EXPERIMENTAL INVESTIGATIONS & DEVELOPMENT OF EMPIRICAL MODEL IN ROTARY ELECTRO DISCHARGE MACHINING USING TAGUCHI METHOD

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ABSTRACT

This work optimizes the parameters of rotary electro discharge machining for hole drilling in EN31carbon steel using Taguchi methodology. The empirical models for prediction of output parameters like Material Removal Rate (MRR) and Surface Roughness (SR) have been developed using regression Four independent input parameters are chosen as variables at four levels for evaluating the output parameters. Analysis of the results, by using Taguchi's recommended signal–noise ratio formulae and ANOVA, has been conducted to identify the significant parameters and their degree of contribution in the process output. In addition, the predictions based on the above developed models have been verified with another set of experiments and are found to be in good agreement with the predicted results.

Keywords: EDM drilling, MRR, SR, Taguchi, ANOVA

1. INTRODUCTION

EDM drilling is well established in the field of manufacturing metal pieces with complicated geometries. It has vast applications like putting holes in turbine blades, fuel injectors, cutting tool for coolant, hardened punch ejector. It is also used to remove broken tools in small holes, making plastic mold vent holes, wire EDM starter holes, mini machines/robots and air vent holes for forging dies. The same can be utilised for dovetail finger pin removal, cross key pin removal, balance hole drilling, removal of steam strainer rivets etc.

2. LITERATURE REVIEW

Material removal and its mechanism has been one of the main concerns for several years. Since the development of this process, researchers have explained the material removal mechanism by developing different thermal models to predict material removal based on melting and evaporation. They predicted that material removal takes place not only by vapour ejection but also due to liquid expulsion.

The effects of axial vibration along with the rotation of electrode on the material removal and electrode wear during electrical discharge machining. Reported that the introduction of high frequency axial vibration on a rotating electrode improves material removal rate significantly for a specified surface finish [1].

Rotary electrode in a modified conventional electrical discharge machine for micro slitting of workpieceand demonstrated successfully the increase in material removal and uniform decrease in electrode wear around its periphery by locating the workpiece above rotary disk electrode [2]. Several authors used rotary electrical discharge machining, along with different flushing techniques, on newly developed composite materials and studied their effect on material removal, electrode wear and surface roughness (SR) [3-6]. Different electrodes such as tubular, solid and electrode with eccentric hole of different materials were used in experimentation. It was observed by the several researchers that complex interaction of large number of process parameters togetherwith some of the process variables [7] is one of the main reasons in controlling the machining output data. Henceforth, they investigated the influence of main electrical parameters and environmental factors on the material removal rate during electrical discharge machining.

Machinability of rotating cylindrical AISI D2 tool steel workpiece with copper electrode in electrical discharge machining. Experimental results indicated that increase in metal removal rate (MRR) and improvement of surface roughness takes place with increase in electrode rotation [8].

It has been observed that there is very little or no work represented on EN31 & no model is available to represent MRR & SR for EN31-Brass combination of workpiece and electrode. And hence the study is focused on EN31 small hole drilling with various input parameters like current, pulse on time, diameter and hole depth to represent MRR. These have been done using Taguchi's technique of design of experiments & multiple regression analysis. Taguchi's technique of design of experiments (DoE) is utilized because the experimental design and analyze of the results can be done with less effort and expenses. Since the method enormously reduces the number of experiments, quality loss of results must be taken into account [9].

2. EXPERIMENT DETAILS

2.1 Machine Specifications

To perform the experiments machine of Sparkonix India Private Limited, which is a leading manufacturer and exporter of EDM machines in India since 1968, is identified. The specification of machine is as below:

Work Table	400 x 300mm
X Travel	250mm
Y Travel	150mm
Z Travel	300mm
Guide Travel Z2	200mm
Electrode Pipe Dia.	0.3 to 3.0mm
Max. Job Height	310mm
Max. Drilling Depth	300mm

Figure 1 EDM drilling machine in cutting

2.2 Experimental Conditions

The experiments conducted four input control factors are selected at 4 levels as shown in the Table 1. Remaining constant parameters are also mentioned in Table 1.

Table 1 Experiment conditions

Sr.	Control Factors(Units)	L1	L2	L3	L4
1	Current, I (Amp.)	10	15	20	25
2	Pulse on time, Ton,(µs)	7	8	9	10
3	Diameter, D (mm)	1.5	2	2.5	3
4	Hole depth, Dt (mm)	10	15	20	25
5	Pulse off time, µs	7			
6	Electrode rotation, rpm	50			
7	Flushing Pressure, Kg/cm2	5			
8	Voltage, V	55			
9	Die electric Fluid	Distilled Water			
10	Work material	EN31			
11	Electrode material	Brass			
12	Taguchi's Orthogonal Array	L16			

3 RESULTS AND DATA ANALYSIS

Any of the manufacturing process generally measured in terms of surface roughness achieved and how fast material is removed. Hence in the experiments conducted, MRR and SR are measured as response factor.

3.1 Signal to Noise ratio analysis

Fig. 2 shows main effects plot for S/N ratio for MRR vs. all input factors for the values tabulated in table 2. Since it is always desirable to maximise the MRR larger is better option is selected. From the above graph it can be seen that highest MRR is achieved at current of 25A, pulse on time of 10µs, diameter of 1.5mm and 25mm depth. Here according to ranks of the slope of SN ratio plot, the effects of various input factors on MRR in sequence of its effect are current, depth, diameter and pulse on time.

Table 2 S/N ratio for MRR & SR

I	Ton	D	Dt	SNRA MRR	SNRA SR
10	7	1.5	10	13.46	-9.99
10	8	2	15	8.97	-10.10
10	9	2.5	20	11.79	-14.00
10	10	3	25	16.34	-12.17
15	7	2	20	16.69	-13.24
15	8	1.5	25	25.19	-10.88
15	9	3	10	19.09	-11.25
15	10	2.5	15	20.11	-10.10
20	7	2.5	25	25.86	-15.71
20	8	3	20	25.86	-13.89
20	9	1.5	15	26.39	-10.08
20	10	2	10	26.14	-10.02
25	7	3	15	27.12	-14.73
25	8	2.5	10	29.06	-13.46
25	9	2	25	27.94	-10.26
25	10	1.5	20	27.44	-12.65

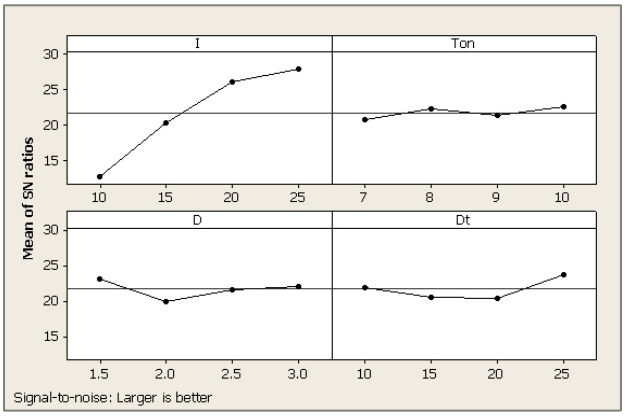

Figure 2 Main effects plot for S/N ratio for MRR

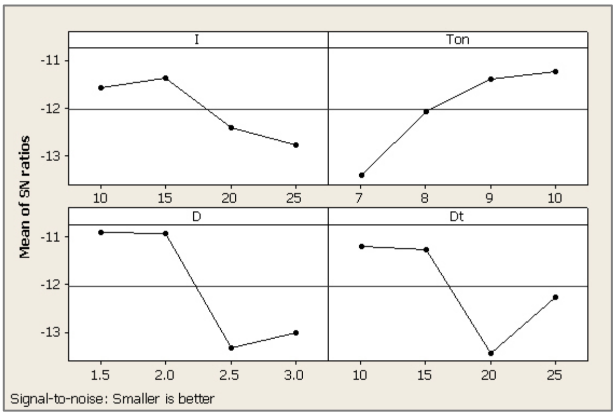

Figure 3 Main effects plot for S/N ratio for SR

Fig. 3 shows main effects plot for S/N ratio for SR vs. all input factors. Since it is always desirable to achieve the best surface finish smaller is better option is selected. From the above graph it can be seen that the best SR is achieved at current of 25A, pulse on time of 10µs, diameter of 2.5mm and 20mm depth. Here according to ranks of the slope of SN ratio plot, the effects of various input factors on SR in sequence of its effect are diameter, depth, pulse on time and current.

3.2 Analysis of Variance (ANOVA)

Table 2 ANOVA for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution	Remarks
I	3	999.841	999.841	333.28	70.8	0.003	90.82775	*
T_{on}	3	29.828	29.828	9.943	2.11	0.277	2.709641	
D	3	21.915	21.915	7.305	1.55	0.363	1.990807	
D_t	3	35.106	35.106	11.702	2.49	0.237	3.189106	
Error	3	14.121	14.121	4.707				
Total	15	1100.81						

S = 2.169 $R_{Sq.}$ = 98.72% $R_{Sq.\ (adj)}$ = 93.59%

Table 3 ANOVA for SR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution	Remarks
I	3	1.4514	1.4514	0.4838	1.26	0.427	40.37992	
Ton	3	3.2238	3.2238	1.0746	2.8	0.21	1.836565	
D	3	4.9114	4.9114	1.6371	4.26	0.132	46.03595	*
Dt	3	2.7487	2.7487	0.9162	2.39	0.247	8.399325	
Error	3	1.1517	1.1517	0.3839				
Total	15	13.4869						

*S = 0.619 $R_{Sq.}$ = 91.46% $R_{Sq.\ (adj)}$ = 87.3%, F_{cr} = 3.285 * - Significant*

Table 2 represents the analysis of variance for MRR of EN31 material for 95% confidence level. From ANOVA it can be concluded that current is significant factor affecting the MRR of EN31 material since respective F values are higher than Fcr. This analysis is correct since corresponding p values are small.

Table 3 represents the analysis of variance for SR of EN31 material for 95% confidence level. From ANOVA it can be concluded that diameter is affecting the SR significantly.

3.3 Empirical model

Empirical expressions have been developed to evaluate the relationship between input and output parameters. The output values of MRR have been used to construct the empirical expressions.

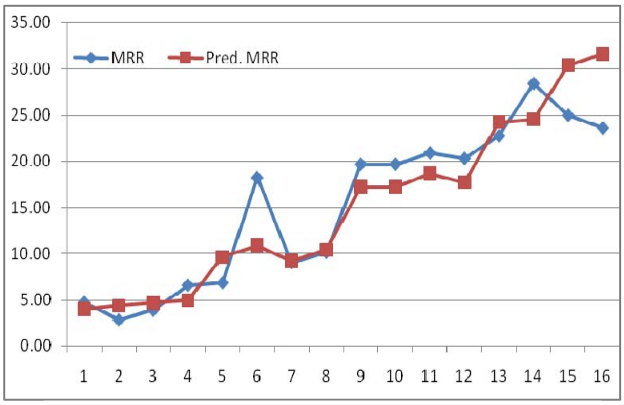

Figure 3 Graph showing error between actual MRR and predicted MRR

The developed empirical model for MRR is given by

MRR = $A(I)^a(T_{on})^b(D)^c(D_t)^d$ (1)

By performing multi parameter linear regression analysis on the data regression constants are calculated which are as given as follows :

MRR = $0.0137.\ (I^{1.982}\ .\ T_{on}^{0.411}.D_t^{0.154})/\ (D^{0.108})$ (2)

The predicted MRR is calculated based on eqn. 2 and compared with experimental values. The average error for this equation is 2.51%. Fig. 4 shows graph for actual MRR and predicted MRR. It can be seen that values are very close for actual and predicted MRR for EN31 material and empirical model is predicting very much close values to the actual.

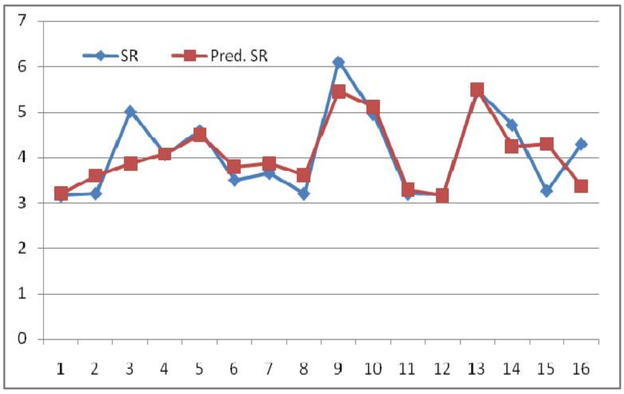

Figure 4 Graph showing error between actual SR and predicted SR

The developed empirical model for SR is given by

SR = $A(I)^a(T_{on})^b(D)^c(D_t)^d$ (3)

By performing multi parameter linear regression analysis on the data regression constants are calculated which are as given as follows :

$SR = 4.487 \, . \, (I^{0.0.1676} \, . \, D^{0.433} \, . \, D_t^{0.212})/(T_{on}^{0.712})$ (4)

The predicted SR is calculated based on eqn. 4 and compared with the experimental values. The average error for this equation is 0.9%**.** Fig. 6.82 shows graph for actual SR and predicted SR. It can be seen that values are very close for actual and predicted SR for EN31 material and empirical model is predicting very much close values to the actual.

4 CONCLUSIONS

In this investigation, modelling of some of the most important technological parameters are proposed for rotary electrical discharge machining process. Taguchi method is used to determine the main influencing factors affecting the selected technological variables such as MRR, SR. These outputs have been studied as a function of design factors such as peak current, pulse on time, diameter and depth. The other factors like pulse off time, duty factor, electrode rotation, flushing pressure of water, voltage etc. remained constant throughout the experiments. 1st order empirical models were developed for prediction of various output process parameters during rotary electrical discharge machining, using non-linear regression with logarithmic data transformation. The proposed models have been successfully applied to estimate the values of MRR and SR under various machining conditions.

Through the Taguchi analysis for MRR it has been observed that current affects the MRR at the highest level and in order depth, diameter and pulse on time respectively are affecting the MRR. Even it has been seen, through the main effects plots of SN ratio, to achieve highest MRR within the experimental data range optimized conditions are 25amp current, 10µs pulse on time, 1.5mm diameter and 25mm depth. Further based on the results of ANOVA analysis it has been seen that current is significant factor affecting MRR.

Through the Taguchi analysis for SR it has been observed that diameter affects the SR at the highest level and in order depth, pulse on time and current respectively are affecting the SR. Even it has been seen, through the main effects plots of SN ratio, to achieve the best SR within the experimental data range optimized conditions are 25amp current, 10µs pulse on time, 2.5mm diameter and 20mm depth. Further based on the results of ANOVA analysis it has been seen that diameter is significant factor affecting the SR.

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