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MULTI RESPONSE OPTIMIZATION OF PROCESS PARAMETERS IN ELECTRICAL DISCHARGE MACHINING IN AISI D2 TOOL STEEL USING GREY RELATIONAL ANALYSIS

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ABSTRACT

Electrical discharge machining (EDM) is a well-established machining option for manufacturing geometrically complex or hard material parts that are extremely difficult-to-machine by conventional machining processes. In this research work to study the effect of process parameter Current(Ip), Pulse ON-time(Ton), Pulse Off-time(Toff), and constant Gap Voltage (V) on metal removal rate(MRR), electrode wear rate (EWR) and surface roughness on machining of AISI D2 tool steel. The L9 orthogonal array for the three machining parameters at three levels each based on the Taguchi experimental method was adopted to determine EDM machining characteristics. The experiments were performed in a random order, Analysis of variance (ANOVA) was performed and a grey relational grade obtained from the grey relational analysis is used to solve the EDM process with the optimal levels for the multiple performance characteristics responses were established. Experimental results have shown that machining performance in the EDM process can be improved effectively through this approach.

Keywords: *EDM, Electrode wear and Grey Relational Analysis.*

1. Introduction

At present, EDM is a widespread technique used in industry for high-precision machining of all types of conductive materials such as: metals, metallic alloys, graphite, or even some ceramic materials, of any hardness. Luis et al [1] have studied Material removal rate (MRR) and electrode wear study on the EDM of silicon carbide. The process parameters identified were current intensity, pulse-on-time, duty cycle, open circuit voltage and flushing pressure. The responses are electrode wear rate (EWR) and MRR. The study showed that high MRR within the work interval of current intensity and open circuit should be fixed as high as possible. Reduced electrode wear in flushing pressure (20 – 60 Kpa) decreases in the wear on the electrode.

Yusuf Keskin et al [2] worked on the effect of machining parameters on surface roughness in EDM. It was reported that surface roughness shows increasing trend with an increase in the discharge duration. This is mainly due to more discharge energy released during this time and expanding the discharge channel. Puertas et al [3] have studied optimization of machining parameters for EDM of boron carbide. The process parameters were current intensity, pulse-on-time, duty cycle. The responses were EWR, MRR and Surface roughness. It was reported that surface roughness increases significantly with the pulse time. The electrode wear tends to increases slightly when the duty cycle increases.

Zare pour et al [4] reported statistical analysis on electrode wear in EDM. Experiments which have been carried out tool steel DIN 1.2714 work piece material used in forging dies and cylindrical copper electrode as a tool electrode. The process parameters were current intensity, pulse-on-time, voltage, Engaging time. The responses are EWR. It was reported that predictive model was derived out of regression analysis. Ali Ozgedik et al [5] carried out an experimental investigation of tool wear in EDM. Experiments which have been carried out AISI 1040 steel work piece material and cylindrical copper as a tool electrode. It was found that experimentally that workpiece removal rate increases with increasing pulse duration. The increases in tool wear with increasing pulse duration. Payal et al [6] have studied machine surface of tool steel. Experiments which have been carried out tool steel EN-31 work piece material and cylindrical copper and brass electrode as a tool electrode. The process parameters were current intensity, pulse-on-time, and

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pulse of time. The responses were MRR and Heated affected Zone (HAZ). It was reported that for high discharge current, copper electrode show highest MRR, while brass gives good surface finish and normal MRR. Nevzat Aslan et al [7] study the multi-response optimization of process parameter of a lab scale thickness using grey relation analysis. Experiments were conducted to Taguchi L16 orthogonal array to find out the relationship between the responses and process parameter. Manoj Mathew et al [8] conducted experiment on taguchi L934 orthogonal array. Taguchi – grey method analysis was used to optimize the effect of boronising process on pre-carburised low carbon steel of grade AISI 1015.

2. Experimental Procedure

The equipment used to perform the experiment was a Die – Sinking EDM machine of type ELECTRONICA- XPERT SERIES with servo-head (constant gap) and positive polarity for electrode was used to conduct the experiments as shown in the fig 1. Commercial grade IPOL Spark oil (specific gravity= 0.763, freezing point= 94°C) was used as dielectric fluid with internal flushing pressure of 22 Kgf/cm^2 square shaped copper tool with positive polarity of electrode.

The selected parameters for experiment are shown in Table 1. The experiments were conducted on AISI D2 tool steel. The work material (130 x 130 x 10 mm) and electrode used were made of electrolytic copper (with a cross section of 19 x 19 mm). The chemical composition of AISI D2 tool steel is shown in Tables 2. Fig 2. shows the experimental setup.

Table 1: Process Parameter

Factors	Level1	Level2	Level3
Current (A)	5	10	15
Pulse on time (μs)	20	40	75
Pulse on time (μs)	15	20	30
Dielectric used	IPOL Spark oil		

Table 2: Chemical Composition (wt.%) of AISI D2 Tool Steel

Element	C	Mn	Si	Cr	Ni	V	P
Wt %	1.40	0.60	0.60	11	0.30	1.10	0.03

The material removal rate (MRR) is expressed as the workpiece removal weight (WRW) under a period of machining time in minute (T),

$$MRR \quad (g / \text{min}) = \frac{WRW}{T} \qquad (1)$$

The Electrode wear (EW) is expressed as the Volume of material removed from electrode and to Volume of material removed from part

$$\text{EW(g/min)} = \frac{\text{Volume of Material removed from Electrode}}{\text{Volume of Material removed from part}} \qquad (2)$$

The surface roughness is measured by Surtronic3+,Taylor Hobson with a cut-off length of 0.8 mm and sampling number of 5 (traverse length is 0.8×5=4 mm). The initial weights of the workpiece and tool were weighed using 1mg accuracy digital weight machine. The workpiece was held on the machine table using a specially designed magnetic fixture.

Fig. 1 The CNC EDM Electronica- xpert series

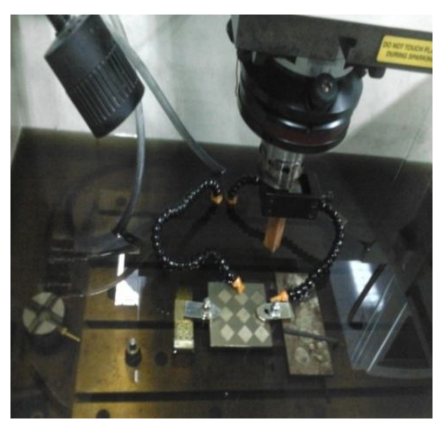

Fig. 2 Experimental Set Up

2.1 Design of experiment

L_9 (3^3) orthogonal array is selected and the values are given in table 3. Accordingly nine experiments are carried out to study the effect of machining input parameters. The conditions for selection of orthogonal array used in the experiment are degree of freedom (DOF) for factors: levels – 1.

DOF for OA : No of trials-1

DOF of L9 orthogonal array : 9-1 = 8

For 3 factors and 3 levels L9 orthogonal array is shown in the Table 3.

2.2 Grey relational analysis

The taguchi method is used for the optimization of the single response variable. The multi-response variables are complicated and complex problems to be solved. The grey relational analysis based on grey system is a statistical technique used to solve the multi response optimization. The black is represented in a system as lack of information, but the white is full of information. Thus, if in a system the information that is either incomplete or uncertain is called Grey system. The Grey system represents a system with incomplete information. The Grey relation is the relation with incomplete information. The Grey relational analysis helps to take decisions under imperfect and unclear situation. It also computes influence of various factors and their relation. The table.4 shows the experimental data.

Table 3: Experimental Layout Using an L9 (3*3) Orthogonal Array

S.No	I (A)	Ton (μs)	Toff (μs)
1	5	20	15
2	5	40	20
3	5	75	30
4	10	20	15
5	10	40	20
6	10	75	30
7	15	20	15
8	15	40	20
9	15	75	30

The first step in the Grey relational analysis is data preprocessing. It is normally carried out due to variable units and range used for the different factors of the experiment. The data preprocessing includes transferring the original sequence to a comparable sequence. Initially the S/N ratio of the quality characteristics of the process to be optimized is converted into normalized S/N ratio. The S/N ratio is normalized as Zij ($0 \leq$ Zij ≤ 1) by the following formula to avoid the effect of adopting different units and to reduce the variability. It is necessary to normalize the original data before analyzing it with the grey relational theory. Eq.(3) is used for the S/N ratio with Larger the better and Eq.(4) is used for the S/N ratio with Smaller the better.[5]

Table 4: Experimental Data for MRR, EWR

S.No	CURRENT (A)	PULSE ON TIME (μs)	PULSE OFF TIME (μs)	MRR (g/min)	EWR %	SURFACE ROUHNESS (μm)
1	5	20	15	0.0070	3.1250	3.43
2	5	40	20	0.0203	1.8190	4.24
3	5	75	30	0.0560	1.0470	6.35
4	10	20	15	0.0659	2.8900	4.53
5	10	40	20	0.1810	2.2090	6.29
6	10	75	30	0.2180	0.9170	6.67
7	15	20	15	0.2610	1.3700	6.63
8	15	40	20	0.4120	1.0980	7.99
9	5	75	30	0.4750	0.8840	10.93

$$z_{ij} = \frac{y_{ij} - \min(y_{ij}, i = 1,2,...n)}{\max(y_{ij}, i = 1,2,...n) - \min(y_{ij}, i = 1,2...n)} \qquad (3)$$

$$z_{ij} = \frac{\max(y_{ij}, i = 1,2,...n) - y_{ij}}{\max(y_{ij}, i = 1,2,...n) - \min(y_{ij}, i = 1,2...n)} \qquad (4)$$

In the grey relational analysis, the degree of grey relation is defined by the extent of the relation between two sequences. When only one sequence, Yo (k), is available as the reference sequence, and all other sequences serve as comparison sequences, it is called as the grey relation coefficient. The average value of the grey relational coefficient is called as the grey grade and the multi-response optimization results are based on the grey relational grade. The grey relational coefficient and grey relational grades are computed by the Eqs. (5) - (6).

$$\gamma(y_o(k), y_i(k)) = \frac{\Delta\min + \psi\Delta\max}{\Delta_{oj}(k) + \psi\Delta\max} \tag{5}$$

Where

J=1, 2…n; k=1, 2…m, n is the number of experimental data items and m is the no of responses. $y_o(k)$ is the reference sequence ($y_o(k)$ =1,k=1,2…m); $y_j(k)$ is the specific comparison sequence. $\Delta_{oj}(k) = \left\| y_o(k) - y_j(k) \right\| =$ the absolute value of the difference between $y_o(k)$ and $y_j(k)$ $\Delta_{min} = \min_{\forall j \in i} \min_{\forall k} \left\| y_o(k) - y_j(k) \right\|$ is the smallest value of $y_j(k)$ $\Delta_{max} = \max_{\forall j \in i} \max_{\forall k} \left\| y_o(k) - y_j(k) \right\|$ is the largest value of $y_j(k)$ ψ is the distinguishing coefficient which is defined in the range $0 \le \psi \le 1$

$$\overline{\gamma_j} = \frac{1}{k}\sum_{i=1}^{k} \gamma_{ij}$$

where $\overline{\gamma_j}$ is the grey relational grade for the jth experiment and k is the no of performance characteristics. A higher grey relational grade implies the parameter closer to the ideal sequence. Therefore, on the basis of the grey relational grade, the factor effect can be estimated and the optimal level for each controllable factor can also be determined. After the optimal level of the design parameters has been selected, the next step is to predict and verify the quality characteristic using the optimal level of the design parameters. The predicted grey relational grade using optimal edm parameters can be calculated by the Eq. (8).

$$\gamma = \gamma_m + \sum_{i=1}^{q} (\overline{\gamma_i} - \gamma_m) \tag{6}$$

γ_m denotes the mean grey relational grade, $\overline{\gamma_i}$ denotes the grey relational grade at the optimal level and q is the number of EDM process parameters that significantly affect the MRR, EWR and surface roughness

2.4 Analysis of variance (ANOVA)

Analysis of variance is a technique to categorize the effect of individual factors. For identifying the significant factors ANOVA is performed using the Grey relational grade values. Results from the ANOVA can determine very clearly the effect of each factor on the performance characteristics.

3. Results and discussion

The S/N ratio and Normalized S/N ratio for the MRR ,electrode wear and surface roughness were calculated from the Eqs. 3 to 6. The value of distinguishing coefficient ψ is taken as 0.5, as equal weightage is given for both the responses. The value of grey relational grade and rank of each experiment are given in table 5. It is clearly evident from the table.5 that EDM parameters of the experiment No. 9 have the highest grey grade. Therefore experiment No.9 has the optimal parameter setting for the best multi-response characteristics of MRR, EWR and surface roughnessThe average grey relational Grade values for each level of the parameter were calculated and tabulated in the response Table 6. The procedure for finding out the average grey relational grade for each of the levels was calculated by grouping the grey relational grade at the factor level for each column in the orthogonal array and taking its average. The grey relational grade for the factor S at level 1 can be calculated by

$$\gamma S1 = \frac{1.0000 + 0.3383 + 0.9697}{3} = 0.7777 \tag{7}$$

The average grey relational grade values of all the parameters at various levels were calculated by the above procedure. The Higher the relational grade, better the performance of the parameter at that level. Therefore, the optimal level of the parameter is the level with the highest value of the average grey relational grade value.

Table 5: Grey Relation Grade for MRR, EW and SR

S.NO	Grey relation grade	Order
1	0.5555	7
2	0.5690	6
3	0.5978	4
4	0.4984	8
5	0.4896	9
6	0.6613	3
7	0.5864	5
8	0.6928	2
9	0.7777	1

The difference between the Max and Min value of the grey relational grade is also indicated in table 6 and table 7. The value of the Max-Min of the EDM parameters were 0.6646 for current, 0.6117 for pulse on time and 0.6506 for pulse off time. The maximum of the Max-Min value indicates most effective factor affecting multi- response characteristics. The optimal combination of EDM parameters A3 B2 C3 and the corresponding factors, current 15A, Pulse on time 40µs, Pulse off time 30µs that produced a high value of grey regression grade is 0.7777. fig 3 shows the grey relation grade

Table 6: Machining Parameter and Grey Relation Grade

S.No	Machining parameters level	Grey relational grade
1	A1	0.5497
2	A2	0.5791
3	A3	0.6646
4	B1	0.5867
5	B2	0.6117
6	B3	0.6055
7	C1	0.5608
8	C2	0.5577
9	C3	0.6506

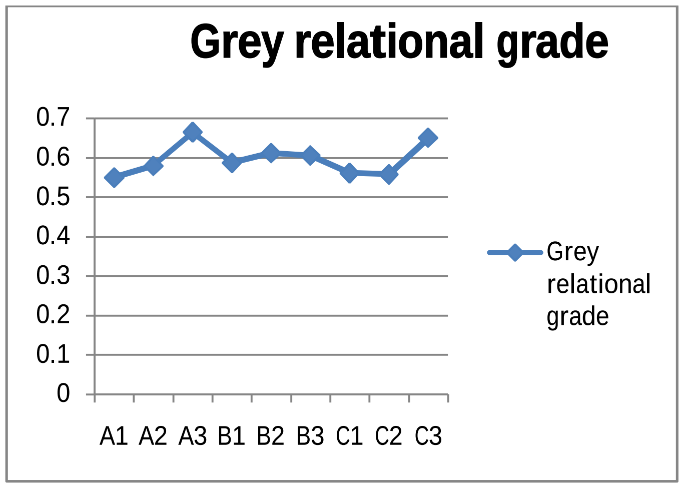

Fig.3. Grey Relation Range

Table 7: Response Table of the Average Grey Relational Grade

Control factor	Average grey relational grade by factor level			Max-Min
	Level 1	Level 2	Level 3	
Current (A)	0.5467	0.5791	0.6646	0.6646
Pulse on time (µs)	0.5867	0.6117	0.6055	0.6117
Pulse off time (µs)	0.5608	0.5577	0.6506	0.6506

4. Conclusion

Experiments were conducted according to Taguchi method by using the machining set up and the designed square shaped electrodes with impulse flushing. The control parameters like constant discharge current (A), varying Pulse on time (TON) and Pulse off time (TOFF) were varied to conduct 9 different experiments and the weights of the work piece and Tool and dimensional measurements of the cavity were taken for calculation of MRR, EW and surface roughness for the following conclusions are arrived :

- The maximum material removal rate a current of 15 A, pulse on time of 75µs and pulse off time of 30µs, 0.4750 is obtained.
- The optimal combination of EDM parameters A3 B2 C3 and the corresponding factors, current 15A, Pulse on time 40µs, Pulse off time 30µs that produced a high value of grey regression grade is 0.7777.
- Current of 5A, pulse on time of 20µs and pulse off time of 15µs, the minimum value of 3.43 µm is obtained for surface roughness.

The electrode wear ratio is decreased as keeping the current as constant and increasing the pulse on time and pulse off time

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