Journal of Material Science and Mechanical Engineering (JMSME)
Print ISSN: 2393-9095; Online ISSN: 2393-9109; Volume 2, Number 3; April-June, 2015 pp. 248-253

http://www.krishisanskriti.org/jmsme.html

Parametric Optimization of EDM Process using Grey Relational Analysis

Uttam Kumar Mohanty[1] and Jaydev Rana[2]

[1]*M-Tech Research Scholar, Department of Mechanical Engineering, Veer Surendra Sai University of Technology, Burla, Odisha, India*
[2]*Department of Mechanical Engineering, Veer Surendra Sai University of Technology, Burla, Odisha, India*
E-mail: [1]uttam.vssut2015@gmail.com, [2]jranauce@yahoo.co.in

Abstract—*Electrical discharge machining (EDM) is a well-known non-conventional machining process for manufacturing geometrically complex shape from hard conducting materials that are extremely difficult to machine by conventional machining processes. This non-contact machining technique has been used from simple tool and dies making process to various micro scale applications. In the present paper, experiments have been planned using L9 orthogonal array to obtain optimal level combination of input process parameters such as current, pulse on time and voltage. A multi-response optimization technique using Grey Relational Analysis (GRA) has been used to optimize simultaneously the material removal rate (MRR), tool wear rate (TWR), surface roughness (SR) and radial overcut (ROC). The effects of various input process parameters on the overall performance of EDM have been studied using ANOVA Technique.*

Keywords: *Multi-response Optimization Technique, Grey Relational Analysis, Electro discharge machining, ANOVA Technique*

1. INTRODUCTION

Electrical discharge machining is a very popular non-conventional machining process developed since 1943 at the Moscow University [1]. This process is widely used in aerospace, automobile and mold making industries to machine hard and difficult to machine metals and their alloys. In this process, the material is removed by succession of electrical discharges occur between the work piece and the electrode. Both the work piece and electrode are submerged in a dielectric fluid (like kerosene, deionized water etc.).During the process of electrical discharge, a discharge channel is created where the temperature approximately reaches to 12000°C [2] as a result of which the material is removed by evaporation and melting[3-5] from both the electrode and work piece.

Electrical discharge machining is governed by thermal phenomena [6, 7] due to which it not only removes material from the work piece but also changes the metallurgical properties in the heat affected zone. During the process of material removal, some of the molten work piece material remained solidified by the cooling effect of the dielectric as well as by the conduction of bulk part of work piece material. Because of the above process recast layers are formed at the top surface of work piece. Since the material removal is due to the formation of large number of craters whose shape and size varies with the process parameter, a rough surface is formed. Although there is no direct contact between the work piece and the tool, because of the mechanism of EDM process craters are formed in the work piece as well as on the surface of the tool result some tool wear.

In view of the above facts, researchers are continuously trying to obtain a suitable combination of process parameters which will result in high MRR, low tool wear, better surface finish with very low recast layer formation. M.J Mohd, etal [8] optimized surface roughness using Response Surface Methodology. S.K Singh and N, Kumar [9] optimized the EDM process parameter to get better surface finish on the Titanium alloys. P.Malhotra and A.Kohli [10] studied the effect of various process parameters like pulse on time, pulse off time, current and flushing pressure on material removal rate, tool wear rate and surface finish of the H-11 tool steel using one variable at a time approach. S. Chandramouli etal [11] optimized the EDM process separately for MRR, TWR and surface finish.

In the present paper, MRR, TWR, Surface Roughness (SR) and radial overcut (ROC) have been optimized simultaneously using Grey Relational Analysis. A suitable combination of input process parameters likes current, pulse on time and voltage has been determined using the above optimization technique. The experiment has been planned using L9 orthogonal array since the number of input parameter and levels (low, medium, high) are three.

2. EXPERIMENTATION

2.1. Machine Details

Experiments have been conducted on a Die Sinking Electro Discharge Machine as shown in Fig.1 with the following specification as shown in Tab.1.

Fig. 1: Die Sinking EDM Machine

Table 1: Die Sinking EDM Machine Specification

Model size	G-30i
Dimension of Work Table, , $mm \times mm$	350×220
Longitudinal Movement(X), mm	220
Cross Movement(Y), mm	130
Work tank dimension(inside), $mm \times mm \times mm$	$600 \times 370 \times 280$
Max. work piece weight, kg	75
Max. work piece height, mm	150
Quill travel mm	200
Tool Vertical travel (Z-axis), mm	200
Max. dielectric over table, mm	225
Max. Electrode weight, kg	135
Dielectric Fluid capacity, lit	135
Generator Capacity, Amp	25

2.2. Work piece

The work piece material used in this study was High Carbon Steel with the following properties as shown in Tab.2

Table 2: Properties of work piece material

Hardness, HRB	Density, $\frac{g}{mm^3}$	Weight, g	Melting Point, °C
87.75	7.9×10^{-3}	206.9	1510

The dimension of the work piece was taken as 150mm×40mm×4.5mm.

2.3. Electrode

The electrode material used in this experiment was copper with the following properties as shown Tab.3.

Table 3: Properties of Electrode material

Hardness, HRB	Density, $\frac{g}{mm^3}$	Weight, g	Melting Point, °C
67	.0076	38.0542	1080

The diameter and length of electrode were taken as 10mm and 100mm respectively.

2.4. Plan of Experiment

The experiment has been planned on the basis of Taguchi's L_9 orthogonal array. Accordingly, the different levels and various sets of input process parameters are presented in Tab.4 and Tab.5 respectively.

Table 4: Input process parameter range and their level

Sl. No	Parameter	Unit	Symbol	Range	Level		
					1	2	3
1	Current	Amp	I	5-15	5	10	15
2	Pulse on time	μ sec	Ton	100-500	100	300	500
3	Voltage	Volt	V	30-50	30	40	50

Table 5: Input process parameter as per L_9 Orthogonal Array

Exp. No	Current(I) in Amp	Pulse on time(Ton) in µsec	Voltage (V) in volt
1	5	100	30
2	5	300	40
3	5	500	50
4	10	100	50
5	10	300	30
6	10	500	40
7	15	100	40
8	15	300	50
9	15	500	30

2.5. Experimental Procedure

Before performing the experiments, the initial weights of work piece as well as electrode were taken with the help of a semi micro-balance. The work piece was then fitted in the fixture of the Work Table. Similarly, the tool was also fitted in the tool holder .The work piece was positioned properly under the tool. The machine was started as per the prescribed procedure stated in the manual after setting the appropriate current, pulse on time and voltage as shown in Tab.5.Machining was continued till the machining depth reaches to 1mm into the work piece material and the corresponding machining time was noted. After machining was over, the work piece as well as the tool was detached and the final weights of both work piece and tool were taken. Following the above procedure, nine sets of experiments were conducted along a line on the surface of the work piece by selecting nine different sets of input parameters.

2.6. Experimental Results

In order to determine the MRR, TWR and ROC, the following formulas were followed.

Material removal rate, $$MRR = \frac{w_b - w_a}{\rho \times t}, \frac{mm^3}{\min} \quad (1)$$

where w_b and w_a are the weights of work piece before and after machining in gram respectively, ρ is

The density of work piece material in $\frac{g}{mm^3}$ and t is the machining time in minutes.

Tool wear rate, $TWR = \frac{w_{tb} - w_{ta}}{\rho \times t}, \frac{mm^3}{\min}$ (2)

Where w_{tb} and w_{ta} are the weights of tool before and after machining in gram respectively, ρ is the density of electrode material in $\frac{g}{mm^3}$ and t is the machining time in minutes.

Radial overcut, $ROC = \frac{D-d}{2}, mm$ (3) where D is the diameter of machined hole in mm and d is the diameter of tool electrode in mm.The average surface roughness was measured for each machined surface using Taylor Hobson's Talysurf as shown in Fig.2.

Fig. 2: Taylor Hobson's Talysurf

The values of ROC were measured by means of digital vernier. The values of MRR, TWR, SR and ROC were calculated using Eq.1-3 and presented in Tab.6.

Table 6: Experimental Results of MRR, TWR, SR, ROC

Exp. No	MRR	TWR	SR	ROC
1	4.337	.029	3.53	.230
2	3.157	.010	3.73	.175
3	1.638	.001	2.00	.245
4	14.291	.187	4.43	.270
5	10.204	.082	5.33	.295
6	8.996	.026	4.83	.250
7	16.467	2.282	4.13	.250
8	18.619	.326	4.57	.265
9	14.212	.240	4.97	.320

3. MULTI-RESPONSE OPTIMIZATION

For the present EDM process, a simple multi-response optimization technique using Grey Relational Analysis (GRA) approach has been followed due to the following advantages i.e. (i) It does not require the help of any software and(ii) The procedure is very simple and the industry personnel can prefer this technique for their applications.

3.1. Optimum level combination of process parameters

For each input parameter there will be a maximum Grey Relational Grade corresponding to particular level of that parameter. That level of the input parameter is the optimum level. Similarly for other input parameters there will be different levels corresponding to maximum Grey Relational Grade. The combinations of all these levels are treated as *optimum level combination*. The following steps are followed to determine optimum level combination:

Step-I
Collection of experimental results (performance characteristics) by conducting experiments following suitable orthogonal array. (L_9 Orthogonal array in the present case)

Step-II
Calculation of loss function of the individual performance characteristics by using the following formula

For smaller the better

$$L_{ij} = \frac{1}{n} \times \sum_{k=1}^{n} y^2_{ijk} \quad (4)$$

For larger the better

$$L_{ij} = \frac{1}{n} \times \frac{1}{\sum_{k=1}^{n} y^2_{ijk}} \quad (5)$$

Where 'n' represents the number of repeated experiments for a perticular set of process parameter and L_{ij} is the loss function of the ith performance characteristics on the jth experiments and y_{ijk} is the experimental value of the ith Performance characteristics in the jth experiment at the kth test.

Step-III
Determination of S/N ratio using the following formula

$$\eta_{ij} = -10 \log L_{ij} \quad (6)$$

Step-IV
Normalization of S/N ratio: It is scaled between 0 and 1

$$Y_{ij} = \left(\frac{\eta_{ij} - \eta_i^{\min}}{\eta_j^{\max} - \eta_i^{\min}} \right) \quad (7)$$

Where Y_{ij} =Scaled signal to noise ratio value for ith performance characteristics in the jth experiment.

Step-V

Computation of the grey relational coefficient:

Grey relational coefficient (γ_{ij}) for the ith performance characteristics in jth experiment is calculated as following

$$\gamma_{ij} = \left(\frac{\Delta_i^{\min} + \xi \Delta_i^{\max}}{\Delta_{ij} + \xi \Delta_i^{\max}} \right) \tag{8}$$

Where $\Delta_{ij} = |1 - Y_{ij}|$, $\Delta_i^{\min} = \min\{\Delta_{ij}, \Delta_{2j}..........\Delta_{mj}\}$

$$\Delta_i^{\max} = \max\{\Delta_{ij}, \Delta_{2j}..........\Delta_{mj}\}$$

And ξ is the distinguishing co-efficient, ξ lies (0, 1).usually the value of ξ is taken to be 0.5

Step-VI

Calculation of the grey relational grade (GRG) using the following formula

$$GRG_j = \sum_{i=1}^{m} w_i \gamma_{ij} \tag{9}$$

Where, W_i is the weightage factor for the ith response $\sum_{i=1}^{m} w_i = 1$, m=number of performance characteristics.

Step-VII

Determination of mean GRG of each factor and grand mean grey relational grade (GRG_m) using following formula

$$GRG_x = \frac{\sum_{anyonecombination} GRG_j}{3} \tag{10}$$

And

$$GRG_m = \frac{\sum_{j=1}^{9} GRG_j}{9} \tag{11}$$

Where GRG_x =mean GRG of any factor (either I or Ton or V)

GRG_j = GRG of any one combination (either low or medium or high)

Step-VIII

Determination of optimum level:

Optimum level represents the level corresponding to higher values of GRG. The GRG values of each experiment were calculated using Eq.4 to 9 and were presented in Tab.7.It may be noted that for MRR the loss function calculated by taking *larger the better* where as for, TWR, SR and ROC the loss function is calculated by taking *smaller the better*. Weightage factor for MRR, TWR, SR and ROC have taken as 0.6, 0.2, 0.1 and 0 .1 respectively. From Tab.8, it was observed that the optimum combination level being I_{III} T_{onI} V_{III}.Using the above steps the optimum level

Combination is presented in Fig.6.Table

Table 7: Calculation of Grey Relational Grade

Exp No	**Quality Loss, L_{ij}**				**Normalized loss, η_{ij}**				**Scaled Quality Loss**			
	MRR	**TWR**	**Ra**	**ROC**	**MRR**	**TWR**	**Ra**	**ROC**	**MRR**	**TWR**	**SR**	**ROC**
1	0.0532	0.0008	12.4609	0.0529	12.74	30.97	-10.96	12.77	0.40	0.57	0.42	0.55
2	0.1003	0.0001	13.9129	0.0306	9.99	40	-11.43	15.14	0.27	0.70	0.36	1.00
3	0.3727	0.000001	4.0000	0.0600	4.29	60	-6.02	12.22	0	1.00	1.00	0.44
4	0.0049	0.0350	19.6249	0.0729	23.10	14.56	-12.93	11.37	0.89	0.32	0.19	0.28
5	0.0096	0.0067	28.4089	0.0870	20.18	21.74	-14.53	10.60	0.75	0.43	0.00	0.13
6	0.0124	0.0007	23.3289	0.0625	19.07	31.55	-13.68	12.04	0.70	0.58	0.10	0.41
7	0.0037	5.2075	17.0569	0.0625	24.32	-7.17	-12.32	12.04	0.95	0.00	0.26	0.41
8	0.0029	0.1063	20.8849	0.0702	25.38	9.73	-13.20	11.54	1.00	0.25	0.16	0.31
9	0.0050	0.0576	24.7009	0.1024	23.01	12.40	-13.93	9.90	0.89	0.29	0.07	0.00

Exp. No	Value of Δ_{ij}				Grey Relational Coefficient, γ_{ij}				Grey Relational Grade(GRG_j)
	MRR	TWR	SR	ROC	MRR	TWR	SR	ROC	
1	0.60	0.43	0.58	0.45	0.45	0.54	0.46	0.53	0.48
2	0.73	0.30	0.64	1.00	0.41	0.63	0.44	0.33	0.45
3	1.00	1.00	0.00	0.56	0.33	0.33	1.00	0.47	0.41
4	0.11	0.68	0.81	0.72	0.82	0.42	0.38	0.41	0.66
5	0.25	0.57	1.00	0.87	0.67	0.47	0.33	0.36	0.57
6	0.30	0.42	0.90	0.59	0.63	0.54	0.36	0.46	0.57

7	0.05	1.00	0.74	0.59	0.91	0.33	0.40	0.46	0.70
8	0.00(min)	0.75	0.84	0.69	1.00	0.40	0.37	0.42	0.76
9	0.11	0.71	0.93	1.00	0.82	0.41	0.35	0.33	0.64

Table 8: Level average Values of Individual Input Parameters

Factor	Level-I	Level-II	Level-III
I	0.45	0.60	0.70(max)
Ton	0.61(max)	0.59	0.54
V	0.56	0.57	0.61(max)

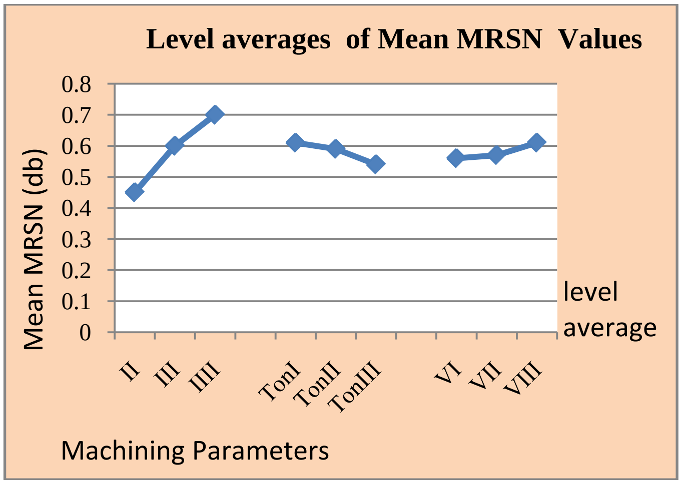

Fig. 6: Multi response Grey relational Grade graph taking weightages w_1=0.6, w_2=0.1, w_3=0.1, w_4=0.1

3.2. Procedure for obtaining Percentage contribution of each process parameter

Percentage contribution is the sharing characteristics of each factor among the total performance characteristics. The following steps are followed to determine percentage contribution of each process parameter.

Step-I:
Determination of sum of square:

Sum of square due to a factor (SS_f), total sum of square (SS_t) and sum of square due to error (SS_e) can be calculated using the following expression

$$SS_f = q\sum_{q=1}^{q}(GRG_q - GRG_m)^2 \quad (12)$$

$$SS_t = \sum_{j=1}^{9}(GRG_j - GRG_m) \quad (13)$$

$$SS_e = SS_t - \sum SS_f \quad (14)$$

Where q is a multiplying factor whose value equal to number of levels

Step-II
Determination of degress of freedom:

The degrees of freedom (DOF) for each parameter as well as for total degree of freedom are calculated using following formula

DOF for any factor, X= number of levels-1 (15)

Total DOF=Total no. of experiments-1 (16)

Step-III
Determination of mean square (MS) value by using the following formula

Mean square for each factor $(MS_f) = \dfrac{SS_f}{DOF}$ (17)

Step-IV

Calculation of percentage (%) Contribution:
% Contribution of each factor

$$= \frac{SS_f}{SS_t} \times 100 \quad (18)$$

Using Eq.11-18 and values of Tab.7 and Tab.8 the results of ANOVA is presented in Tab.9.

Table 9: Results of ANOVA

Factor	SS	DOF	MS	% Contribution
I	0.0951	2	0.0476	84.3085
Ton	0.0078	2	0.0039	6.9149
V	0.0042	2	0.0021	3.7234
Error	0.0057	2	0.0029	5.0532

Using the above steps the percentage contribution of each factor is represented in Fig.7.

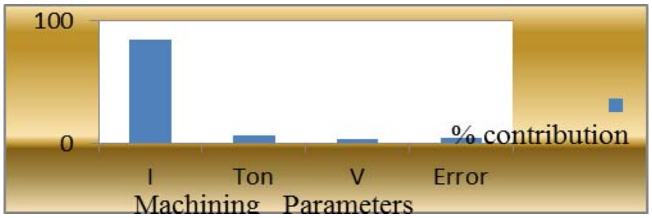

Fig. 7: Percentage Contribution of input parameters using Grey Relational Analysis Technique

4. CONFIRMATION TEST

A Confirmation test was performed and the result was compared with the predicted value as shown in Tab.10.

Table 10: Results of Confirmation Test

Response Parameter	Initial Parameter Combination	Optimum Parameter Combination		% prediction Error
		Experimental	Predicted	
Level	IITonIVI	IIIITonIVIII	IIIITonIVIII	
MRR	4.337	20.3604	19.6784	3.35

TWR	0.029	1.3502	1.254	7.13
SR	3.53	4.5915	4.474	2.56
ROC	.230	4.3345	4.169	3.82

From Table.10, it was observed that the percentage prediction error found to be less than 8%.

5. CONCLUSION

The following conclusions are obtained from the present investigation:

(i)Among current, pulse on time and voltage, the influence of the current on the overall performance of EDM is highest. The Percentage contribution of current for the present investigation was found to be 84.3085%. On the other hand voltage has the least effect on the overall performance of EDM (i.e.3.7234%).

(ii) The optimum level combination of current(I), pulse on time(T_{on}) and voltage(V) was determined and the values are high level of current(I=0.70 dB), low level of pulse on time($T_{on} = 0.61$ dB)and highest level of voltage (V=0.61dB).

(iii) A confirmation test has been conducted to obtain percentage prediction error.

REFERENCES

[1] Albinski, K., Musiol, K., Miernikiewicz, A., Labuz, S., and Malota, M., "Plasma temperature in electro discharge machining", In: Proceedings of the 11th International Symposium for Electro Machining, 1995, 17, 143–152.

[2] Chandramouli, S., Balraj, Srinivas, U. and Eswaraiah, K., "Optimization of Electrical Discharge Machining Process parameters Using Taguchi Method", International Journal of Advanced Mechanical Engineering, 2014, 4, 425-434

[3] DiBitonto, D.D., Eubank, P.T., Patel, M.R., and Barrufet, M.A., "Theoretical models of the electric al discharge machining process-I: a simple cathode erosion model", Journal of Applied Physics, 1989, 66 (9), 4095 -410.

[4] Dijck, F., "Physic-mathematical analysis of the electro discharge machining Process", Ph.D. Thesis, katholieke University, Heverlee, Netherland, 1973, 61–62

[5] Malhotra, P. and Kohli, A., "Performance Study of Electrical Discharge Machining with H-11 Tool steel using one Variable at a Time approach", International Journal for Science and Emerging Technologies with Latest Trends, 2013, 12(1), 15-20

[6] Mohd, M.J., Sheikh, K., Singh, B. and Malhotra, N., "Modeling and analysis of machining parameters for surface roughness in powder mixed EDM using RSM approach", International Journal of Engineering, Science and Technology 4(3), 2012 45-52

[7] Montgomery D.C: Design of experiment, second ed. John willey and Sons, New York, 1985.

[8] Patel, M.R.., Barrufet, M.A., Eubank, P.T. and DiBitonto, D.D., "Theoretical models of the electrical discharge machining process-II: the anode erosion model", Journal of Applied Physics 66 (9), 1989, 4104–4111

[9] Salah, N.B., Ghanem, F. and Atig, K.B., "Numerical study of thermal aspects of electric discharge machining process", International Journal of Machine and Manufacture 46(7-8), 2006, 908-911

[10] Salman, Ozlem. And Kayacan, CengiZ, M., "Evolutionary programming for modeling the EDM parameters for rough ness", Journal of Materials processing Technology 200, 2008, 347-355

[11] Singh, S.K and Kumar N., "Optimizing the EDM Parameters to Improve the Surface Roughness of Titanium Alloy (Ti-6AL-4V)", International Journal of Emerging Science and Engineering 1, 2013 2319–6378

[12] Zingerman, A.S., "The effect of thermal conductivity upon the electrical erosion of metals", Journal of Technical Physics 1 (2), 1956, 1945–1958