

Optimization of EDM Process Parameters Using GRA & Taguchi Method



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Abstract EDM devices require input for process variables such as current, pulse-on time and pulse-off time while keeping voltage, work time, jump, servo speed and spark gap values constant. According to the fundamental tenets of the grey relational analysis (GRA) approach, the selected alternative should have the “greatest degree of grey relation” to the positive-ideal solution and the “smallest degree of grey relation” to the negative-ideal option. Using a design matrix developed by Dr. Genichi Taguchi, Taguchi orthogonal array (OA) design is a sort of general fractional factorial design that enables you to consider a chosen subset of combinations of various factors at various levels. Despite the fractionality of the design, the elements can be assessed independently. This paper discusses applications of GRA and OA, to increase material removal rate and decrease electrode wear rate by optimizing the machining parameters of electro-discharge machining (EDM) using P20 tool steel. The factors selected to decrease time and save money are material removal rate (MRR) and electrode wear rate (EWR), and the machining parameters to achieve the same are current- I , pulse-on time- T_{ON} and pulse-off time- T_{OFF} . After using the optimal combination of machining parameters, applying grey relational and Taguchi method, optimal values were determined for improved performance of the machining process.

Keywords EDM · Taguchi method · Grey relational analysis · MRR · EWR

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1 Introduction

Electrical discharge machining, (EDM), is a process that cuts metal with the help of an electric current, with the gap that has to be maintained between the electrode and the workpiece. The connected power supply helps in generating a potential between them as both are good conductors of electricity. An electric field would be established which is dependent on a few factors such as the gap that is present between tool and workpiece and the potential difference applied. The energy from the potential difference applied is able to melt metal due to which the metal is machined. Finally, a crater is formed in the work piece that is almost of the similar shape as that of the tool. The EDM process is able to cut the metals easily and with a set of parameters can provide different levels of finishing as required, with no need for any post-machining process or treatment. In sum, saving time and costs while providing the necessary surface finish.

2 Literature Survey

Nayak and Routara [1], discuss the conclusion of Taguchi method to optimize individual factor selected like MRR and EWR in EDM [1]. Maiyar et al. [2] discusses the optimization of parameters in a milling operation for Inconel 718 alloy by using the combination of Taguchi method paired with the grey relational analysis. Finally, confirmation tests were carried out to compare the results, and the results conclude that the end milling machining performance process can be improved effectively [2]. Seelan and Rajesh [3] discuss about metals having high corrosion resistance properties with higher mechanical properties having their significant applications in modern times. Aluminium alloy LM25, which is having good mechanical properties with combined corrosion resistance properties, is stir cast with titanium and boride salt to get Al-TiB₂, which is used for this study with copper as electrode. For optimizing the process parameters, Taguchi method is used, selecting L9 orthogonal array [3]. Jeevamalar et al. [6] concluded that current was major parameter followed by pulse-on and pulse-off time for MRR & EWR [6]. Nadpara, V. J., & Choudhary [4] also concluded that MRR and EWR were mainly affected by current [4]. Singh et al. [5] discuss optimizing multiple performance characteristics such as pulse-on time, pulse-off time, discharge current and gap voltage [5]. Prajapati and Trivedi [7] found MRR was at its highest at 6 amps of current, 100 μ s of pulse-on time and 40 μ s of pulse-off time. EWR was maximum at current of 4 amps, pulse-on and pulse-off times of 100 μ s and 50 μ s, respectively [7]. Gaikwad et al. [8] presented effect of control factors on MRR & EWR for die sinking EDM of SS316 [8]. Banker et al. (2014) have focused on optimizing the process parameters of EDM in terms of MRR [9]. Ohdar et al. [10], presented effect of control factors on MRR & TWR for EDM of M.S. using Taguchi's DOE [10].

3 Experimental Setup

Dielectric medium is EDM fluid, i.e. Ipol Spark erosion oil 350. Graphite electrode is used with density of 1.85 g/cc. Table 1 shows array 3 signal levels and 3 factors; therefore, L9 orthogonal array was chosen to optimize the parameters like input current(I), (T_{ON}) pulse-duration, pulse-on time and (T_{OFF}) pulse-off time while keeping other characteristics constant. Tables 2 and 3 illustrate the parametric values arranged and divided into readings based on L9 array.

Table 1 Machining parameters

	Level 1	Level 2	Level 3
Current (AMP)	4	6	8
T _{ON}	80	100	120
T _{OFF}	60	80	100

Table 2 Arrangement into L9 orthogonal array

I	T _{ON}	T _{OFF}
4	80	60
4	100	80
4	120	100
6	80	80
6	100	100
6	120	60
8	80	100
8	100	60
8	120	80

Table 3 Machining time and weight difference for P20 tool steel

Exp. no.	(I)	(T _{ON})	(T _{OFF})	W _B -W _A (g)	E _B -E _A (g)	T (MINS)
1	4	80	60	4.14	2.2	54
2	4	100	80	5.58	1.58	48
3	4	120	100	3.68	1.9	56
4	6	80	80	4.24	1.02	38
5	6	100	100	9.43	2.5	46
6	6	120	60	12.74	1.96	73
7	8	80	100	4.51	1.5	103
8	8	100	60	6.82	1.52	86
9	8	120	80	8.58	1.4	53

Table 4 Calculation of MRR and EWR

Exp. no.	I	T _{ON}	T _{OFF}	MRR	EWR
1	4	80	60	9.77	22.02
2	4	100	80	14.81	17.86
3	4	120	100	8.37	18.34
4	6	80	80	14.21	14.57
5	6	100	100	26.11	29.38
6	6	120	60	22.24	14.53
7	8	80	100	5.58	7.87
8	8	100	60	10.10	9.56
9	8	120	80	20.62	14.28

For calculating **MRR**, we are using the formula:

$$\frac{(W_B - W_A) * 1000}{D * T} mm^3 / min$$

For calculating **EWR**, we are using formula:

$$\frac{(E_B - E_A) * 1000}{D * T} mm^3 / min$$

where W_B/E_B = Workpiece/electrode weight before machining (g)

W_A/E_A = Workpiece/electrode weight after machining(g).

D = Density of P20 steel (g/cc) = 8.96 g/cc and T = Time (mins.)

Results after calculating MRR and EWR are listed in Table 4.

3.1 Taguchi Method

Analysis was carried out using Taguchi method by L9 orthogonal array on Minitab 19 software; response tables and graphs were generated for getting optimized values.

3.2 Inference from Taguchi Method

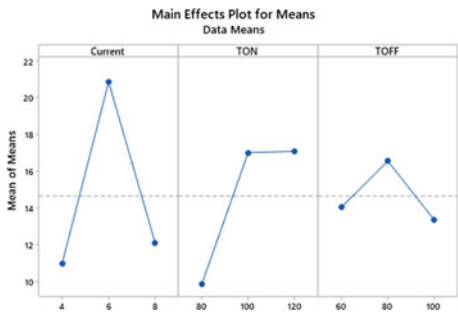
Choose ‘Larger the better’ option for getting S/N ratio values in Minitab software for MRR. The graph on main effects plot for S/N ratio for MRR and the response table are shown below in Fig. 1.

The graph on the main effects plot for mean is shown in Fig. 2, with the relevance of each process parameters that were rated as per delta value from high to low.



Data for S/N Ratio			
Larger is Better			
<u>Level</u>	<u>I</u>	<u>T_{ON}</u>	<u>T_{OFF}</u>
1	20.56	19.26	22.28
2	26.11	23.95	24.25
3	20.44	23.90	20.57
Delta	5.67	4.69	3.68
Rank	1	2	3

Fig. 1 S/N ratio larger is better for MRR

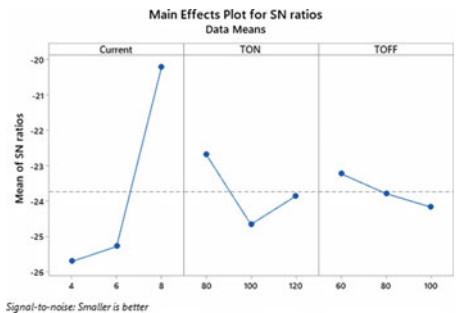


Data for Means			
<u>Level</u>	<u>I</u>	<u>T_{ON}</u>	<u>T_{OFF}</u>
1	10.986	9.851	14.036
2	20.853	17.011	16.553
3	12.103	17.080	13.353
Delta	9.867	7.229	3.200
Rank	1	2	3

Fig. 2 Main effects plot for means of MRR

To acquire S/N values for EWR, we would similarly select the “smaller the better” option in the Minitab software, and then generate a main effects plot for S/N values as shown in Fig. 3, as well as a response table.

Accordingly, we receive the graph for the mean’s primary effects as shown in Fig. 4, along with the relevance of each of the process parameters that were rated in the response table based on their delta values, from high to low.



Data for Means			
<u>Level</u>	<u>I</u>	<u>T_{ON}</u>	<u>T_{OFF}</u>
1	-25.72	-22.68	-23.24
2	-25.29	-24.67	-23.80
3	-20.21	-23.87	-24.18
Delta	5.51	1.99	0.94
Rank	1	2	3

Fig. 3 S/N ratio for EWR

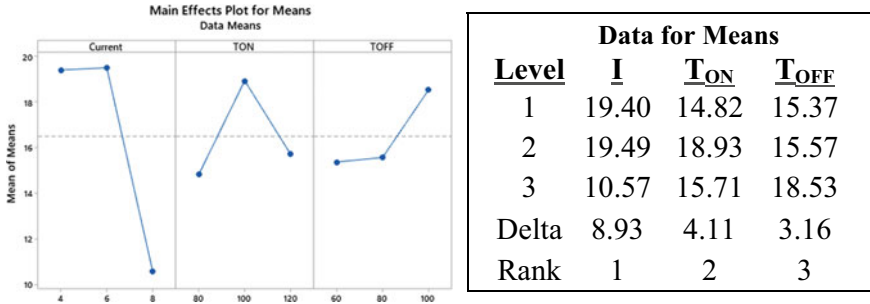


Fig. 4 Main effects plot for means of EWR

Table 5 Normalized values for MRR and EWR

Exp. No.	I	T _{ON}	T _{OFF}	MRR	EWR	MRR normalize	EWR normalize
1	4	80	60	9.77	22.02	0.2041	0.3422
2	4	100	80	14.82	15.29	0.4501	0.5356
3	4	120	100	8.37	18.33	0.1359	0.5137
4	6	80	80	14.21	14.57	0.4204	0.6885
5	6	100	100	26.11	29.38	1.0000	0.0000
6	6	120	60	23.56	12.59	0.8115	0.6904
7	8	80	100	5.58	7.87	0.0000	1.0000
8	8	100	60	10.10	11.94	0.2202	0.9214
9	8	120	80	20.63	14.27	0.7331	0.7025

4 Using Grey Relational Analysis (GRA) to Verify Optimized Values

Data pre-processing is necessary in GRA because the range and unit in one data sequence may vary from the others.

For the MRR, we use ‘larger the better’ characteristic and can be normalized as: $x_i^*(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)}$	For the EWR, we use ‘smaller the better’ characteristic and can be normalized as: $x_i^*(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(k) - \min x_i(k)}$
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where $x_i^*(k)$ and $x_i^*(k)$ are the sequence after pre-processing data and comparability sequence, respectively, $k = 1$ for MRR/EWR; $i = 1, 2, 3, \dots, 9$ for expt. numbers 1 to 9.

Calculations were carried out for readings 1 to 9 for MRR with normalized values are shown in Table 5.

Calculating the deviation sequence for each reading using following formula $\Delta_{0i}(k) = |x_0^*(k) - x_i^*(k)|$, $\Delta_{0i}(k)$: deviation sequence of reference sequence $x_0^*(k)$ and the comparability sequence $x_i^*(k)$.

Table 6 DEVIATION SEQUENCES FOR MRR AND EWR

Exp. NO	MRR Normalize	EWR Normalize	MRR Deviation	EWR Deviation
1	0.2041	0.3422	0.7959	0.6578
2	0.4501	0.6550	0.5499	0.4644
3	0.1359	0.5137	0.8641	0.4863
4	0.4204	0.6885	0.5796	0.3115
5	1.0000	0.0000	0.0000	1.0000
6	0.8758	0.7807	0.1885	0.3096
7	0.0000	1.0000	1.0000	0.0000
8	0.2202	0.8108	0.7798	0.078
9	0.7331	0.7025	0.2669	0.2975

Table 7 Grey relational coefficient and grade

Exp. No.	MRR coefficient	EWR coefficient	GRA grade
1	0.3858	0.4318	0.4088
2	0.4762	0.5184	0.4973
3	0.3665	0.5070	0.4367
4	0.4631	0.6162	0.5396
5	1.0000	0.3333	0.6667
6	0.7262	0.6176	0.6719
7	0.3333	1.0000	0.6667
8	0.3907	0.8642	0.6275
9	0.6520	0.6269	0.6395

MRR and EWR with deviation sequence values shown in Table 6.

The grey relational coefficient is defined as follows: $\xi_i(k) = \frac{\Delta_{\min} + \zeta \Delta_{\max}}{\Delta_{gi}(k) + \zeta \Delta_{\max}}$, ζ distinguishing or identification coefficient. ζ was taken 0.5, as all parameters have equal preference.

The grey relational grade is calculated by: $\gamma_i = \frac{1}{n} \sum_{k=1}^n \xi_i(k)$.

Grey relational coefficient for MRR and EWR and grey relational grades were calculated for each reading, **using above equations**, are shown in Table 7.

4.1 Inference from GRA

Based on arrangement of signal values in L9 OA for each parameter, mean of grey relational grade was calculated for each of these signal values. Simultaneously, the difference between highest and lowest mean grade was calculated and that difference

Table 8 Significance of machining parameters through grey relational grade

Process parameters	Grey relational grade			Main effects (Max–Min)	Rank
	Level1	Level2	Level 3		
I (Amps)	0.4476	0.6261	0.6445	0.1969	1
T _{ON} (μsec)	0.5384	0.5972	0.5872	0.0588	2
T _{OFF} (μsec)	0.5694	0.5588	0.5900	0.0312	3

was then ranked from 1 to 3 with highest value given rank 1 and lowest ranked 3 (Table 8).

The difference between the max value and min value for the parameter I is highest, followed by T_{ON} and T_{OFF}. Hence, the ranking level of the parameters is 1, 2, and 3, respectively.

4.2 Conformation Test

A verification test is carried out to double check the analysis done previously. A random setting level is chosen from the experiments conducted so as to compare the change with the optimal parameters determined. Here, the setting level is of level 1 of I, level 2 of pulse-on time, T_{ON} and level 2 of pulse-off time, T_{OFF}.

The estimated grey relational grade, using the optimal level of the process parameters, can be calculated as:

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

where γ_i is the mean of grey relational grade at the optimum level, γ_m is the mean grey relational grade and q is the number of machining parameters (Table 9).

The grey relational grade is increased by 0.1889 or 38%.

The characteristic material removal rate is increased by 6.6 **mm³/min** or 45%.

The characteristic electrode wear rate is decreased by 5.08 **mm³/min** or 28%.

Table 9 Comparison with previous experiment

	Initial machining parameters	Optimal machining parameters
Setting level	A1B2C2	A3B2C3
Grey relational grade	0.4973	0.6862
Material removal rate	14.82	21.416
Electrode wear rate	17.86	12.788

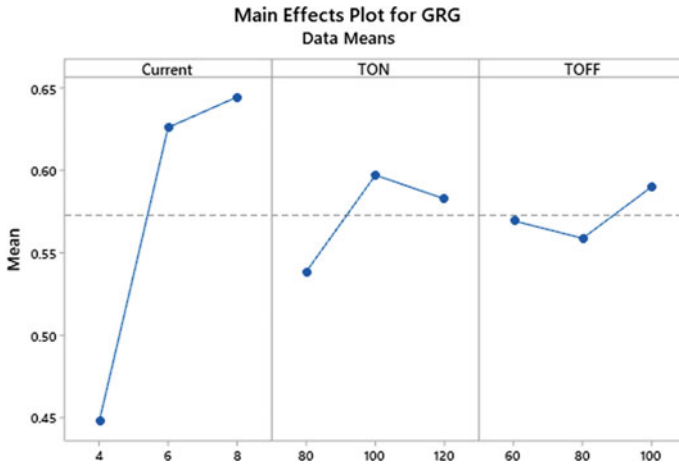


Fig. 5 Main effects plot for GRG data means

5 Result

Taguchi Method:—MRR is affected the highest by I, followed by T_{ON} and T_{OFF} .

MRR is maximized at I-6(amp); pulse-on time-(120 μ s) & pulse-off time-(80 μ s).

EWR is affected the highest by I(Current) followed by T_{ON} and T_{OFF} .

EWR is maximized at I-8(amp); T_{ON} (80 μ s) & T_{OFF} (60 μ s).

Grey Relational Analysis:—The analysis had showed that most significant parameters were ranked as 1. current (I), 2. T_{ON} and 3. T_{OFF} (Fig. 5).

6 Conclusion

The results after employing the Taguchi method, Minitab software, grey relational analysis and conformation tests, showed the importance of parameters selected and helped in determining their optimal values, thus improving the efficiency by saving time and saving costs for the company. It was observed that the characteristic material removal rate increased by 6.6 mm^3/min or 45%, and the characteristic electrode wear rate decreased by 5.08 mm^3/min or 28%. The optimal values obtained resulted in overall improvement of the EDM process, and the reduced time can be used for other value adding activities.

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