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ANALYSIS USING RESPONSE SURFACE METHODOLOGY (RSM) BASED EXPERIMENTAL DESIGN ON MAGNETIC FIELD ASSISTED EDM PROCESS

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ABSTRACT

RSM is an experimental design technique that is used to find a relationship between the dependent and the independent variable. RSM makes use of a Central Composite Design (CCD) for the experimental layout according to which experiments are done. In this research, RSM is used to explore the correlation between process parameters and performance parameters for magnetic field assisted EDM process. Magnetic field assisted EDM is a relatively new area of research and it has not been implemented on the large scale. Four process parameters namely Gap voltage (V), Peak current (I_p), Pulse on time (T_{on}) and Duty factor (τ) were considered as input factors whereas Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (R_a) were considered as performance characteristics. Copper was used as tool material. D2 tool steel, which is used in several applications in the manufacturing section, was used as work-piece. Optimal settings were identified for each performance characteristic using contours plots and machining was done at these settings.

Index Terms*— Magnetic field, RSM, D2 tool steel*

I. INTRODUCTION

EDM is an unorthodox machining process where material removal takes place from the work-piece by emission of controlled sparks from the tool when both are placed extremely close to each other, submerged in a weakly conductive dielectric medium. In this process the negative terminal of DC power source is connected to the tool and the positive terminal of the DC power source is linked to the work-piece. When the voltage across the gap is sufficiently increased to about 250V, dielectric fluid breaks down and plasma is produced between the tool and the workpiece. The extremely high temperature developed causes the work-piece material is vaporize thereby forming small craters. Repeating the process again and again the required shape is formed. The dielectric fluid helps to wash away the debris from the machining gap and also serves as a coolant for the process. Complex shapes and contours can be produced using this process. Since EDM is a precision machining process, the time involved in machining is high. Higher MRR results in faster machining of the work-piece, this reduces the time involved in machining. TWR and surface roughness are the other two important parameters which also need attention. Several researchers have worked in this field to strike an optimum balance between these performance parameters. In this work, Magnetic field has been put to use to exploit its benefits on the EDM process and thereby optimize the process settings using optimization techniques such as RSM. Lin et al. (2009) studied the effect of magnetic field on EDM machining attributes. The benefits of magnetic force assisted EDM were confirmed from the higher MRR that was achieved. Bergaley and Sharma (2013) optimized the electrical and non-electrical input parameters for optimal value of MRR and TWR. The research showed that the peak current has significant effect on MRR. Rajukar et al. (2013) studied the influence of magnetic field on the plasma created and confirmed that the plasma gets confined due the effect of Lorentz force. The confined plasma results in higher MRR from the parent material. Sethy et al. (2013) adopted a novel method to find out the multi-objective optimal condition using Principal Component Analysis (PCA) based on Grey Relational Analysis (GRA) for characteristics such as MRR, TWR and surface roughness during EDM of AISI P20 tool steel. They determined optimal settings for different performance parameters and carried out machining at these settings. Sahu et al. (2013) had adopted RSM to establish effect of various process parameters such as MRR, TWR and surface roughness of machined component for conventional EDM.

Literature suggested that there were some positive effects on the performance parameters by implementing magnetic field assisted EDM. It was found that hardly any literature existed where RSM has been used to optimize magnetic field assisted EDM. This work aims at optimizing magnetic field assisted EDM using RSM.

II. EXPERIMENTAL SETUP

Experiments were carried out in EDM machine made by ELECTRONICA with a model name PS50. Commercial grade EDM oil was used as dielectric fluid. D2 tool steel which was cut into square faced blocks with side of 40mm and thickness of 25mm were used. The hardness of this material was found to be 55HRC. Chemical composition and density were found out by performing confirmation tests in the lab. Copper was used as tool for all experiments. A total of 25 copper tools were milled to exact dimension as shown in Fig 1. All experiments were carried out in positive polarity setting. Permanent magnets made of neodymium of grade N35 were used to bring about the magnetic field effect. A 6 inch 4-jaw chuck which has independent jaw movement was used as a clamping device which held the magnets and the workpiece together. The whole setup was placed in the bed of the EDM machine and the experiments were carried out as shown in Fig 2.

Fig. 1. Copper tool

Fig. 2. Experimental setup

A digital Gauss meter was used to measure the intensity of the magnetic field as shown in Fig 3.

Fig. 3. Measurement of magnetic field intensity

MRR and TWR were found based on loss of weight of work-piece and tool material respectively. The tool and the work-piece were weighed before and after machining on a weighing machine with a least count of 0.0001g. To measure surface roughness, Subtronic 3+ machine designed by Taylor and Hobson was used which had a cut of length of 0.80mm.

III. EXPERIMENTATION

Table I. shows the list of factors and the coding of natural variables.

Table I. Coding of natural variables

Level	**-2**	**-1**	**0**	**1**	**2**
Gap Voltage (Machine setting), (A)	1st level	2nd level	3rd l	4th level	5th level
Peak Current (A), (B)	2	6	10	14	18
Pulse on time (units), *(C)*	10	25	40	55	70
Duty Factor (units), (D)	1	3	5	7	9

The minimum possible number of experiments (N) for 4 factors (k=4) can be determined from the following equation :-

$$N = n_c + n_a + n_0 \qquad (1)$$

Where,

n_c - Number of Corner points. -1 and 1 ($n_c = 2^k$).

Here k = 4 . $n_c = 2^4 = 16$

n_a - Number of axial points or star points. -2 and 2.

$n_a = k \times 2 = 8$

n_0 - Number of center points. $n_0 = 1$

Total number of experiments , N = 16 + 8 + 1 = 25

The RSM experimental layout based on CCD is shown in the following table II.

Table II. RSM experimental layout

Experiment Number	**A**	**B**	**C**	**D**	**Gap voltage (Machine setting)**	**Peak Current (A)**	**Pulse on time (Units)**	**Duty Factor (Units)**
1	-1	-1	-1	-1	2	6	25	3
2	1	-1	-1	-1	4	6	25	3
3	-1	1	-1	-1	2	14	25	3
4	1	1	-1	-1	4	14	25	3
5	-1	-1	1	-1	2	6	55	3
6	1	-1	1	-1	4	6	55	3
7	-1	1	1	-1	2	14	55	3
8	1	1	1	-1	4	14	55	3
9	-1	-1	-1	1	2	6	25	7
10	1	-1	-1	1	4	6	25	7

11	-1	1	-1	1	2	14	25	7
12	1	1	-1	1	4	14	25	7
13	-1	-1	1	1	2	6	55	7
14	1	-1	1	1	4	6	55	7
15	-1	1	1	1	2	14	55	7
16	1	1	1	1	4	14	55	7
17	-2	0	0	0	1	10	40	5
18	2	0	0	0	5	10	40	5
19	0	-2	0	0	3	2	40	5
20	0	2	0	0	3	18	40	5
21	0	0	-2	0	3	10	10	5
22	0	0	2	0	3	10	70	5
23	0	0	0	-2	3	10	40	1
24	0	0	0	2	3	10	40	9
25	0	0	0	0	3	10	40	5

Figure 4. shows some samples of the work-pieces after machining.

Fig. 4. Machined samples

IV. RESULTS AND DISCUSSION

A. Mathematical models

Mathematical model was developed to establish the relationship between the process and the performance parameters. This mathematical model predicts the results for the different performance characteristic considered. Minitab17 software was used for this purpose. A second order quadratic equation was used to predict MRR, TWR and surface roughness.

$$\text{MRR (mg/min)} = 348.00 - 41.42\,V + 79.25\,I_p + 38.08\,T_{on} + 34.92\,\tau - 30.02\,V{*}V - 20.52\,I_p{*}I_p - 31.52\,T_{on}{*}T_{on} - 14.52\,\tau{*}\tau - 12.13\,V{*}I_p - 11.37\,V{*}T_{on} - 6.62\,V{*}\tau + 21.63\,I_p{*}T_{on} + 11.38\,I_p{*}\tau + 4.13\,T_{on}{*}\tau$$

$$\text{TWR (mg/min)} = 6.06 - 1.075\,V + 8.450\,I_p - 8.470\,T_{on} + 0.353\,\tau + 0.103\,V{*}V + 2.938\,I_p{*}I_p + 2.381\,T_{on}{*}T_{on} + 0\ .173\,\tau{*}\tau - 0.535\,V{*}I_p + 0.112\,V{*}T_{on} + 0.385\,V{*}\tau\ 6.740\,I_p{*}T_{on} - 0.033\,I_p{*}\tau - 0.265T_{on}{*}\tau$$

$$\text{Surface roughness } (R_a) = 9.600\ - 0.117\,V + 0.667\,I_p + 2.283\,T_{on}0.550\,\tau + 0.388\,V{*}V - 0.462\,I_p{*}I_p\ \ 0.062\,T_{on}{*}T_{on} + 0.03{*}\tau + 0.100\,V{*}I_p + 0.225\,V{*}T_{on} + 0.425\,V{*}\tau + 0.250\,I_p{*}T_{on} - 0.200\,I_p{*}\tau - 0.125\,T_{on}{*}\tau$$

B. Identification of optimal setting for MRR

Optimal settings for MRR were identified using contour plots that were obtained from Minitab17 software. Machining was carried out at these settings.

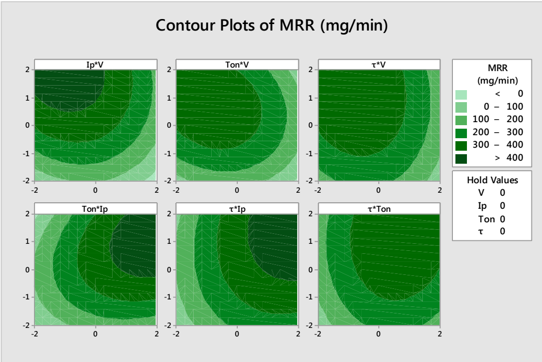

Fig. 5. Contour plot for MRR

Table III. below shows the optimal levels for achieving high MRR for magnetic field assisted EDM process. It can be seen that high levels of peak current (I_p) and pulse on time (T_{on}) are preferred when maximum MRR is required. This is due to the fact that high level of peak current along with pulse on time produces deeper craters in each sparking cycle. Also the presence of the magnetic field also facilitates in efficient MRR. The Lorentz force confines the plasma due to which the sparking intensity is more, thereby creating higher rate of material removal.

Machining was carried out at optimal setting and the MRR was found to be 492 mg/min.

Table III Optimal levels for MRR

Process parameters	**Levels**
Gap voltage (Machine setting)	1^{st} level
Peak current (A)	18
Pulse on time (units)	70
Duty factor (units)	9

C.Identification of optimal settings for TWR

Optimal settings for TWR were identified using contour plots that were obtained from Minitab17 software. Machining was carried out at these settings.

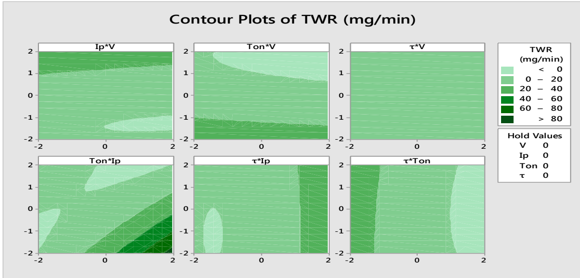

Fig. 6. Contour plot for TWR

Table IV. below shows us the optimal levels for TWR for magnetic field assisted EDM. It can be seen that peak current is kept at its lowest level. Low level of peak current results in lower TWR. For copper tool, TWR increases as the current is increased due to its low melting point. It is also found that TWR reduces upon increasing pulse duration. This can be attributed to the fact that increased pulse duration would result in the generation of massive amount of carbon from dielectric that was used. The carbon could deposit on the electrode surface to form a layer, resulting in a lower TWR.

While machining at optimal setting, it is found magnetic field assisted EDM produced a TWR of 0.86 mg/min.

Table IV. Optimal levels for TWR

Process parameters	**Levels**
Gap voltage (Machine setting)	5^{th} level
Peak current (A)	2
Pulse on time (units)	70
Duty factor (units)	3

D. Identification of optimal levels for surface roughness

Optimal settings for surface roughness were identified using contour plots that were obtained from Minitab17 software. Machining was carried out at these settings.

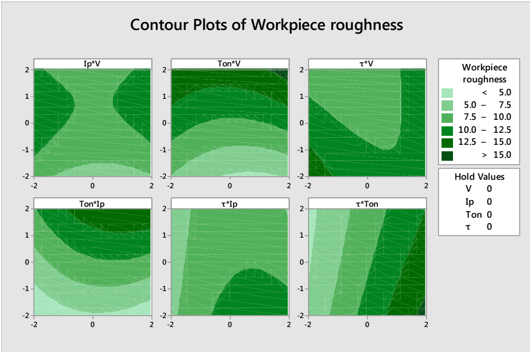

Fig. 7. Contour plot for surface roughness

Table V. shows the optimal level of surface roughness for magnetic field assisted EDM. It can be seen that low level of peak current is preferred when better surface roughness is necessary. Moreover magnetic field also plays an important role is achieving a better surface finish. This is due to the fact in magnetic field assisted EDM the width of the crater formed is smaller with less micro-crack when compared to conventional EDM where the crater formed in is much wider which accounts for the higher surface roughness observed in them.

While machining at optimal setting, lowest surface roughness of 2.0 μm was observed for magnetic field assisted EDM.

Table V. Optimal levels for surface roughness

Process parameters	Levels
Gap voltage (Machine setting)	3rd level
Peak current (A)	2
Pulse on time (units)	10
Duty factor (units)	9

V. Conclusion

It is clearly seen that MRR is greatly influenced by the effect of peak current (I_p) and pulse on time (T_{on}). MRR increases with increase in peak current and pulse on time. TWR reduces with the decrease in peak current. Surface roughness improves with the reduce in peak current. The R^2 value for the mathematical models determined is well over 90%. This confirms that almost all sources of variation are accounted for in the model. More importantly, magnetic field plays a positive role in the EDM process with respect to performance parameters.

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