Optimization of Effective Parameters During Electric Discharge Machining of Incoloy 800

Nishant Kumar, P. Sudhakar Rao

Abstract: Experimental work is totally focused on the inclusive work material Incoloy 800 because of its low cost and effective thermal properties The aim of this proposed work is to find out the optimum condition using RSM technique under the influence of effective parameters which includes MRR, TWR, Surface Roughness so that process parameters such as pulse on time, current, voltage can be optimized while working with Incoloy 800 as a work material. Incoloy 800 has inevitable properties in heat application and machining because of its nickel, chromium and iron content. It also comes under the category of super alloy having various important application in aerospace industries. Chromium present in the alloy helps in heat resistance. Internal oxidation during machining is resisted by iron present in the alloy. The nickel content present in Incoloy 800 maintains ductile and austenitic structure. Therefore, alloy 800 can be machined easily as per desired shape. Because of its moderate strength, low cost and good resistance to oxidation and carburization at elevated temperatures, alloy 800 and its grades are center of attraction for alloy manufacturing companies.

Keywords: Electric Discharge Machine (EDM), Surface Roughness (SR), Material Removal Rate (MRR), Tool Wear Rate (TWR), Radial Overcut (RO), Response Surface Methodology (RSM), Ultimate Tensile Strength (UTS), Yield Tensile Strength (YTS).

I. INTRODUCTION

Electric Discharge Machining is a non-traditional machining process which is used for the machining of materials having optimum hardness. EDM is generally performed to remove unwanted material from the workpiece so as to give desired shape and size. Even complex shapes can also be generated using EDM. This process requires electric current between cathode and anode where tool is made cathode and work material is made anode. Machining in EDM requires electrically conductive work material. Electrical spark or thermal energy is used in EDM for the removal of unwanted material with the help of such discrete sparks in order to create desired shape. Process of material removal in EDM starts with the connection of the electrode and workpiece with electric source which generates high voltage across the small gap present between them. Electric field gets created in the insulating dielectric due to presence of such high voltage.

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***** Correspondence Author
Nishant Kumar*, Mechanical Department, National Institute of Technical Teachers training (NITTTR) Sector 26, Chandigarh, India.
P Sudhakar Rao Mechanical Department, National Institute of Technical Teachers training (NITTTR) Sector 26, Chandigarh, India.

This electric field gets generated between electrode and the work piece which causes conducting particles present in the dielectric to focus at the points of strongest electrical field. Material removal takes place due to generation of discrete spark in the gap present between electrode and workpiece. Spark releases due to dielectric break down caused due to high potential difference, thereby removing sufficient or desired amount of material from the work piece surface. EDM requires conducting material for functioning, In general workpiece material should be electrically conductive in nature. One of the materials which comes under the categories of super alloys and having considerable importance in EDM is INCOLOY 800. Which may be prepared in the form of sheet and annealed heat treated. Incoloy 800 having UTS of 586 MPa and YTS of 276 MPa. This super alloy has a wide application in aerospace industry as it contains 30% of Nickel and around 20% of chromium including iron, carbon, magnesium, Sulphur, silicon, copper, aluminum and titanium. These compositions provide high strength, stiffness and corrosion resistance to the material which is essential during machining. Also because of its low cost and better strength and resistance properties with regard to oxidation and carburization at elevated temperatures, alloy 800 and its grades are a center of attraction for alloy manufacturing industries Using Incoloy 800 as work material is one of the big challenges for machining industry also. Thermal properties of work material are more pronounced for considering material removal rate rather than its strength and hardness. Input parameters will be considered so as to give more impact on the response parameters which includes gap voltage, peak current and pulse on time. Values of these input parameters will be taken into account in order to obtain response parameters which will be applied for optimization so as to give best and economical machining in EDM.

II. RESPONSE PARAMETERS USED IN EDM

Values of response parameters i.e. Material Removal rate and Tool Wear Rate are being calculated using standard formula whereas Surface Roughness is calculated using Surface Roughness Tester.

A. Material Removal Rate: The material removal rate is one of the most important response parameters which needs to be maximized. It is the amount of material which gets removed while machining. The material removal rate can be calculated from the weight difference before and after machining on the workpiece.

Weight difference is generally measured using Weighing machine.

$$MRR = (w1 - w2)/time \qquad - Equation\ 1$$

Where,

w1 = weight of workpiece before machining
w2 = weight of workpiece after machining

B. Tool Wear Rate: The tool wear rate is defined as the amount of material removed from the tool while machining per unit time. The tool wear rate can be calculated from the weight difference before and after machining at the tool. Weight difference is generally measured using Weighing machine.

$$TWR = (w1 - w2)/time \qquad - Equation\ 2$$

Where,

w1 = weight of tool before machining
w2 = weight of tool after machining

C. Surface Roughness: Surface roughness is measured using Surface Roughness Tester.

III. LITERATURE SURVEY

Gaikwad et al [1] performed experiment to optimize different parameters for consideration which includes current, pulse off time, pulse on time and fluid pressure in order to minimize TWR and maximize MRR. Stainless steel of 316 grade with copper as electrode. Taguchi technique was used to analyze these factors and results concluded that MRR and TWR were largely affected by pulse off time and current. Copper electrode were used for machining SS 316.

George et al [2] presented process optimization on C-C composites as work material using Taguchi Method to determine TWR and MRR. The most effective parameters come out to be gap voltage, pulse on time and peak current which largely effected the MRR and TWR.

Ahmet and Ulas [3] Experiment showed that MRR, SR and TWR increases with increase in pulse duration and pulse current. The study was done using Taguchi method. The work piece material used as Titanium alloy (Ti–6Al–4V). Various machining conditions were applied during machining of Titanium alloy. Further experiment revealed that MRR, SR and TWR increases with process parameters while using different electrode material in particular order with pulse duration of 200us. Highest MRR given by graphite electrode which is followed by electrolytic copper and aluminum. Lowest wear rate was also shown by graphite electrode due to its high melting point while best performance was exhibited by aluminium electrode with regard to surface finish.

Cheron et al [4] experiment were performed to compare copper and graphite electrode as tool material and results were optimized which concluded that copper electrodes gives higher material removal rate as compared with electrode material graphite while using XW42 tool steel as work material for electrical discharge machining. Further his research work verified that copper is best suited for roughing surface while graphite electrode suited for finishing surface.

Alidoosti et al [5] performed experiment in order to determine in order to determine EDM characteristics of work material during machining of NiTi alloy(nickel-Titanium). Machining parameters were evaluated for optimum performance in which MRR, SR and EWR was taken as Input parameters. Results were obtained after optimization of parameters showed that increase in pulse current increases MRR. Further, higher pulse current and large pulse duration increases MRR and at the same time with increase in pulse duration relative electrode wear ratio decreases.

Hessler et al. [6] Experimental investigation was done on surface properties while machining two different nickel-titanium alloys. After investigation done on alloys similar surface characteristics was observed which includes formation of craters and micro cracks while machining these alloys. Material recast layer and crater size also observed to be increased with the increase in pulse duration.

Bari et al. [7] Investigated the effect of electrode polarity and discharge current while working with Inconel 718 as work material in EDM copper–tungsten powder was used as electrode after being processed significantly. Result showed that maximum MRR and minimum TWR occurs at positive polarity whereas minimum SR was observed at negative polarity.

Rajesha et al [8] Studied the machining analysis of Inconel 718 in which copper tool electrode was shaped into hollow tube-like cross section, the most dominant factors which effects MRR are discharge current and duty factor. Input parameters discharge current, medium flushing pressure, sensitivity control and gap control when helped in obtaining better surface finish when kept at low values. Above result were analyzed using Taguchi design of experiment.

Bharti et al [9] Taguchi methodology was applied to show that with increase in pulse duration, MRR and SR were observed to increase and as well with discharge current. Experiment correlates different process parameters and performance characteristics oh Inconel 825 during die sinking EDM.

Kang and Kim [10] Investigation was done using Hastelloy X which is based on nickel-based super alloy as work material, carbon deposition was observed on tool surface on increasing pulse-on time which increases material removal rate. Therefore, it has been concluded that MRR also leads to deposition of carbon on work piece surface.

Lee and Tai [11] Process optimization and analysis was carried out which revealed that with increase in pulse current and pulse on duration, the surface roughness also increases. Further increase in pulse duration effected by both the induced stress and average white layer thickness. As determined from results, EDM parameters are also related to crack formation.

Muthukumar et al [12] mathematical model were presented while machining of Incoloy 800 as work material to determine radial overcut in electrical discharge machining. Experiments concluded radial overcut can be minimized by lowering the values for current and voltage. Response Surface methodology was adopted to determine at optimum results and analysis were performed using ANNOVA. Further results also clarified that pulse off time has lower influence than voltage for obtaining the optimized values.

Paul et al [13] machining response were studied on MRR using Inconel 800 as work material with copper tool as electrode for an EDM process. Various operating parameters Pulse on time. off time and pulsed current were set up for the experimentation. Response surface methodology were used for generating the model for MRR using above given parameters. Analysis were made using Regression analysis procedure in order to determine the relationship between input-output parameters. Finally, results were obtained which clearly indicated that in order to increase the spark energy across the electrode gap, current value need to be increased which also increases MRR value.

Kuppam et al [14] Investigation was done using Inconel 718 on EDM. Drilling was done on work material which revealed that peak current has to be increased in order to ensure rise in MRR. Other parameters which also shows rise in MRR are duty factor and electrode speed. Investigation also concluded on Average surface roughness which is found to increase on increasing the values for peak current and pulse on time. Whereas increase in electrode speed also leads to further rise in surface roughness. RSM techniques has been used by author and analyzed mathematical models were developed to generate response of MRR and SR.

Aveek et al [15] Experiments were performed using Taguchi Gray Analysis using Inconel 825 as work material. In order to increase MRR and decrease SR, some of the parameters which have major effect includes Pulse duration, dielectric flow rate, servo feed and pulse-off time. Further considerable effect includes corner servo voltage, wire feed rate, spark gap voltage, and wire tension. Finally, it has been concluded that Taguchi Gray Analysis is most suitable for wire cut EDM during machining of Inconel 825. Optimum values were obtained with Inconel 825 gives 105 µs pulse on time, 30 V spark gap voltage, 50 µs pulse off time.

Karunakaran and Chandrasekaran. [16] Electric discharge machining was carried out using Inconel 800 as work material and machinability results were obtained after optimization. The average values of various output parameters were obtained as 0.27603 g/min of MRR, 1.71 µm SR and .00255 g/min of TWR when setting the optimum or optimized values as 5 A of peak current, 8 µs pulse on time and 4 µs pulse off time

Mahendra and Deepak [17] studied the effect dielectric mixed with powder in EDM which has been analyzed during machining of Inconel 718 with copper electrode having 6 mm diameter. Dielectric used is Kerosene oil mixed with SiC, aluminium oxide and graphite powder mixed as per standard in kerosene. Effect of various parameters which includes peak current, pulse on time, different dielectric medium and duty cycle were observed on MRR and TWR. Optimum machining condition was selected for Inconel 718 as work material. Experiments showed that the addition of powder in kerosene leads to high MRR and minimum TWR. Results were generalized using Taguchi Method. Analysis was done using Analysis of variance method for process optimization considering MRR and TWR.

IV. EXPERIMENTAL METHODOLOGY

There are different ways for designing an experiment in Experimental methodology. One of the oldest techniques used is Taguchi Methodology which used rarely now a days. Research Surface methodology is used significantly for the purpose of optimization It is most simple and less calculative approach used for the purpose of optimization. It is a statistical modelling technique employed for multiple regression analysis of data in order to solve equations simultaneously. It also provides the behavior of a system, using the optimum number of experimental observations. Therefore, most reliable and basic method for optimization of process parameters taken as Response Surface Methodology. In this method all the process parameters Peak Current, Gap Voltage and Pulse on time will be varied accordingly to optimize MRR, TWR and SR. Design Expert software is used for analysis and optimization purpose with three input and three response factors. Three levels were taken as default. Box-Behnken was taken as design type for simpler Run. User defined design type model can also be used but it will produce 27 runs as compared to Box-Behnken design model with 17 runs in same input and response parameters.

V. RESULTS AND DISCUSSION

The objective of experiment is to optimize the process parameters to get maximum Material removal rate, minimum tool wear rate and minimum surface roughness. Seventeen experiment designed by RSM is performed using various input parameters viz. Peak current, gap voltage and pulse on time. With the help of input values of process parameters taken during experimentation, MRR, TWR and SR can be easily calculated as discussed in previous chapters. It is to be noted that pulse off time has been kept constant throughout the process so as to simplify the experimentation.

Table 1: Input and Response parameter

Std	Run	Peak Current (Amp)	Gap Voltage (V)	Pulse on time (µs)	MRR (g/min)	TWR (g/min)	SR (µm)
Order		**Input Parameters**			**Response Parameters**		
6	1	15	45	50	0.008	0.008	6.25
11	2	10	30	100	0.01	0.004	7.72
13	3	10	45	75	0.014	0.002	7.21
2	4	15	30	75	0.01	0.001	7.71

1	5	5	30	75	0.006	0.002	5.86
16	6	10	45	75	0.012	0.002	6.1
14	7	10	45	75	0.014	0.001	7.43
10	8	10	60	50	0.01	0.004	7.07
5	9	5	45	50	0.008	0.002	5.94
8	10	15	45	100	0.016	0.002	6.99
3	11	5	60	75	0.016	0.001	7.24
9	12	10	30	50	0.004	0.004	6.3
15	13	10	45	75	0.014	0.006	6.85
4	14	15	60	75	0.01	0.002	7.14
12	15	10	60	100	0.008	0.002	7.96
17	16	10	45	75	0.006	0.002	5.91
7	17	5	45	100	0.012	0.001	7.74
Pulse off time				**100 µs**			

Now each response parameters will be optimized through graphical representation showing variation with respect to input parameters.

a) **Material Removal Rate**: Variation of Material removal rate with Voltage and current shows that within the voltage range of 50 V to 60 V and Peak current of more than 10 A, MRR is higher.

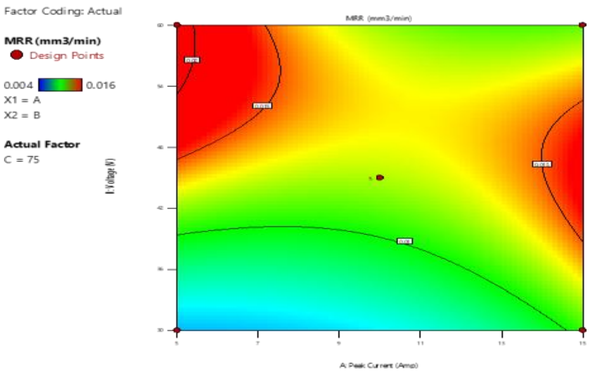

Fig 1: Variation of MRR against Input parameters

b) **Tool Wear Rate**: Variation of Tool Wear Rate with Voltage and current shows that within the voltage range of 54 V to 60 V and Peak current of more than 13 A, TWR is minimum.

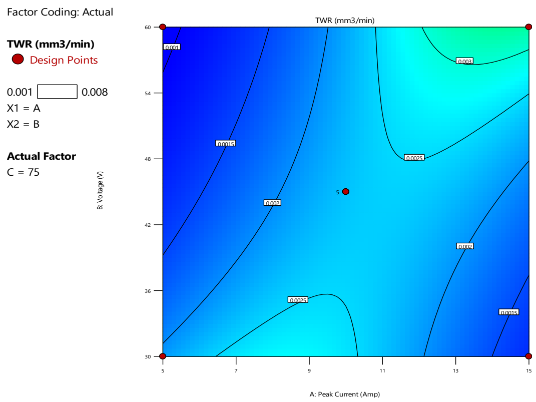

Fig 2: Variation of TWR against Input parameters

c) **Surface Roughness**: Variation of Surface Roughness with Voltage and current shows that within the voltage range of 50 V to 60 V and Peak current near to 5 A, SR is minimum.

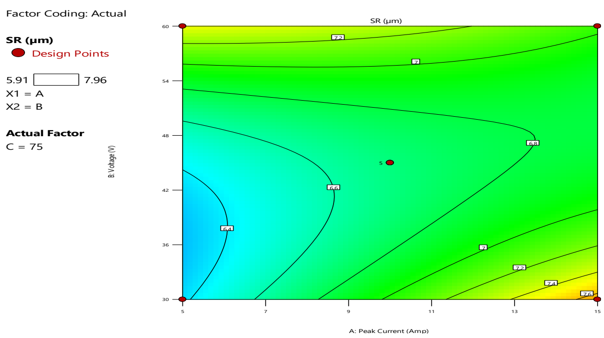

Fig 3: Variation of SR against Input parameters

Finally process model will be optimized to give following results based on maximum MRR, minimum TWR and minimum SR at desirability 0.836.

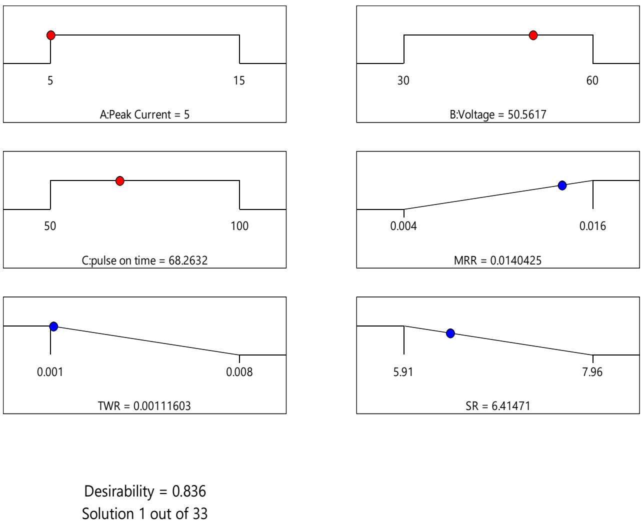

Fig.4 Optimized value of parameters

Variation of response parameter MRR shown in diagram gives the range of values of input parameters set in the beginning. Graph having higher density color gives most optimum values for MRR. Each input parameters viz. Pulse on time, Peak current, Gap Voltage has effect on response parameters. The process parameters have been verified and opted for percentage error also. Minimum value of error shows that the results can be used for optimization and can be said the regression model used in the experiment is accurate because the percentage error is less than 5. Considering the desirability approach of the model, it is evident the desirability of the combined model is 0.836 which is considerable within the range of experiment.

Table 2: Optimized Results

Peak Current (Amp)	Gap Voltage (Volt)	Pulse on Time (µs)	MRR (g/min)	TWR (g/min)	SR (µm)
5	50.56	68.26	0.014	0.0011	6.41

VI. CONCLUSIONS

Result obtained from analysis and optimization using RSM, we have found that the optimized value for input and response parameters. It is clear that the surface roughness obtained from experimentation is larger as compared with the average values. This shows that at higher current surface roughness is more but at the same time MRR is also higher. Tool wear also considered into account but having nominal effect. Therefore, in order to obtain the high material removal rate, peak current should be around 5 A so that so that low surface roughness and low tool wear rate is obtained.

VII. LIMITATIONS AND FURTURE SCOPE

a) Copper electrode as a tool material possess difficulty in machining.
b) Pulse off time is kept constant.
c) Type of dielectric is limited to EDM oil.
d) Surface finish reduces considerably after machining
e) Graphite electrode can be used for machining.
f) Inconel 800HT can also be used for machining and optimization.
g) Other parameters like pulse off time, type of dielectric can also be used.
h) Optimization can be done at lower values of current and more higher values of pulse on time.

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AUTHORS PROFILE

Nishant Kumar Graduated from Punjab Technical University, Pursuing M.tech in Mechanical Engineering Department, from National Institute of Technical Teachers training (NITTTR) Sector 26, Chandigarh, India, PH-+91-9915477316.
E-mail: nishu180192@gmail.com.

P Sudhakar Rao Completed PHD from IIT Roorkee, currently working as Assistant professor in Mechanical Department, National Institute of Technical Teachers training (NITTTR) Sector 26, Chandigarh, India, PH-0172-2759617. E-mail: psrao.iitr@gmail.com

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