Multi Response Optimization of Process Parameters in EDM Using Soft Computing Techniques

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Abstract: *In this paper a combination of Gray Relational Analysis (GRA) and GRA based Principal Component Analysis (PCA) are used for optimizing the Electrical Discharge machining responses, such as material removal rate(MRR), and Tool wear rate(TWR). The input parameters considered for this analysis are pulse on time (µ seconds), flushing pressure (kg/cm2), voltage (V), and peak current (amperes) to see the effect on the responses. The GRA based PCA is used to compute the weight of the responses during the optimization. Subsequently, the effects of each of these input parameters are analyzed and presented. These results provide the information that how to control the parameters so as to get the maximum MRR without losing the tool accuracy.*

Key words: **GRA, GRA based PCA, MRR, TWR**

I. Introduction

Aluminum alloy 2014 is one of the most extensively used among the 2000 series aluminium alloys. AA-2014 is used in wide variety of applications due to its high hardness, ease of machinability. It is commonly extruded and forged. Aluminium alloy 2014 is commonly used in aerospace structural applications due to its high strength. Other applications include military vehicles, bridges, weapons manufacturing and structural applications [1]. T. Roy et al. [2] studied the effect of EDM Parameters based on tool overcut using Stainless Steel. The process parameters considered were pulse on time, duty cycle, discharge current and gap voltage. Taguchi's L9 orthogonal array was selected for conducting the experiments. The optimal cutting parameters for minimum tool overcut were determined. It was observed that TOC decreases initially and then increases with a gradual increase in pulse on time. Duty cycle causes an increase in TOC initially but decreases afterwards.

Raghuraman S et al. [3] investigated on optimization of EDM parameters using taguchi method and grey relational analysis for mild steel 2026. The research work was carried out to identify the optimal set of process parameters such as current, pulse ON and OFF time in Electrical Discharge Machining (EDM) process and to optimize three performance characteristics such as rate of material removal, wear rate on tool, and surface roughness value on the work material for machining Mild Steel IS 2026 using copper electrode. This work demonstrates the utilization of Taguchi methods for optimizing the EDM parameters and multiple response characteristics. ShantisagarBiradar et al. [4] proposed optimization of EDM Process using grey relational analysis. Based on the orthogonal array determined using factorial design, experiments were conducted on High Carbon High Chromium Die steel (HCHCr) and analysed using GRA. Current is the most dominant parameter for the titanium nitride coated copper electrode that has high influence on both MRR and EWR followed by pulse on time.From the literature, it is observed that few works have been reported on EDM on the materials like Tungsten Carbide ceramics, Ti-5Al-2.5Sn, heat treated EN-31, mild steel is 2026, 304 Stainless Steel and different mathematical models were used to validate the experimental results.

The objective of the present work is an attempt to find the feasibility of machining AL-2014on EDM machine with copper used as an electrode. In this paper, a combination of Gray Relational Analysis (GRA) and Principal Component Analysis (PCA) based GRA were applied to optimize the Electrical Discharge machining responses, such as material removal rate (MRR) and Total wear rate (TWR). The input parameters considered for this analysis are pulse on time (T_{on}), Pulse Off time (T_{off}) **,**voltage(V) and Peak current(IP). The PCA is used to compute the weight of the responses during the optimization. Subsequently, the effects of each of these input parameters are analyzed. These results provide the information that how to control the parameters so as to get the maximum MRR without losing the surface accuracy and tool accuracy.

II. Experimental work

In this study, an EDM machine was used as the experimental machine. Copper used as an electrode of diameter 10mm and machining was carried on the Al-2014 work piece. Kerosene was employed as dielectric fluid to improve the machining performance. Machining experiments for determining the optimal machining parameters were carried out setting pulse on time in the range of 60-180 micro seconds, peak current in the range of 12-18 amps, voltage in the range 30-120 volts, flushing pressure in the range 1-2 (kg/cm^2). In the machining process considering the four input parameters pulse on time (Ton), flushing pressure (kg/cm^2), voltage (V), Peak current(IP) and performing measures are material removal rate and tool wear rate.

Fig 1 Workpiece before experiment

Table 1 Process parameters and their levels

Process Parameters	Level-1	Level-2	Level-3
Pulse on time(Ton)	60	120	180
Peak current(IP)	12	18	24
Voltage(V)	30	90	120
Flushing pressure(kg/cm$^{2)}$	1	1.5	2

Table 1 gives the process parameters considered in the experimental work. Pulse on time, peak current, voltage and flushing pressure are considered with three different levels.

Table 2 Experimental results

S.No	Pulse On Time(µsecs)	Peak Current (Amp)	Voltage (V)	Flushing Pressure (Kg/cm^2)	MRR (mm^3/min)	TWR (mm^3/min)
1	60	12	30	1	1.0085	5.5274
2	60	18	90	1.5	1.238	6.935
3	60	24	150	2	0.799	4.3011
4	120	12	90	2	1.1075	5.5423
5	120	18	150	1	1.0705	5.7235
6	120	24	30	1.5	1.126	5.7504
7	180	12	150	1.5	1.1334	6.2263
8	180	18	30	2	1.0998	6.2365
9	180	24	90	1	1.08499	6.47102

L-9 orthogonal array is considered as shown in table 2 and nine experiments were performed to study the responses material removal rate and tool wear rate.

Fig 2 Workpiece after experiment

III. Grey relational analysis

In GRA, the first step of grey relational analysis is to normalize (in the range between0 and 1) the experimental data according to the type of performance response.

Step 1: Normalization of S/N ratio

Tool wear rate- smaller the better performance characteristic can be expressed as

$$y_i{}^*(k) = \frac{\max y^{(0)}{}_i(k) - y^{(0)}{}_i(k)}{\max y^{(0)}{}_i(k) - \min y^{(0)}{}_i(k)} \text{---------------------Eq (1)}$$

k = 1, 2 for Tool wear rate. i = 1, 2, 3 . . . 9 for experiment number1–9.

Material removal rate-larger the better performance characteristic can be expressed as

$$y_i{}^*(k) = \frac{y^{(0)}{}_i(k) - \min y^{(0)}{}_i(k)}{\max y^{(0)}{}_i(k) - \min y^{(0)}{}_i(k)} \text{---------------------Eq(2)}$$

k = 3 for Material removal rates. i = 1, 2, 3,. . .9 for experiment number 1-9.

Table 3 GreyRelational Generation

S.NO	MRR (mm^3/min)	TWR (mm^3/min)
1	-14.9235	-14.85
2	-1.8544	-16.82
3	1.9468	-12.6715
4	-0.8868	-14.87
5	-0.5924	-15.1532
6	-1.03	-15.1939
7	-1.0876	-15.884
8	-0.8262	-15.8988
9	-0.7085	-16.2194

The absolute difference of the compared series and the referential series should be obtained by using the following formula

$$\Delta x_i(k) = \left| x_0(k) - x_i(k) \right| \text{--------------------------------------Eq (3)}$$

$$y_i^*(k) = \frac{y_i^{(o)}(k) - \min y_i^{(o)}(k)}{\max y_i^{(o)}(k) - \min y_i^{(o)}(k)} \qquad y_i^*(k) = \frac{y_i^{(o)}(k) - \min y_i^{(o)}(k)}{\max y_i^{(o)}(k) - \min y_i^{(o)}(k)}$$

Table 4 Normalization of Responses

S.NO	MRR (mm^3/min)	TWR (mm^3/min)
1	0.4685	0.52511
2	0	1
3	1	0

4	0.25455	0.5299
5	0.332	0.5982
6	0.2168	0.608
7	0.2017	0.7743
8	0.2704	0.7779
9	0.3014	0.8552

Step 2: Grey Relational Coefficient (GRC)

Grey relational coefficient for all the sequences gives the relationship between the ideal (best) and actual normalized experimental results. The GRC can be expressed as:

$$y_i^*(\text{k}) = \frac{\Delta_{min}+\phi\Delta_{max}}{\Delta_i(\text{k})-\phi\Delta_{max}}$$ --Eq (4)

Table 5 Grey Relational Coefficient

S.NO	MRR	TWR
1	0.5163	0.4878
2	1.05	0.3333
3	0.3333	1
4	0.6626	0.4855
5	0.601	0.4553
6	0.6975	0.4513
7	0.7126	0.3924
8	0.649	0.3913
9	0.6239	0.3689

Step 3: Grey Relational Grade (GRG)

The overall evaluation of the multiple performance characteristics is based on the GRG. The grey relational grade is an average sum of the GRC, and can be expressed as:

$$\varepsilon_i = \frac{1}{n}\sum_{\varepsilon_i}^{n} k = 1\, w_k \gamma_i(k)$$ --Eq (5)

Table 6Grey Relational Grade

S. No	Pulse On Time (Micro Secs)	Peak Current (Amp)	Voltage (V)	Flushing Pressure (Kg/Cm^2)	MRR (mm^3/min)	TWR (mm^3/min)	GRG	Rank
1	60	12	30	1	0.5163	0.4878	0.5021	8
2	60	18	90	1.5	1.05	0.3333	0.6954	1
3	60	24	150	2	0.3333	1	0.6665	2
4	120	12	90	2	0.6626	0.4855	0.5741	4
5	120	18	150	1	0.601	0.4553	0.5282	6
6	120	24	30	1.5	0.6975	0.4513	0.5744	3
7	180	12	150	1.5	0.7126	0.3924	0.5525	5
8	180	18	30	2	0.649	0.3913	0.5202	7
9	180	24	90	1	0.6239	0.3689	0.4964	9

IV. GRA– basedPCA method

The S/N ratio with lower the better (LTB) and higher the better (HTB) are represented in the equations 6 and 7 respectively.

Step 1: Lower the Better response variable

$$\eta_{ij} = -10log\frac{1}{n}\sum_{i=1}^{n} {y_i}^{-2} \text{--Eq (6)}$$

Step 2: Higher the Better response variable

$$\eta_{ij} = -10log\frac{1}{n}\sum_{i=1}^{n} {y_i}^{2} \text{--Eq (7)}$$

Table 7 S/N ratio with LTB &HTB

S.NO	MRR (mm^3/min)	TWR (mm^3/min)
1	-14.9235	-14.85
2	-1.8544	-16.82
3	1.9468	-12.6715
4	-0.8868	-14.87
5	-0.5924	-15.1532
6	-1.03	-15.1939
7	-1.0876	-15.884
8	-0.8262	-15.8988
9	-0.7085	-16.2194

By using equations 6 and 7 S/N ratio of responses MRR and TWR is calculated and tabulated in the above table.

Table 8 Covariance matrix

X1-X1BAR	X2-X2BAR	A*B	EIGEN VALUES		
A	B	0.21538	0.3573	-0.9345	A
0.4957	0.4345	1.97511	0.9345	0.3573	B
-1.2863	-1.5355	6.57117			
2.5148	2.613	-0.1321			
-0.3187	0.4145	-0.00319			
-0.02433	0.1313	-0.04185			
-0.46193	0.0906	0.31144			
-0.5195	-0.5995	0.15856			
-0.25813	-0.6143	0.13128			
-0.14043	-0.9349	1.020644			

$$PCS_{il} = a_{l1}\eta_{i1} + a_{l2}\eta_{i2} + \ldots\ldots + a_{lj}\eta_{ij} \text{ ---Eq (8)}$$

Where $a^2_{l1} + a^2_{l2} \ldots\ldots + a^2_{lj} = 1.$

Table 9 PCS values

PCS		NORMALISATION	
MRR	TWR	MRR	TWR
0.5832	-0.308	0.4733	0.4645
-1.8945	0.6534	0	0
3.3404	-1.4165	1	1
0.2735	0.4459	0.4141	0.1002
0.114	0.0696	0.3837	0.282
-0.083	0.464	0.346	0.0915
-0.7459	0.2713	0.2194	0.1846
-0.6663	0.0217	0.2346	0.3052
-0.9238	-0.2028	0.1854	0.4136

$$y_i^*(\mathrm{k}) = \frac{\Delta_{min}+\emptyset\Delta_{max}}{\Delta_i(\mathrm{k})-\emptyset\Delta_{max}}$$ ………….Eq (9)

Table 10 PCA based GRC

MRR	TWR
0.5163	0.4878
1.05	0.3333
0.3333	1
0.6626	0.4855
0.601	0.4553
0.6975	0.4513
0.7126	0.3924
0.649	0.3913
0.6239	0.3689

$$\gamma = \frac{1}{n}\sum_{i=1}^{n} w\zeta_{ij}$$ ……………………………….Eq (10)

Table 11 Overall Quality Performance Index

GRADE	RANKING
0.5161	8
1	1
0.3333	9
0.6901	4
0.6026	7
0.7182	2
0.7127	3
0.6508	5
0.6386	6

V. Taguchi Analysis

Table 12 Response Table for Signal to Noise Ratios Larger is better

Level	Pulse on time	Peak current	Voltage	Pressure
1	-5.096	-3.970	-4.117	-4.680

2	-3.499	-2.710	-2.372	-1.939
3	-3.523	-5.438	-5.628	-5.499
Delta	1.597	2.728	3.256	3.560
Rank	4	3	2	1

Table 13 Response Table for Means

Level	Pulse on time	Peak current	Voltage	Pressure
1	0.6165	0.6396	0.6284	0.5858
2	0.6703	0.7511	0.7762	0.8103
3	0.6674	0.5634	0.5495	0.5581
Delta	0.0538	0.1878	0.2267	0.2522
Rank	4	3	2	1

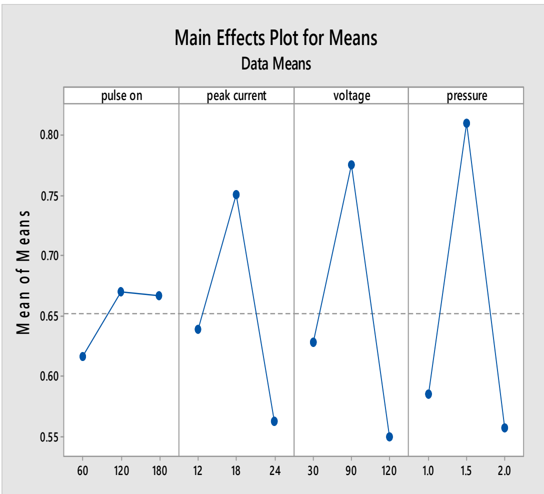

Fig 3 Main Effects Plot for Means

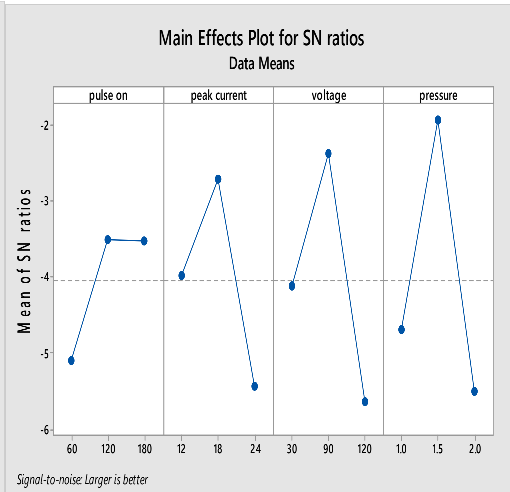

Fig 4 Main effects plot for S/N ratios

5.1 Comparison of GRA and GRA based PCA

Table 14 Grey Relational Grade

S.NO	Pulse on time(µsecs)	Peak current (amp)	Voltage (v)	Flushing pressure (kg/cm^2)	MRR (mm^3/min)	twr (mm^3/min)	GRG	Rank
1	60	12	30	1	0.5163	0.4878	0.5021	8
2	60	18	90	1.5	1.05	0.3333	0.6954	1
3	60	24	150	2	0.3333	1	0.6665	2
4	120	12	90	2	0.6626	0.4855	0.5741	4
5	120	18	150	1	0.601	0.4553	0.5282	6
6	120	24	30	1.5	0.6975	0.4513	0.5744	3
7	180	12	150	1.5	0.7126	0.3924	0.5525	5
8	180	18	30	2	0.649	0.3913	0.5202	7
9	180	24	90	1	0.6239	0.3689	0.4964	9

Table 15 PCA based GRA

MRR	TWR	GRADE	RANKING
0.5163	0.4878	0.5161	8
1.05	0.3333	1	1
0.3333	1	0.3333	9
0.6626	0.4855	0.6901	4
0.601	0.4553	0.6026	7
0.6975	0.4513	0.7182	2
0.7126	0.3924	0.7127	3
0.649	0.3913	0.6508	5
0.6239	0.3689	0.6386	6

By comparing the two methods hybrid technique PCA based GRA gives accurate results than a conventional technique Principal Component Analysis.

VI. Conclusion

This paper has utilized Grey Relational Analysis (GRA) and Principal Component Analysis (GRA) based PCA for optimization of the EDM process with multiple performance characteristics. The optimal parameters for both MRR and TWR are Pulse on time 60µm, Peak current 18amp, Flushing pressure 1.5kg/cm^2 and Voltage 90V. The four factors are pulse on time (Ton), flushing pressure (kg/cm^2)**,** voltage(V), Peak current(IP) with three levels were considered. By using Grey Relational Analysis peak current is effecting more on MRR. Peak current, Voltage and pulse on time have higher effect on TWR and have the least influence on MRR.By using GRA based PCA peak current and voltage shows more influence on MRR. Voltage and pulse on time vary directly with TWR and MRR was least affected.

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