Journal of Basic and Applied Engineering Research
p-ISSN: 2350-0077; e-ISSN: 2350-0255; Volume 3, Issue 13; October-December, 2016, pp. 1169-1171

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

Taguchi-Grey Relational based Multi-Objective Optimization of Process Parameters in Electric Discharge Machining of Aluminium with Copper Electrode

Rashed Mustafa Mazarbhuiya[1], P.K. Choudhury[2] and M. Rahang[3]

[1,2]*Assam Engineering College*
[3]*NIT, Meghalaya*
Email: [1]itsrashed110@gmail.com, [2]prasantaaec13@gmail.com

Abstract—*This paper involves the multi-objective optimization of process parameters in EDM (Electric Discharge Machining) done upon aluminium work piece with copper electrode for obtaining maximum material removal rate (MRR) and minimum surface roughness (SR).The important machining parameters were selected as discharge current, flushing pressure, pulse-on time and polarity. Experiments were conducted by selecting two operating levels for the said four parameters according to Taguchi's Design of Experiments. Using Grey Relational Analysis (GRA) the multi-objective optimization was performed to determine the optimal solution. Analysis of Variance (ANOVA) was carried out to determine the most contributing and significant input parameter/parameters. The optimal level of input parameters are found to be 16A for discharge current, 1010 µs for pulse-on time, 5kgf/cm^2 for flushing pressure and normal polarity. The ranking of the process parameters reveals that polarity is the most dominant parameter on the output response followed by current. From the analysis it was experienced that in case of MRR the polarity is the most significant factor followed by current, whereas for surface roughness the current was found to be the only significant factor while machining on aluminium work piece with copper electrode.*

1. INTRODUCTION

EDM is an important manufacturing process for machining hard metals and alloys. This process is widely used for producing dies, molds and finishing parts for aerospace, automotive and surgical components. The process is capable of getting required dimensional accuracy and surface finish by controlling the process parameters [1]. EDM performance is generally evaluated on the basis of Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (SR). It is a non-traditional concept which is based on the principle of removing material by means of repeated electrical discharges between the tool termed as electrode and the work piece in the presence of a dielectric fluid [2]. EDM uses thermal energy to achieve a high-precision metal removal process from a fine, accurately controlled electrical discharge. The electrode is moved towards the work piece until the gap is small enough so that the impressed voltage is great enough to ionize the dielectric [3].The material is removed with the erosive effect of the electrical discharges from electrode and work piece. EDM does not make direct contact between the electrode and the work piece thus it can eliminate mechanical stresses, chatter and vibration problems during machining [2, 4].

The objective of this paper is to determine the optimal levels of the process parameters for EDM process using Taguchi approach. This work was done on aluminium as work piece material and copper as electrode material. Grey Relational Analysis was applied to obtain the optimum value of the process parameters. The process parameters such as current, pulse on time, flushing pressure and polarity were optimized with the considerations of multiple performance characteristics such as material removal rate and surface roughness value on the work material. Analysis of Variance (ANOVA) was then analyzed to determine the most significant input parameter/parameters.

2. MATERIAL AND METHODOLOGY:

2.1 Material and machine:

Aluminum is chosen as the work piece material and copper is used as the electrode. The electrode material properties are given in Table 2.1.The experiment has been conducted on EDM model F25 series of Sparkonix India Private Limited, Pune available at the Laboratory as shown in Fig. 2.1. Table2.2 shows the working conditions of EDM. The EDM has the optimum working current of 25A with maximum work-piece weight of 650kg and maximum electrode weight of 35kg. The X-axis and Y-axis movements are given to the work table and Z-axis movement is on the tool holder. A servo mechanism controls the downwards movement of the tool holder during machining. Hydrocarbon oil is used as a dielectric medium. The dielectric tank has a capacity of 400 liters. The flushing pressure can be read on separate gauge fitted on the left side of the working tank.

Table 2.1: Properties of electrode material

Properties	Value
Melting point	1083˚C
Elastic modulus (E)	$1.23\text{x } 10^5 N/mm^2$
Poisson's ratio	0.26
Density	$8.9\ gm/cm^3$

Fig. 2.1: EDM machine

Table 2.2: Working conditions of EDM

Working conditions	Description
Work piece	Aluminium
Electrode Material	Copper
Dielectric medium	Hydro-carbon oil.

The control parameters at two different levels and four different response parameters considered for multiple performance characteristics in this work are shown in table 2.3

Response parameters considered in this study are as follows-

- Material removal rate (mm^3/min)
- Surface Roughness (R_a value in µm)

Table 2.3 Control parameters with their respective levels

Control Parameters		Levels	
		1(low)	2(high)
A	Discharge Current (A)	8	16
B	Pulse On- time (µs)	463	1010
C	Flushing pressure (kgf/cm^2)	5	10
D	Polarity	N(Normal)	R(Reverse)

2.2 Details of the Experiment:

2.2.1 Design of Experiment:

Design of experiment is an effective tool to design and conduct the experiments with minimum resources. Orthogonal array is a statistical method of defining parameters that converts test areas into factors and levels. Orthogonal array creates an efficient and concise test suited with fewer test cases without compromising test converge. In this work, L_8 Orthogonal Array design matrix is used to set the control parameters to evaluate the process performance. Pilot experimentation was done to explore the working range of input parameters for the selected work-piece material. Experiments were run according to each combination of parameters considered in the Orthogonal Array and the corresponding responses i.e., Material Removal Rate (MRR) and surface roughness (Ra value) were calculated. The work piece was weighted before and after the machining by using electronic precision balance to calculate the material removal rate. The surface roughness of the work piece was evaluated using surface measuring unit.

The experiment is conducted based on varying the process parameters, which affect the machining process to obtain the required quality characteristics. Quality characteristics are the response values or output values expected out of the experiments. The quality characteristics most commonly used are:

1) Larger the better
2) Smaller the better
3) Nominal the best

As the objective is to obtain the high material removal rate (MRR) and best surface finish, it is concerned with obtaining larger value of MRR and smaller value of surface roughness. Hence the required quality characteristics for high MRR is larger the better, which states that the output must be as large as possible and surface roughness is smaller the better, which states that the output must be as low as possible.

2.2.2 Selection of orthogonal array:

Based on the calculation done for total degrees of freedom (DOF) in case of four factors at two levels each with no interaction, the best suited orthogonal array L_8 has been selected for this experimental work.

2.2.3 Running of the experiments and data collection:

Experiments were conducted as per L_8 orthogonal array, assigning various values of the levels to the process parameters and final results are given in the Table 3.1

Table 3.1 Calculation of MRR and R_a

Sl. No.	A	B	C	D	MRR (mg/min)	R_a(µm)
1	8	463	5	N	6.54	8.1
2	8	463	10	R	0.47	5.95

3	8	1010	5	R	0.27	8.29
4	8	1010	10	N	6.18	10.2
5	16	463	5	R	3.32	10.0
6	16	463	10	N	11.68	12.4
7	16	1010	5	N	12.11	22.3
8	16	1010	10	R	3.56	14.55

2.3 Optimization using Grey Relational Analysis (GRA):

Multi-objective optimization is performed using GRA to arrive at the best operating level .GRA is carried out to obtain the optimal set of process parameters based on the output responses. The steps involved in Taguchi's Grey Relational Analysis are:

STEP 1:-

The transformation of S/N Ratio values from the original response values was the initial step. For that the equations of "larger the better" is used for MRR and "smaller the better" is used for surface roughness values. Subsequent analysis was carried out on the basis of these S/N ratio values.

Type1: S/N=-10log$\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{Y^2}_i}\right]$ Larger the better (1)

Type2: S/N=-10 log $\left[\frac{1}{n}\sum_{i=1}^{n}{Y_i}^2\right]$ smaller the better (2)

Where Yij is the value of the response 'j' in the i^{th}experiment condition, with i=1, 2, 3…n; j = 1, 2…k

After that using eq. (1) and eq. (2) we normalize the S/N ratio values given in Table 3.2. Yij is normalized as Zij (0 ≤ Zij ≤ 1) by the following formula to avoid the effect of adopting different units and to reduce the variability. The normalized output parameter corresponding to the larger-the-better criterion can be expressed as

$$Z_i = \frac{Y_{ij} - \min(Y_{ij}, i=1,2,....n)}{\max(Y_{ij}, i=1,2,....n) - \min(Y_{ij}, i=1,2,.....n)} \quad (5)$$

Then for the output parameters, which follow the smaller-the-better criterion can be expressed as

$$Z_i = \frac{\max(Y_{ij}, i=1,2,....n) - Y_{ij}}{\max(Y_{ij}, i=1,2,....n) - \min(Y_{ij}, i=1,2,.....n)} \quad (6)$$

Table 3.2 Signal-to-Noise ratios

S.NO.	MRR	Ra	S/N ratio		NORMALIZED S/N RATIOS	
			MRR	Ra	MRR	Ra
1	6.54	8.1	16.312	-18.169	0.838	0.234
2	0.47	5.95	-6.559	-15.490	0.146	0
3	0.27	8.29	-11.373	-18.371	0	0.251
4	6.18	10.2	15.820	-20.172	0.823	0.408
5	3.32	10.0	10.423	-20	0.659	0.393
6	11.68	12.4	21.389	-21.868	0.991	0.556
7	12.11	22.3	21.663	-26.966	1	1
8	3.56	14.55	11.029	-23.257	0.678	0.677

STEP 2:

In this step computing grey relational coefficient (GC) for the normalize S/N ratio values. Before that the deviation sequence for the reference and comparability sequence were found out. Grey relational coefficients along with deviation sequence were given in Table 3.3. The grey relational coefficient can be expressed as

$$GC_{ij} = \frac{\Delta_{min} + \lambda\, \Delta_{max}}{\Delta_{ij} + \lambda\, \Delta_{max}}$$

Where i=1,2….n experiments and j=1,2….m response

GC_{ij}= grey relational coefficient for the *i*th experiment/trial and *j*th dependent variable/response

Δ= absolute difference between Y_{oj} and Y_{ij} which is a deviation from target value and can be treated as a quality loss

Y_{oj}= optimum performance value or the ideal normalized value of *j*th response

Y_{ij}=the *i*th normalized value of the *j*th response/dependent variable.

Δ_{min}=minimum value of Δ

Δ_{max}=maximum value of Δ

λ is the distinguishing coefficient which is defined in the range 0≤λ≤1 (the value may be adjusted on the practical needs of the system)

After that the grey relational grade was determined by averaging the grey relational coefficient corresponding to each performance characteristic. It is given in the Table3.3. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade. The grey relational grade can be expressed as

$G_i = \frac{1}{m}\sum GC_{ij}$ Where m is the number of responses

Table 3.3 Normalized S/N ratios with Grey Relational Grade

SL. NO	NORMALIZED S/N RATIOS		Δ_{MRR}	Δ_{Ra}	CG_{MRR}	CG_{Ra}	G_i	RANK
	MRR	Ra						
1	0.838	0.234	0.162	0.767	0.861	0.566	0.713	5
2	0.146	0	0.854	1	0.539	0.5	0.519	8
3	0	0.251	1	0.749	0.5	0.572	0.536	7
4	0.823	0.408	0.177	0.592	0.849	0.628	0.739	4
5	0.659	0.393	0.340	0.607	0.746	0.622	0.684	6
6	0.991	0.556	0.009	0.444	0.991	0.692	0.842	2
7	1	1	0	0	1	1	1	1
8	0.679	0.677	0.322	0.323	0.757	0.756	0.757	3

STEP 3:

Similar to GRC, GRG gives the degree of closeness of the experimental results to the ideal result, in which MRR is maximum and Ra is minimum. The larger the grey relational grade, the better is the multiple performance characteristics From Table 3.3, it can be seen that Experiment no. 7 has the best multi-performance characteristic as it has the high GRG value. This level have 16 A for discharge current, 1010µs for pulse on time 5kgf/cm^2 for flushing pressure and Normal polarity from experiment 7 is a near optimal solution.

Table 3.4 Effects of the Factors on the Grey Relational Grade

FACTORS	LEVEL 1	LEVEL 2	RANK
CURRENT (A)	0.627	**0.821**	2
PULSE ON TIME (B)	0.689	**0.758**	4
FLUSHING PRESURE (C)	**0.733**	0.714	3
POLARITY (D)	**0.824**	0.624	1

Since the motive of this work is to find a level of machining parameters with maximum MRR and minimum Ra, the multi - objective optimization of machining parameters for EDM process is converted to optimization of GRG. So mean GRG for each level of the input parameters and their total mean are calculated (Table3.4). From this table, the optimal level of input parameters is found to be 16amps for discharge current, 1010 µs for pulse-on time, 5kgf/cm^2 for flushing pressure and normal polarity. The ranking of the process parameter reveals that polarity is the most dominant parameter on the output response followed by current. The optimal parameter combination was determined as $A_2B_2C_1D_1$.

2.4 Analysis of variance (ANOVA):

Influences of controlling factors on MRR:

Analysis of variance (ANOVA) is performed to obtain the percentage contribution of the factors and their significances. From the ANOVA for MRR as shown in Table3.5 it was observed that polarity and current are the significant factors while machining aluminum work piece with copper electrode and among these two, polarity was found to be the more significant.

Table 3.5 ANOVA for MRR

SOURCE	SUM OF SQUARE	DOF	MEAN SQUARE	F-RATIO	C (%)
A	37.023	1	37.023	*34.416	25.600
B	0.0015	1	0.0015	0.00141	0.0011
C	0.0153	1	0.0153	0.01423	0.011
D	104.329	1	104.329	*96.983	72.152
Error	3.227	3	1.0758		2.232
TOTEL = 144.496		7			100

$Tabulated\ F_{0.05,1,3} = 10.13$ *Significant

Influences of controlling factors on Surface Roughness:

From the ANOVA studied for the effect of factors on Surface Roughness as indicated in Table 3.6, the current only was found to be the most significant factor amongst all.

Table 3.6 ANOVA for Surface Roughness

SOURCE	SUM OF SQUARE	DOF	MEAN SQUARE	F-RATIO	C (%)
A	89.178	1	89.178	*13.098	48.637
B	44.604	1	44.604	6.551	24.327
C	3.906	1	3.906	0.574	2.130
D	25.241	1	25.241	3.707	13.766
Error	20.425	3	6.808		11.140
TOTEL	183.354	7			100

$Tabulated\ F_{0.05,1,3} = 10.13$ *Significant

3. RESULTS AND DISCUSSION:

(i) Polarity and Discharge Current: MRR increases with the increase in current with both +ve and –ve polarity but it drastically increases with the increase in current with +ve polarity as compared to –ve polarity. With an increase in current the available spark energy during discharge increases leading to higher MRR. Similarly surface roughness also increases with the increase in current with both +ve and –ve polarity although the SR obtained with –ve polarity is relatively lower as compared to SR obtained with +ve polarity. Lower current value gives lower SR. Increase in SR with increase in current may be attributed to the increase in energy content of the spark. Generally polarity is to be determined by specific experiments and is a matter of tool material, work material, current density and pulse length combinations [5,7].

(ii) **Flushing Pressure**: Flushing in the dielectric through the gap of electrode and work piece is necessary to remove the unwanted micro debris produced during the machining, which tends to short circuit the electrodes leading to damage of both tool and work piece. As the flushing pressure increases the value of surface roughness considerably reduces since it tries to reduce the irregularities, but very high flushing pressure may again distort the already made surface finish. So, in order to get better surface finish the obtained low level of flushing pressure is justified in compromising with material removal rate [6]

(iii) **Pulse-on time**: The higher pulse on-time and pulse current corresponds to higher material removal rate since it is directly proportional. Extended on-time gives more heat to work piece, which means the recast layer will be larger and the heat affected zone will be deeper. However too much extended pulse on-time may again lead to low MRR. The experimental results reveal that for a constant pulse on-time, the surface roughness increases with increasing pulse current and it also increases with increasing pulse on-time for a constant current [5,7]

4. CONCLUSIONS:

In this investigational experiment on EDM to know the effect of machining parameters i.e., ***discharge current, pulse-on time, flushing pressure and polarity*** over responses i.e., ***material removal rate and surface roughness*** in the aluminum work piece using the Copper electrode with side flushing method, it was experienced that the factors affected the responses differently although both these responses are important from the industrial point of view. From the above calculation and analysis the following points can be concluded-

- The optimum parameter combination is found to be. $A_2B_2C_1D_1$ i.e.,16A for discharge current, 1010 µs for pulse-on time, 5kgf/cm^2 for flushing pressure and normal polarity.
- Since the machine is primarily meant for material removal process, so more emphasis has been given on MRR rather than surface roughness.
- The study reveals that polarity is the most dominant parameter on the output response followed by current.
- From ANOVA it was observed that for MRR the polarity is the most significant factor followed by current and for surface roughness the current was only the significant factor while machining aluminum work piece with copper electrode.

5. ACKNOWLEDGEMENT

The authors express their sincere thanks and gratitude to Department of Mechanical Engineering of Assam Engineering College and NIT Silchar, Assam for providing the facility of tools and equipment for doing the experimental research work.

REFERENCES

[1] Sohani, M. S., Gaitonde, V. N., Siddeswarappa, B., Deshpande, A. S.,2009 ―Investigations into the Effect of Tool Shapes with Size Factor consideration in Sink Electrical Discharge Machining (EDM) Process‖, International Journal of Advance Manufacturing Technology 45:1131-1145

[2] Kuriachen Basil, Josephkunju Paul and Jeoju M.Issac, "Spark Gap Optimization of WEDM Process on Ti6Al4V", International Journal of Engineering Science and Innovative Technology (IJESIT) 2(1), 364-369(2013)

[3] S. Datta and S. S. Mahapatra, "Modeling, Simulation and Parametric Optimization of Wire EDM Process Using Response Surface Methodology Coupled with Grey-Taguchi Technique", International Journal of Engineering, Science and Technology,162-183 (2010).

[4] C.D.Shah, J.R.Mevada and B.C.Khatri, "Optimization of Process Parameter of Wire Electrical Discharge Machine by Response Surface Methodology on Inconel-600", International Journal of Emerging Technology and Advanced Engineering, 3(4), 2250-2459(2013)

[5] Naveen Beri*, Harish Pungotra, Anil Kumar "Effect of Polarity and Current during Electric Discharge Machining of Inconel 718 with CuW Powder Metallurgy Electrode" Proceedings of the National Conference on Trends and Advances in Mechanical Engineering, YMCA University of Science & Technology, Faridabad, Haryana, Oct 19-20, 2012

[6] Amitabha Ghosh, Asok Kumar Mallik, "Manufacturing Science" second edition. Published by Affiliated East-West Press Private Limited. 105 Nirmal Tower, 26 Barakhamba Road, New Delhi 110001. ISBN 978-81-7671-063-3

[7] P.K.Mishra. The Institution of Engineers (India) Textbook Series. "Nonconventional Machining" Narosa Publishing House Pvt. Ltd. 22 Delhi Medical Association Road. Daryaganj, New Delhi 110002 ISBN 978-81-7319-138-

About the authors:

Rashed Mustafa Mazarbhuiya[1]: Rashed Mustafa Mazarbhuiya is doing his PG course in the department of mechanical engineering, Assam Engineering College under the guidance of P.K. Choudhury, Assistant Professor, Assam Engineering College.

P.K. Choudhury[2]: Prasanta Kr. Choudhury is presently working as an Assistant Professor in the department of Mechanical Engineering, Assam Engineering College, since 2007.So far he has supervised many undergraduate and postgraduate projects along with publications in national and international conferences/journals. His research interests include Design and Process Optimization, Process Modelling and Application of Artificial Intelligence Techniques in Manufacturing as well as Pollution Engineering.

M.Rahang[3]: Dr. Maneswar Rahang[3] is presently working as an Assistant Professor in the department of Mechanical Engineering, NIT, Meghalaya. His field of research includes Manufacturing Process, Advanced Manufacturing Techniques and Surface Treatments.