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Parametric Optimization of Process Parameters of an Electric Discharge Machine

Shubham Parashar[1], Vipin Rawat[2], Shahrukh[3], Vivek Kumar[4], Adhirath Mandal[5], Sudhir Kumar[6] anad Rohit Garg[7]

[1,2,3,4]*Student, Greater Noida Institute of Technology*
[5,6,7]*Greater Noida Institute of Technology*
E-mail: [1]prashar226@gmail.com, [2]msr.rawat1965@gmail.com, [3]shahrukhansari30@gmail.com, [4]mekumarvivek5@gmail.com, [5]adhirath.mandal@gmail.com, [6]hodme@gnit.net, [7]rohit_garg@yahoo.com

Abstract—*This paper discusses the application of the Taguchi method to optimize the machining parameters for machining of AISI 304 Steel work piece by electro-discharge machining (EDM) for individual responses such as material removal rate and surface roughness. Moreover, a multi-response performance characteristic was used for optimization of process parameters with application of grey relational analysis. The machining parameters are selected as current, pulse-on-time and pulse-off-time whereas the response variables selected as material removal rate (MRR) and surface roughness (Ra). The results from confirmation runs indicated that the determined optimal combination of machining parameters improved the performance of the machining process.*

1. INTRODUCTION

Electrical Discharge Machining (EDM) is a non-traditional manufacturing process based on removing material from a part by means of a series of repeated electrical discharges (created by electric pulse generators at short intervals) between a tool, called electrode, and the part being machined in the presence of a dielectric fluid. Electrical Discharge Machining (EDM) is a process that is used to remove metal through the action of an electric discharge of short duration and high current density between the tool and the work piece. In EDM, a potential difference is applied between the tool and work-piece. Both the tool and the work material are conductors of electricity. The tool and the work material are immersed in a dielectric medium. Generally kerosene or de-ionized water is used as the dielectric medium. A gap is maintained between the tool and the work-piece. Depending upon the applied potential difference and the gap between the tool and work-piece, an electric field would be established.

2. LITERATURE REVIEW

This review outlines some of the recent reports published in literature on machining of different materials in EDM to find out the effect of the input parameters taken, on the responses.

Y.S Liao [1] in 1997 premeditated on the machining-parameters optimization of wire electrical discharge machining. An approach to determine the parameters were performed. The design was based upon the Taguchi quality approach with analysis of the variances (ANOVA). In the research the significant factors affects the machining performance factors such as Material removal rate (MRR), gap width, surface roughness (SR), sparking frequency, average gap voltage and normal ratio. In the investigation results demonstrate that the machining models were appropriate and the machining parameters mollify the real requirements. In 2001 Kuo-Ming Tsai et.al.[2], studied the dimensional analysis for surface finish in electrical discharge machine process .The process parameter for the model were peak current ,pulse duration, electrical polarity and property of the materials .They analysed and verified the result by taguchi method. For the experimentation Cu, Gr (ISEM-8), Ag-w were used for electrode and AISI EK 2, AISI D2, AISI H13 were used as the work piece material. In the investigation the methodically analyse and verification was performed by taguchi method. In the result it was determined that the predictions for the semi empirical model for the best fitting parameters were obtained by nonlinear optimization methods detected as the good verification experiment. In 2001 investigation was observed by Pei-Jen Wang et.al. [3], on electrical discharge machine. Peak current, pulse duration, electrical polarity were as performance procedure parameters. The response parameter considered were material removal rate and tool wear rate .In experimentation copper, Gr (ISEM-8) and Ag-w were used as electrode material and EK -2,AISI D2,AISI H13 as work piece material. It was determined that the model was able to give reliable predictions for new process parameters. Puertas et.al. [4] in 2003 studied on the machining parameters of electrical discharge machining. The modelling of the Ra and Rq parameters in function of current, pulse time and pause time were arranged. Factorial doe were united with techniques of regression for the modelling behavior of the functions which was also reliant on the different types of the variables. It was observed that a strong collaborations between the current and the pulse time due to increase in feed rate of current it was observed that surface roughness be contingent for the better arc constancy causing a uniform production of sparks. Yih-Fong et.al. [9] in 2007 studied the Multi-objective optimization of high-speed EDM process using a Taguchi fuzzy-based. They studied the optimization of electric discharge machining parameter by the use of SKD11 as work piece and copper as an electrode. They use surface finish as response parameter .in the experimentation it was concluded that the effect on the accuracy and precision of machining processes were mainly affected by pulse time ,duty cycle ,peak value of discharge current .Other parameter powder size, powder concentration were affected at low level.. In 2009,Mohd. Amir [13] studied the implementation of Taguchi method on EDM process of Tungsten Carbide. In the research the tungsten carbide was used as the work piece material and graphite as an electrode material. Peak-current, voltage, pulse-on-time and pulse-off-time were considered as process parameters. MRR, EWR and SR were as response parameters. Govindan et.al. [14] in 2010 studied the Experimental categorization of material removal in dry electrical discharge drilling. Material removal rate (MRR) and Tool wear rate (TWR) were measured as output parameter or response parameters. It was observed in the experimental conditions that at the low discharge energies, single-discharge in dry electrical discharge machining could give larger MRR and the crater radius as equated to dielectric EDM.

3. EXPERIMENTAL DETAILS

3.1 Experimental set up

During this study, a series of experiments on AISI-304 of size 90mm x 50mm x 5mm was conducted on a EXCETEK ED 30 ZNC electrical discharge machine to examine the effects of input machining parameters such as pulse on time, Voltage and current, on the material removal rate and surface roughness. The electrode taken was copper rod of diameter 10 mm. Hydro-Carbon Oil was used as dielectric fluid in this experimentation. The machining tests were carried out with a total time of 7 minutes for each experiment. The pressure and temperature of the dielectric fluid was assumed to be constant throughout the experiment. The material removed from the work piece is then determined from the weight differences before and after undergoing EDM process. The surface roughness is measured by stylus type profilometer (Mitutoyo Surf test SJ-201).

3.2 Tool material & Work-piece material used

The electrode material used during this current study was electrolytic copper rod of diameter 10mm having 99.9% copper as shown in Fig.1. The work-piece material is AISI 304 steel as shown in Fig.2

Fig.1 Electrode used in experiment

3.3 Machine Tool

EXCETEK ED 30 ZNC machine shown in Fig.3 is a die-sinking machine used in this experiment. It is energized by a 60 A pulse generator. Hydro-Carbon Oil was used as dielectric fluid during the experiments. All the machining work has been done in this machine taking copper electrode and AISI-304 as work-piece for experiments.

Fig.2 Stainless steel AISI 304 plate

Fig. 3 EXCETEK ED 30 ZNC machine

Table 1: Factors and levels of process parameters

Parameters	Symbol	Unit	Level 1	Level 2	Level 3
Discharge current	Ip	A	5	7	9
Pulse on time	Ton	µs	50	150	200
Voltage	V	V	45	55	65

3.4 Process parameters

The selected process parameters are: Current (A), Pulse-on time (µs) and Voltage (V).

4. DESIGN OF EXPERIMENTS

As 3 process parameters with 3 levels are selected, the total number of experiments as per full factorial design should be 27. Taguchi proposes the L9 orthogonal array for three level three factor design which corresponds to only 9 experiments. This reduces the machining time and cost. The process variables (design factors) with their values on different levels are listed in Table 1. The experimental layout for the three process parameters using the L9 orthogonal array is shown in Table 2. Table 3 shows the experimental results after machining.

Table 2: Experimental layout using an L9 orthogonal array

Run No.	Current	Pulse on time	Voltage
1	5	50	45
2	5	150	55
3	5	200	65
4	7	50	55
5	7	150	65
6	7	200	45
7	9	50	65
8	9	150	45
9	9	200	55

Table 3: Experimental results

Run No	MRR	SR
1.	4.198	7.044
2.	5.799	8.244
3.	4.838	9.511
4.	6.884	6.377
5.	8.623	8.911
6.	9.428	8.245
7.	8.414	9.512
8.	12.113	5.321
9.	13.178	5.767

5. GREY RELATION ANALYSIS

Grey relational analysis owes its origin to grey system theory. Any system in nature is not white (full of precise information), but on the other hand, it is not black (completely lack of information) either, and it is mostly grey (a mixture of black and white). Grey relational analysis is based on the grey system theory, and compares and computes the dynamic causalities of the subsystems of a given system. For better performance of a machining process the MRR should be high whereas the surface roughness should be low. Thus, it is a case of multi response optimization, which is different from that of a single performance characteristic. In the grey relational analysis, data preprocessing is first performed in order to normalize the raw data for analysis. In this study, a linear normalization of the experimental results for MRR and surface roughness were performed in the range between zero and one, which is also called the grey relational generation. In the EDM operation, the material removal rate should be higher. Therefore the normalized data processing for the material removal rate is the higher-the-better performance characteristics considered and is expressed as

$$x_i(k) = \frac{y_i(k) - min\, y_i(k)}{max\, y_i(k) - min\, y_i(k)} \qquad (1)$$

In the grey relational analysis, the normalized data processing for surface roughness (Ra) corresponding to lower-the-better criterion is expressed as

$$x_i(k) = \frac{max\, y_i(k) - y_i(k)}{max\, y_i(k) - min\, y_i(k)} \qquad (2)$$

Eq (1) is used for the ―larger-the-better responses and Eq (2) is used for the ―lower-the- better responses, where $x_i(k)$ is the value after grey relational generation, min $y_i(k)$ is the smallest value of $y_i(k)$ for the kth response, and the max $y_i(k)$ is the largest value of $y_i(k)$ for the kth response. An ideal sequence is $x_0(k)$ where (k= 1, 2 for MRR and Ra respectively). The grey relational coefficient (k)ξi can be calculated as

$$\varepsilon_i(k) = \frac{\Delta_{min} + \psi\Delta_{max}}{\Delta_{oi}(k) + \psi\Delta_{max}} \qquad (3)$$

WhereΔ_{oi} = $x_0(k)$ -x_i (k) = difference of the absolute value between $x_0(k)$ and $x_i(k)$; Ψ= distinguishing coefficient between zero and one, the purpose of which is to weaken the effect of Δ_{max} when it gets too big, and thus enlarges the difference significance of the relational coefficient. In the present case, ψ = 0.5 is used. Then the overall grey relational grade is calculated by averaging the grey relational coefficient corresponding to each selected process response using Eq.(4). The overall grey relational grade is shown in Table 5

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \varepsilon(k) \qquad (4)$$

Table 4: Data processing of each performance characteristic (Grey relational generation)

Exp. No	MRR	Ra
Ideal Sequence	**1**	**1**
1	**0**	**0.58888**
2	**0.17828**	**0.30255**
3	**0.07127**	**0.00024**
4	**0.29911**	**0.74803**
5	**0.49276**	**0.14340**
6	**0.58240**	**0.30231**
7	**0.46948**	**0**
8	**0.88140**	**1**
9	**1**	**0.89358**

Table 5.Grey relational grade of performance characteristic

Exp. No.	Grade
1	0.44894
2	0.47245

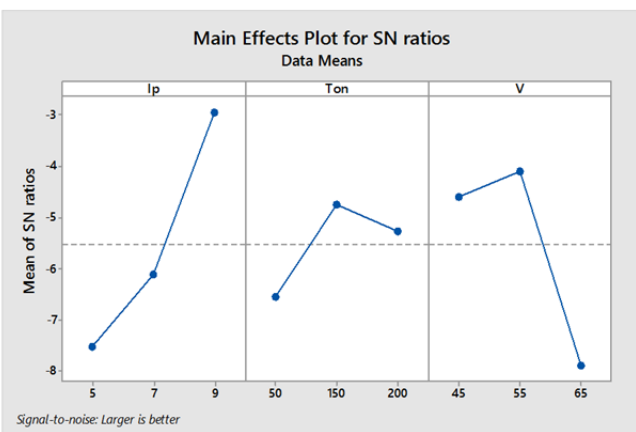
3	0.34990
4	0.55049
5	0.444132
6	0.49396
7	0.42056
8	0.92319
9	0.93573

The higher grey relational grade represents that the corresponding experimental result is closer to the ideally normalized value. In other words, optimization of the complicated multiple performance characteristics can be.

6. DETERMINATION OF OPTIMAL LEVEL

The larger the grey relational grade, the better is the multiple performance characteristics. However, the relative importance among the machining parameters for the multiple performance characteristics still needs to be known, so that the optimal combinations of the machining parameter levels can be determined more accurately with the help of fig 4 and table 6 obtained from Minitab.

The optimal parameter combination was determined as A3(current), B2 (pulse on time) and C2 (voltage).In the grey relational grade graph, it is clearly mentioned that third level of current, second level of pulse on time, second level of voltage (A3B2C2) are the optimal combination of process parameters for multiple performance characteristics.



Graph 1: Grey relational grade graphs of multiple performance characteristics

Table 6: The Main Effects of the Factors on the Grey Relational Grade

LEVEL	Ip	Ton	VOLTAGE
1	0.4238	0.4733	0.6220
2	0.4962	0.6133	0.6529
3	0.7598	0.5932	0.4049

The optimal parameter combination was determined as A3(current), B2 (pulse on time) and C2 (voltage).In the grey relational grade graph, it is clearly mentioned that third level of current, second level of pulse on time, second level of voltage (A3B2C2) are the optimal combination of process parameters for multiple performance characteristics.

7. CONFIRMATION TESTS

The confirmation test for the optimal parameters with its levels were conducted to evaluate quality characteristics for EDM of Stainless Steel AISI-304. Table 5 shows highest grey relational grade, indicating the initial process parameter set of A3B2C2 for the best multiple performance characteristics among the nine experiments. Table 7 shows the comparison of the experimental results for the optimal conditions (A3B2C2) with predicted results for optimal (A3B2C2) EDM parameters. The response values obtained from the experiments are MRR = 13.178 mm³/min and the surface roughness is 5.767µm.

Table 7: Confirmation test

	Confirmation test value(9, 150, 55)	**Predicted Value(9, 200, 55)**
LEVEL	**A3B2C2**	**A3B3C2**
MRR	**14.121**	**13.178**
SR	**5.468**	**5.767**

% error for MRR = $\frac{\text{Yact.} - \text{Yth}}{\text{Yth}}$ x 100

= 7.15%

% error for S.R = $\frac{\text{Yact.} - \text{Yth}}{\text{Yth}}$ x 100

= 5.18%

The comparison again shows the good agreement between the predicted and the experimental value with an error of less than 30%.

8. CONCLUSION

Taguchi's Signal – to – Noise ratio and Grey Relational Analysis were applied in this work to improve the multi-response characteristics such as MRR (Material Removal Rate) and Surface Roughness of Stainless Steel AISI-304 during EDM process. The conclusions of this work are summarized as follows:

1. The optimal parameters combination was determined as A3B2C2 i.e. pulse current at 9A, pulse-On time at 150µs and Voltage at 55V.
2. The confirmation results were checked with experimental results and a good agreement is found.
3. This work demonstrates the method of using Taguchi methods for optimizing the EDM parameters for multiple response characteristics.

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