609 for optimum combination

After seeing the effect of process parameters on MRR, three dimensional surface and contour plots (Fig. 3- Fig. 8) are developed using Matlab software. These plots can also give further assessment of the correlation between the process parameters and responses. It is seen that MRR increases with an increase of Ip and Ton keeping Toff and V as constant at their central level (Fig. 3).Fig.4 presents the variations of MRR with Ip and Toff keeping other two parameters at their central levels.

Table 4 FOR MRR (AFTER BACKWORD ELIMINATION)

TERM	COEEFICIENT	SE COEEFICIENT	T	P
Constant	0.437296	0.005987	73.038	0
A	-0.02624	0.004406	-5.955	0
B	0.086349	0.004406	19.596	0
C	0.118923	0.004406	26.988	0
D	-0.06197	0.004406	-14.063	0
B*B	-0.00888	0.003995	-2.222	0.037
C*C	0.054652	0.003995	13.679	0
A*B	-0.01979	0.005397	-3.667	0.001
A*C	0.018418	0.005397	3.413	0.003
C*D	0.011684	0.005397	2.165	0.042
R-Sq = 98.68% R-Sq(pred) = 96.13%				
R-Sq(adj) = 98.12%				

The general tendency is with increase in pulse current MRR increases. The effect of pulse current and voltage on MRR is illustrated in Fig. 5 and it is seen that there is a sharp increase of MRR with Ip, however no appeciable increse in MRR with the increase in V. Fig.6 shows the variation of MRR with pulse on time and V keeping constant other two parameters at their midlevels.It is seen that with increase in pulse ontime and pulse off time, MRR increases (Fig. 7).Fig. 8 depicts the variation of MRR with voltage and pulse off time.

Table 5 ANNOVA TABLE FOR THE MODEL

SOURCE	DF	SS	MS	F	P
Regression	9	0.733624	0.081514	174.92	0
Linear	4	0.627052	0.156763	336.39	0
Square	2	0.092695	0.046348	99.46	0
Interaction	3	0.013877	0.004626	9.93	0
Residual Error	21	0.009786	0.000466		
Lack Of Fit	15	0.009785	0.000652	4566.53	0
Pure Error	6	0.000001	0		
Total	30	0.743411			

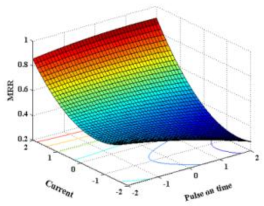

Fig. 3 Surface and contour plot of MRR with current and pulse on time

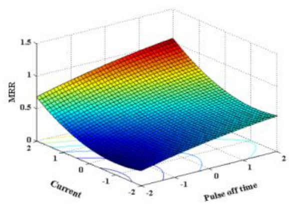

Fig. 4 Surface and contour plot of MRR with current and pulse off time

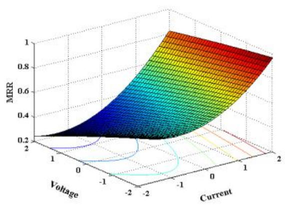

Fig. 5 Surface and contour plot of MRR with Voltage and current

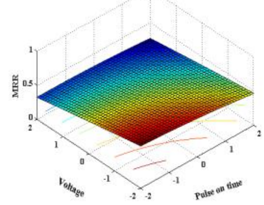

Fig.6 Surface and contour plot of MRR with voltage and pulse on time

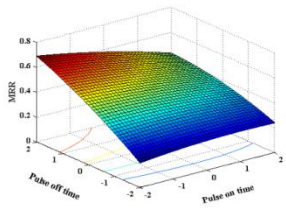

Fig. 7 Surface and contour plot of MRR with pulse off time and pulse on time

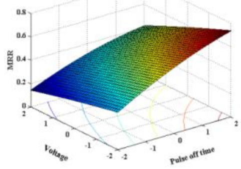

Fig. 8 Surface and contour plot of MRR with voltage and pulse off time.

V. CONCLUSION

It was found that pulse off time, discharge current, voltage and some of their interfaces have a significant effect on MRR in the studied range. A confirmation test also shows the ability of the model to predict the MRR. Successfully attempt has been made to maximize MRR within the experimental range and it is seen that pulse on time of 400 µs, pulse off time of 1600 µs, current of 15A and voltage of 40 V will produce maximum MRR.

Table 6 Conformation test result and comparison with predicted result

T_{ON}	T_{OFF}	I_P	V	MRR		
				Experimental	Predicted	% Error
400	1600	15	40	0.44275	0.4373	1.45

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