Analysis and Optimization of Process Parameters in EDM of RENE 80 Using Taguchi Method

A. Sugunakar, A. Kumar and R. Markandeya

Abstract--- *The present work aims to carry out an experimental investigation into the electrical discharge machining process while machining of Nickel super alloy RENE80. Taguchi L9 orthogonal array is used to plan the experimental layout. Taguchi method is used to analyze the effect of each process parameter such as peak current, pulse on time and pulse off time on chosen machining characteristics namely material removal rate (MRR) and surface roughness (SR) and also to predict the optimal combination of process parameters to get maximum material removal rate and minimum surface roughness separately. Further analysis of variance has been done to identify the significant affect of parameters on machining characteristics. It is found that parameters peak current and pulse on time have a significant affect where as pulse off time has no significant affect on material removal rate and surface roughness. Confirmation experiments are conducted at their respective optimum parametric settings to check the predicted optimal values of performance characteristics. Then percentage errors are calculated and are 0.94 and 4.87 respectively in predicting MRR and SR values.*

Keywords--- *Electrical Discharge Machining, Taguchi Method, Peak Current, Pulse on Time, Pulse off Time, Material Removal Rate, Surface Roughness.*

I. INTRODUCTION

IN EDM, erosion of two electrically conductive materials will occurs by instigation of recurring and continuous spark discharges in a small gap separated them. The melting of work piece will happen when sufficient heat is generated by the each electric spark also some tool material melts. The resistance increases due to evaporation of dielectric in the arc gap till interruption of arc takes place. The current flow between electrodes produces debris which is flushed out by the fluid. This can be done continually to erode a finely controlled element that would be unattainable to machine with traditional machining methods.

However certain defects like porosity, residual stress and micro cracks in the recast layer due to enormous temperature followed by sudden cooling are usually found on the machined

surface. Rajmohan T. et al [1] reported the electrical discharge machining parameters effect such as pulse on time, pulse off time and current on MRR of 304 stainless steel using Taguchi method. They found that maximum MRR can be achieved with different combinations of EDM process parameters. They also noticed that the most significant parameters were current and pulse off time for MRR. They also mention that the optimum cutting parameters can be achieved with minimum number of trails. They opted taguchi method which is efficient methodology to find the optimum process parameters. P.M. George et al [2] worked on the EDM machining of carbon-carbon composite by using a taguchi approach. In this their aim was to derive the optimal setting of the process parameters on the electro-discharge machining (EDM). Qualitek-4 software was used to apply taguchi method. It has been shown that significant improvement in the response parameters such as MRR, SR etc. can be attained with combination of machining parameters at their optimum levels.

Beri et al [3] performed experimental study to evaluate surface roughness of Inconel 718 alloy during electrical discharge machining with powder metallurgy processed electrodes. They investigated process parameters were polarity, electrode type, peak current, pulse on time, duty cycle, gap voltage, retract distance and flushing pressure. To plan and design experiments, standard L₃₆ orthogonal array based on Taguchi methodology was applied. The data was analyzed statistically using analysis of variance (ANOVA). Kamaljit Singh, C S Karla et al. [4] carried out experimental investigation of machining of OHNS Die steel by EDM process. They were chosen the input process parameters as peak current, pulse on time, voltage gap and flushing pressure. To optimize the machining parameters, Taguchi and ANOVA methods were used. From the experiments, it was observed that current has the significant effect on the material removal rate and flushing pressure has the major effect on the hardness of OHNS steel.

Prof. D.V.Ghewade et al. [5] have studied the effect of various process parameters like peak current, gap voltage, duty cycle and pulse on time on Inconel 718. To analyze the effect of machining parameters on MRR, EWR, Radial Overcut and Taper Angle, Taguchi method was used. They were noticed that the MRR mainly affected by peak current and gap voltage. EWR was mainly influenced by Pulse-on time and duty cycle. Peak current and duty cycle have the major effect on ROC and pulse on time (Ton) and duty cycle (t) were main cause for the half taper angle (α°). Kapil Banker et al [6] observed the parametric optimization of Electro Discharge Machine of AISI 304 Steel by using Taguchi Method. To design the experiments, Taguchi method is used with three input parameters at three levels using L9 array.

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DOI: 10.9756/BIJIEMS.10502

Copper is used as tool electrode and AISI 304 steel is used as work piece. Optimization is carried out by using Taguchi method and MINITAB software. The machining parameters were current, T_{on} , T_{off} , Depth of cut while response parameter was material removal rate. From the experimental work, it was noticed that MRR affected mainly by the pulse-on time parameter. It has also observed that copper has higher material removal rate as compared to other material like as aluminum, gun metal, brass, etc. M. Kiyak et al [7] have studied that the effect of EDM settings on surface roughness for machining of AISI P20 tool steel. Discharge current, pulses on time and pulse pause time were the chosen parameters. They were found that with increasing of discharge current and pulse on time, SR increased and with decrease of discharge current and pulse on time and higher pulse pause time a good surface finish was attained. Lee SH et al [8] The machining of EDM will be determined mainly by electrical parameters such as current, pulse duration, voltage and material properties of work piece and electrode like melting temperature etc and also electrical and thermal conductivity as well. Gao et al [9] developed an ANN model of the EDM process and further by using GA they optimized the input process parameters. J. Jeykrishnan, et al [10] investigated to optimize the process variables of EDM by employing a traditional technique. The machining parameters chosen for optimization were pulse on time, pulse off time and current. L9 Orthogonal Array selected to examine the effect of the process variables on the performance parameter i.e. material removal rate. The experimental trials were conducted with positive polarity on AISI D2 die steel and brass chosen as an electrode material. Haron CHC et al [11] reported the influence of process parameters on tool steel using EDM. They have concluded by optimizing the different process parameters, the copper or graphite electrode (as tool) gives the maximum MRR and minimum TWR in machining of AISI 1045 tool steel. George PM, et al [12] have studied that by optimizing the process variables like pulse current, T_{on} and gap voltage of EDM, better MRR was obtained. They have also concluded that the pulse current has been the most significant parameter that effects MRR and then by the gap voltage and T_{on} . Ikram A et al [13] used ANN to optimize the process parameters while varying T_{on} , T_{off} , wire feed velocity, wire tension, voltage and pressure. Taguchi technique used to optimize the responses like SR, MRR and kerf. They have also found out that T_{on} has a significant impact on the responses. All the experiments were conducted by WEDM on D2 die steel. Thomas S et al [14] have studied the response parameters like MRR and TWR, by optimizing the input characteristics such as T_{on} , T_{off} and in Powder Mixed EDM (PMEDM), it was proved that the discharge current is the most significant parameter that affects the output characteristics while machining D2 die steel, followed by T_{on} and T_{off} . Vikram Reddy V et al [15] investigated the electrical discharge machining process during machining of precipitation hardened stainless steel PH17-4. Taguchi method was used to design the experimental layout, to analyze the effect of combination of process parameters on machining characteristics and to predict the optimal choice for

combination EDM process parameters such as peak current, pulse on time and pulse off time that gives optimal process performance characteristics such as material removal rate, surface roughness, tool wear rate and surface hardness. Uyyala S.B et al [16] obtained optimal process parameter combination during EDM of RENE 80 alloy.

It is observed from the literature that, no extensive work has been reported so far in the area of EDM of Nickel alloy RENE80 with electrolyte copper as electrode and EDM oil (SAE450) as dielectric fluid.

The aim of the present work is to find the effect of process parameters such as peak current, pulse on time and pulse off time. Also find their significance on chosen machining characteristics namely MRR and SR. Then the optimal combination of process parameters is obtained for maximum MRR, and minimum SR separately using Taguchi method.

II. EXPERIMENTAL SETUP, PROCEDURE AND EQUIPMENT

Experiments were conducted using Nickel alloy RENE80 as work material and is cut into the sample pieces dimensions of $70 \times 35 \times 4$ mm with help of wire cut EDM process. The chemical composition of the Nickel alloy RENE80 is presented in Table 1.

Table 1: Elemental Composition of RENE 80 Nickel Super Alloy (wt %)

Element	Weight %
Al	5 – 6
Cr	9.5 – 12
Ti	2.5 – 3.2
C	0.13 – 0.2
Mo	3.5 – 4.8
W	4.5 – 5.5
Co	4 – 4.5
B	0.02 max
Ce	0.015max
Si	< 0.4
Mn	<0.4
Fe	0.5 max
Ni	Balance

Table 2: Mechanical and Physical Properties of RENE 80 Nickel Alloy

Work Material	RENE 80 Nickel Super Alloy
Hardness (HRC)	43-45
Ultimate tensile strength (Kg/mm ²)	85
Electrical resistivity nΩ	1300
Thermal conductivity (W/m° K)	11.5
Melting range (°C)	1320 – 1380
Density (g/cm ³)	8.16
Elongation %	3
Reduction in Area %	5 – 7
Creep strength (°C)	975
Creep rupture (Kg/mm ²)	25

Table 3: Physical Properties of Electrolyte Copper

Specific capacity	383 (J/kg °C)
Density	8.95 (g/cm ³)
Melting point	1083°C
Thermal conductivity	394 (W/m °C)
Electrical resistivity	1.673×10 ⁻⁸ Ω m

The mechanical and physical properties of Nickel alloy RENE80 are shown in Table 2. The electrolyte copper of diameter 14mm is chosen as tool material for machining Nickel alloy RENE80 and its physical properties are shown in the Table 3. Commercial EDM oil grade SAE450 is used as the dielectric fluid to conduct all the experiments. All the experiments are conducted on die sinking EDM machine of FORMATICS 50 model which is equipped with ELECTRONICA PRS 20 controller. For selecting the range of input factors trial experiments were conducted. The selected process parameters and their corresponding levels for this experimentation are shown in the Table 4. Table 5 represents the machining conditions. Taguchi L9 Orthogonal array is selected for planning experiments and is shown Table 6. A total number of 9 experimental runs are conducted and each experimental run are repeated three times. Machining time was chosen for conducting each experiment is 3min. Both work pieces and electrodes are cleaned and polished before machining. The Taguchi method uses signal to noise (S/N) ratio to measure the deviation of performance characteristics from the desired values. These are three categories of S/N ratios depending on the types of characteristics like higher-is-the-best (HB), lower-is-the-best (LB) and nominal is the best (NB). MINITAB16 software was used to analyze the experimental data. For weighing the work pieces and electrodes before and after machining a digital weighing balance (citizen) capacity up to 300 g with a resolution of 0.1mg was used. Then the MRR is calculated using equation (1).

$$MRR \left(\frac{mm^3}{min} \right) = \frac{\Delta W}{\rho_w \times t} \quad (1)$$

Where ΔW is the weight difference of work piece before and after machining (g), ρ_w is density of work material (g/mm³), and t is machining time in minutes. Surface roughness (SR) on machined work surfaces are measured using Talysurf surface roughness tester. The SR is represented by the center line average method (Ra). Roughness measurements are carried out in on machined surface with sampling length of 0.8mm and are repeated three times and average values are calculated.

Table 4: Working Range of the Process Parameters and their Levels

Parameter	Symbol	Unit	Level1	Level2	Level3
Peak current, I	A	Amps	10	15	20
Pulse on time, T _{on}	B	μs	25	45	65
Pulse off time, T _{off}	C	μs	24	36	48

Table 5: Machining Conditions

Working conditions	Description
Work piece	RENE80 Nickel super alloy (70mm×35mm×4mm)
Electrode	Electrolyte copper Ø 14mm
Dielectric	Commercial EDM Oil grade SAE 450
Flushing	Side flushing with pressure 0.5MPa
Polarity	positive
Supply voltage	240 V
Machining time	3 minutes

Table 6: Experimental Layout Using an L₉ (3⁴) OA

Sr. No.	Process parameters			
	A	B	C	D
	Peak current	Pulse on time	Pulse off time	Dummy
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

III. RESULTS AND DISCUSSION

It is possible to sort out each process parameter on response at different levels since the experiments are designed in orthogonal nature. The raw data of various responses are collected after conducting experiments are transferred in to their respective S/N ratio values.

A. Effect of Parameters on Material Removal Rate

The average values of MRR and respective S/N ratio values are shown in Table 7. Figure 1 presents main effects plot for means of MRR. Figure 2 shows main effects plot for S/N ratios of MRR. A main effects plot is a plot of the means at each level of a factor. One can use these plots to compare the magnitudes of the various main effects and compare the relative strengths of the effects across factors. However it is important to proceed to evaluate significance by looking at the effects in the analysis of variance Table. It is observed from the Figures 1&2 that MRR increases noticeably with increasing in peak current values from 10A to 20A. The peak current directly effects the spark energy available in the inter electrode gap. The increase in peak current causes increase in discharge energy resulting into higher current density that quickly over heats the work piece that causes increasing in MRR at higher peak current conditions. Also it is observed that the MRR increases with increasing in pulse on time. The spark energy in the plasma channel and the phase of transferring this energy in to the electrodes increases with increasing in pulse on time. This occurrence makes formation of bigger molten material crater on the work material that resulting into increase in MRR. However another observation is that MRR increases slightly with increasing in pulse off time.

Table 7: Experimental Data of MRR and Corresponding S/N Ratios

Exp No	Process Parameters			Response MRR	
	I(A)	Ton(μ s)	Toff(μ s)	Means(mm ³ /min)	S/N Ratio(dB)
1	10	25	24	7.93	17.9855
2	10	45	36	9.20	19.2758
3	10	65	48	12.08	21.6413
4	15	25	36	16.65	24.4283
5	15	45	48	18.98	25.5659
6	15	65	24	21.56	26.6730
7	20	25	48	22.94	27.2119
8	20	45	24	21.62	26.6971
9	20	65	36	24.18	27.6691

Table 8 shows response Table for means of MRR. Table 9 presents response Table for S/N ratios for MRR. This response Table presents the effects of various input factors on MRR. Higher the slope in the main effects plot corresponding values of Δ is higher in the response Table. The rank represents directly the level of effect of input based on the values of Δ . Here according to ranks, the effects of various input factors on MRR in sequence are peak current, pulse on time and pulse off time.

That means peak current affects the MRR at highest level and pulse off time at lowest level. Further ANOVA of the data at 95% confidence level is presented in Table 10 reveals that peak current, and pulse on time, are significant factors affecting the MRR since respective F values are higher than the F_{cr} . This analysis is acceptable since corresponding p values are small and also pulse off time has no significant effect on SR.

Since it is always desirable to maximize the MRR larger the better option is selected. Figure 2 suggested that when peak current is at 20A (level 3), pulse on time is at 65 μ s (level 3) and pulse off time is at 48 μ s (level 3), provide maximum MRR from the work surface. MRR is calculated at its optimal parameter setting and its value is 25.71mm³/min and corresponding S/N ratio is 29.07.

Table 8: Response Table for Means of MRR

Level	I	Ton	Toff
1	9.73	15.84	17.03
2	19.06	16.60	16.77
3	22.91	19.27	18.00
Δ (Max-Min)	13.17	3.43	1.32
Rank	1	2	3

Table 9: Response Table for S/N Ratios of MRR

Level	I	Ton	Toff
1	19.63	23.21	23.79
2	25.56	23.85	23.79
3	27.19	25.33	24.81
Δ (Max-Min)	7.56	2.12	1.02
Rank	1	2	3

Larger is better

Table 10: Analysis of Variance for MRR

source	DOF	Seq SS	Adj SS	Adj MS	F	P
I	2	275.434	290.446	137.717	133.40	0.007
T _{on}	2	19.512	25.134	9.756	9.45	0.096
T _{off}	2	2.809	1.731	1.404	1.36	0.424
Error	2	2.065	1.898	1.032		
Total	8	299.819				

S = 1.01604 $R^2 = 99.31\%$ R^2 (adj) = 97.25%

Figure 1: Main Effects Plots for Means of MRR

Figure 2: Main Effects Plots for S/N Ratios of MRR

B. Effect of Parameters on Surface Roughness

The average values of SR for each trial and their respective S/N ratio values are presented in Table 11. Figure 3 presents main effects plot for means of SR. Figure 4 shows main effects plot for S/N ratios of SR.

Table 11: Experimental Data of SR and Corresponding S/N Ratios

Exp No	Process Parameters			Response SR	
	I (A)	Ton (μ s)	Toff (μ s)	Means (μ m)	S/N Ratio (dB)
1	10	25	24	1.23	-1.7981
2	10	45	36	1.31	-2.3454
3	10	65	48	1.96	-5.8451
4	15	25	36	2.26	-7.0822
5	15	45	48	2.68	-8.5627
6	15	65	24	2.92	-9.3077
7	20	25	48	3.19	-10.0758
8	20	45	24	2.98	-9.4843
9	20	65	36	3.69	-11.3405

Figure 3: Effect of Process Parameters on Mean Data of SR

Figure 4: Effect of Process Parameters on S/N Ratio Data of SR

Further it is observed from the Figures 3 and 4 that there is increase in surface roughness with increase in peak current. This can be attributed to the fact that increase in peak current causes increase in spark energy resulting in the formation of deeper and larger craters result in increase in surface roughness. It is also noticed that surface roughness increases with the increase in pulse on time. The spark energy and time of transferring energy into the work piece increases with increase in pulse on time. This phenomenon leads to increase in formation of molten pool resulting in deeper and larger craters which again results in increase in SR. A small increase in surface roughness value is observed with the increase in pulse off time. This may be due to proper removal of debris from the discharge channel.

Table 12: Response Table for Means of SR

Level	I	Ton	Toff
1	1.500	2.227	2.377
2	2.620	2.323	2.420
3	3.287	2.857	2.610
Δ (Max-Min)	1.787	0.630	0.233
Rank	1	2	3

Table 13: Response Table for Signal to Noise Ratios of SR

Level	I	Ton	Toff
1	-3.330	-6.319	-6.863
2	-8.318	-6.797	-6.923
3	-10.300	-8.831	-8.161
Δ (Max-Min)	6.971	2.512	1.298
Rank	1	2	3

Smaller the better

Table 12 shows response Table for means of SR. Table 13 presents response Table for S/N ratios for SR. This Table presents the effects of various input factors on SR. Higher the slope in the main effects plot corresponding values of Δ is higher in the response table. The rank represents directly the level of effect of input based on the values of Δ . Here according to ranks, the effects of various input factors on SR in sequence of its effect are peak current, pulse on time, and pulse off time. That means peak current affects the SR at highest level and pulse off time at lowest level. Table 14 represents the ANOVA for SR at 95% confidence level.

Table 14: Analysis of Variance for SR

Source	DOF	Seq SS	Adj SS	Adj MS	F	P
I	2	4.89102	4.89102	2.44551	182.80	0.005
T _{on}	2	0.69069	0.69069	0.34534	25.81	0.037
T _{off}	2	0.09242	0.09242	0.04621	3.45	0.225
Error	2	0.02676	0.02676	0.01338		
Total	8	5.70089				

$$S = 0.115662 \quad R^2 = 99.53\% \quad R^2(\text{adj}) = 98.12\%$$

The data presented in the ANOVA reveals the significance of input parameters on SR which is as follows. The peak current, and pulse on time, are significant factors affecting the SR since respective F values are higher than the F_{cr} . This analysis is acceptable since corresponding p values are small. However pulse off time has no significant effect on SR. Since it is always desirable to minimize the SR smaller the better option is selected. From Figure 4 noticed that minimum SR value is attained when peak current at 10 A (level 1), pulse on time at 25 μ s (level 1) and pulse off time at 24 μ s (Level1). Further optimum surface roughness value is calculated as 1.17 μ m and corresponding S/N ratio is -1.88.

IV. CONFORMATION EXPERIMENTS

To verify the predicted optimal values of responses such as MRR, and SR conformation experiments were conducted at their optimal parametric settings. The data obtained from conformation experiments are compared with respective predicted values.

The deviations of predicted values from experimental results are calculated as % error and are found less than 5% and hence they are in good agreement. Further the conformation experimental data presented in Table 15.

$$\% \text{error} = \frac{\text{experimental value} - \text{predicted value}}{\text{experimental value}} \times 100 \quad (2)$$

Table 15: Confirmation Experiments at Optimum Parametric Setting

S.No.	Optimum parameters			Response	Experimental value	Predicted value	%error
	I (A)	T _{on} (μ s)	T _{off} (μ s)				
1	20	65	48	MRR (mm^3/min)	25.47	25.71	0.94
2	10	25	24	SR (μ m)	1.23	1.17	4.87

V. CONCLUSION

Based on the experimental results in the present study, the following conclusions are drawn:

- Responses namely MRR and SR are increased with increasing in peak current and pulse on time. However MRR and SR increase slightly with pulse off time.
- Further the dominant process parameters for optimum response are: I is at 20A, Ton is at 65 μ s and Toff is at 48 μ s yield maximum MRR (25.71 mm^3/min). I is at 10A, Ton is at 25 μ s and Toff is at 24 μ s yield minimum SR (1.17 μ m). Confirmation experiments were conducted at respective optimal parametric settings to verify predicted optimum values. The corresponding % error values are less than 5%

3. Peak current and pulse on time are significant parameters affecting MRR and SR. While pulse off time has no significant affect on MRR and SR.

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