Selection of Optimal Process Parameters in Machining Aerospace Material by Wire Electric Discharge Machining Process

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Abstract— The objective of the present study is to investigate the optimal process parameters of Electric Discharge Machining (EDM) on Inconel 800 alloy material with molybdenum as a tool electrode. The input parameters considered were voltage, pulse on time, pulse off time, current and bed speed for the experimental work and their effect on Material Removal Rate (MRR) and Surface Roughness (Ra) while machining Inconel 800 in Wire Electric Discharge Machining (WEDM). The effect of various process parameters on machining performance is investigated in this study. Taguchi method is used to formulate the experiment and L18 orthogonal array is selected for the experimentation. ANOVA is used to analyze the effect of input process parameters on the machining characteristics. To predict the machining characteristics using Artificial Neural Network (ANN) is used and were later compared with the experimental results. The results of the present work reveal that proper selection of input parameters play a significant role while machining with EDM.

Key words: Artificial Neural Network, WEDM, MRR, Ra, ANOVA, Taguchi Orthogonal Array

I. INTRODUCTION

Electric discharge machining (EDM), known as thermal erosion process is one of the non-conventional machining processes where the tool and workpiece do not come in contact with one another during the machining. EDM is the process in which electrical energy is used to generate electric spark and material removal occurs primarily due to the thermal energy of the electric spark. The excess material is eroded from the workpiece by series of discrete sparks between a work and tool electrode immersed in a liquid dielectric medium.

On the machining surface, each discharge creates a crater in the workpiece and there is an impact on the wire electrode. The dielectric fluid acts as an insulator as well as cooling agent. Since no cutting forces are present it is very ideal for machining delicate parts. The electrical discharges melt and vaporize the minute amounts of the work material which are then ejected and flushed away by the diectric fluid. Sparks occurring at high frequency effectively remove the workpiece material by melting and evaporating from the workpiece.

Taguchi orthogonal array is used to conduct the experiment to get better result for obtaining optimum results. The experimental result is transformed to S/N ratio and ANOVA are used to determine optimum value and relative affect of each factor on the output responses. ANN model is developed to predict the machining characteristics and to compare with the experimental values.

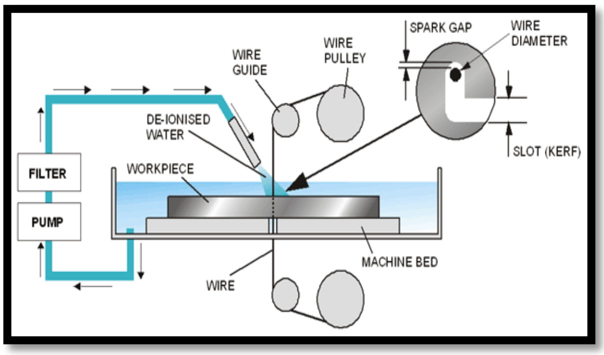

Fig. 1: Wire Electric Discharge Machining Model

II. LITERATURE SURVEY

C. D. Shah et al. (2013) [1] used Inconel 600 for optimization of process parameter of Wire Electric Discharge Machining by Response Surface Methodology. Five variables were chosen to study the performance in terms of MRR. Pulse on time was the most significant factor followed by pulse off time, peak current and wire speed.

S. Dewangan et al (2015) [2] studied optimization of surface integrity characteristics of WEDM process using grey fuzzy logic based hybrid approach. The experiment considering five process parameters against MRR and Ra was carried out. The optimal solutions clearly indicate that pulse on time is the most contributing parameter followed by discharge current for required characteristics of surface integrity.

R. Chalisgaonkar et al (2014) [3] in his research work developed a multi response optimization technique. The effect of the seven process parameters were investigated on MRR & Ra. Three parameters namely wire type, pulse on time, wire offset were the most significant factors.

S. Sivakiran et al. (2012) [4] studied the effects of the process parameters on material removal rate in Wire Electric Discharge Machining of En 31 steel using taguchi's L16 OA. The results indicated that current was the most effective parameter followed by pulse on time, bed speed and pulse off.

H. Singh et al. (2009) [5] studied the effects of the process parameters on material removal rate in WEDM. Influence of various process parameters on MRR was investigated. The results indicated that material removal rate directly increase with increase in pulse on time and peak current while decreases with increase in pulse off time and servo voltage.

M. Rana et al. (2015) [6] used WEDM which was oxygen assisted for process parameter optimization using Artificial Neural Network. The work material that was selected for the experimentation was AISI 202 using taguchi's L16 OA. Results showed that MRR increases comparatively to normal conditions and the Ra is decreased comparatively.

Baljit Singh et al. (2014) [7] investigated the effects of process parameters on MRR in WEDM using Molybdenum wire as cutting tool. Taguchi's design of experiments with seven process parameters with mixed level design was used. The results indicated results indicated that pulse on time is the most significant factor influencing machining parameters having direct effect on MRR followed by pulse off time.

III. EXPERIMENTAL STUDY

A. *Material Selection:*

INCONEL (nickel-chromium-iron) 800 is a standard engineering material for applications which require resistance to heat and corrosion. The alloy exhibits good combination of high strength and workability.

The mechanical properties of the alloy combined with their resistance to higher temperature and corrosion make these alloys exceptionally useful for many applications involving long term exposure to elevated temperature and corrosive atmosphere.

INCONEL 800	
Elements	Specifications (%)
Nickel	32.75
Carbon	0.069
Silicon	0.45
Manganese	0.92
Sulphur	0.005
Chromium	20.69
Iron	43.09
Copper	0.14
Titanium	0.26
Aluminum	0.56

Table 1: Chemical Composition Of The Workpiece

B. *Wire Electric Discharge Machine:*

The experiments were carried out on a wire-cut EDM machine model DK-7725 WEDM machine tool which is manufactured by CONCORD United Products Ltd. Molybdenum wire of diameter 0.18mm was used and demineralized water added with JR3A gel is used as a dielectric fluid to carry out experiments. The parameters like Voltage, pulse-on, pulse-off, current, bed speed were chosen to carry out the experiments.

Fig. 2: Wire Electric Discharge Machine

	Parameters	Units	Levels		
			I	II	III
A	Voltage	volts	75	100	---
B	Pulse ON	µ sec	20	30	40
C	Pulse OFF	µ sec	9	12	15
D	Current	amps	2	4	6
E	Bed speed	µm/ sec	50	150	250

Table 2: Parameters and Their Levels

C. *Surface Roughness Tester:*

SURFEST SJ-210 portable surface measuring unit was used for measuring the surface roughness. The photograph of the test performed is as shown and it was performed on each of the 18 specimen obtained after WEDM process and the corresponding Ra reading were taken. The readings were taken over a mean at three different places so that any error could be taken into account.

Fig. 3: Surface Roughness Tester

Material removal rate (MRR) can be calculated using the equation;

$$MRR = \frac{(2 * Wg + D) * t * L}{T}$$

Where,
Wg = spark gap - "0.02mm"
D = Diameter of wire - "0.18mm"
T = Time taken to cut "min"
L = Distance travelled by tool – "60mm"
t = Thickness of work piece – "10mm"

D. *Artificial Neural Network:*

Artificial Neural network is defined as a data processing system consisting of a large number of simply highly interconnected processing elements called as artificial neurons in an architecture inspired by the human central nervous system.

The work flow for the neural network design process has seven primary steps.

1) Collect data
2) Create the network
3) Configure the network
4) Initialize the weights and biases
5) Train the network
6) Validate the network
7) Use the network

E. *Analysis of Variance (ANOVA):*

To study the significance of the process variables towards MRR, analysis of variance (ANOVA) was performed. After conducting the experiments results were evaluated by using, S/N ratio and ANOVA to find the optimal value and relative parameter influence on the output responses which were MRR and Ra.

The material removal rate is a higher performance characteristic, since the maximization of the quality characteristic of interest is sought and can be expressed as:

MRR = -10 log (Σ (1/y2)/n)

The surface roughness is the lower-the performance characteristic and the loss function for the same can be expressed as:

Ra = -10 log (Σy2/n)

A. Experimental Design:

Dr. Genichi Taguchi developed Taguchi method which was built on traditional concepts of Design of Experiment (DOE). Orthogonal array (OA) is a specially constructed table based on DOE technique to reduce the number of experiments so as to give the optimum set of the preferred parameters. The L18 (2*3) orthogonal array was chosen to conduct the experiment as shown in table.

L18 (2*3) Orthogonal array					
Sr. no.	Voltage	Pulse on	Pulse off	Current	Bed speed
	volts	µ sec	µ sec	amps	µm/sec
1	75	20	9	2	50
2	75	20	12	4	150
3	75	20	15	6	250
4	75	30	9	2	150
5	75	30	12	4	250
6	75	30	15	6	50
7	75	40	9	4	50
8	75	40	12	6	150
9	75	40	15	2	250
10	100	20	9	6	250
11	100	20	12	2	50
12	100	20	15	4	150
13	100	30	9	4	250
14	100	30	12	6	50
15	100	30	15	2	150
16	100	40	9	6	150
17	100	40	12	2	250
18	100	40	15	4	50

Table 3: Taguchi L_{18} (2*3) orthogonal array

IV. RESULTS AND DISCUSSION

A. Experimental Results:

The experiments were conducted in wet condition to study the effect of process parameters over the output response characteristics with the process parameters. The Experimental results for the surface roughness and material removal rate are given in below table.

Sr. No.	MRR	S/N ratio MRR	Ra	S/N ratio Ra
	mm^3/min	(db)	µm	(db)
1	8.3770	18.4618	1.112	-0.9221
2	10.3200	20.2736	0.877	1.1400
3	10.5200	20.4733	0.937	0.5652
4	9.3000	19.3697	1.161	-1.2966
5	12.2200	21.7414	1.416	-3.0212
6	9.9800	19.9826	1.03	-0.2567
7	9.3316	19.3986	0.945	0.4913
8	17.2146	24.7176	1.289	-2.2050
9	6.2372	15.9273	0.935	0.5837
10	18.8500	25.5062	1.312	-2.3586
11	8.0550	18.1213	0.892	0.99270
12	10.6798	20.5706	1.16	-1.2891
13	17.8250	17.8697	1.007	-0.0605
14	9.4132	19.4746	1.205	-1.6197
15	8.0814	18.1493	1.393	-2.8790
16	22.3738	26.9945	1.178	-1.4229
17	10.2860	20.2449	1.118	-0.9688
18	9.9472	19.9538	1.063	-0.5306

Table 4: Experimental Data

B. Studies related to Material Removal Rate:

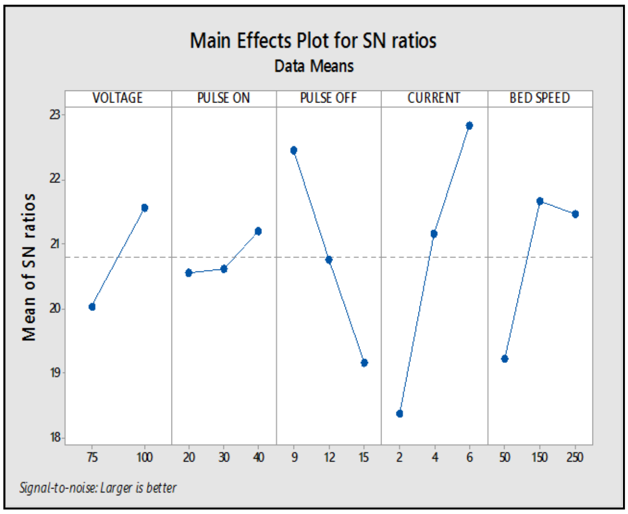

Fig. 4: Signal To Noise Ratio Graph For Material Removal Rate (MRR)

Figure 4 shows the Effect of process parameters on main material removal rate. On the basis of the analysis the S/N ratio for optimized process parameter for achieving better material removal rate while machining Inconel 800 are Voltage :100 volts, Pulse on time :40µs, Pulse off time :9 µs, Current :6 amp, Bed Speed :150µm/s.

Source	DF	Adj. SS	Adj. MS	F-Value	P-Value
Voltage	1	26.916	26.916	5.24	0.051
Pulse On	2	8.179	4.090	0.80	0.48
Pulse OFF	2	79.259	39.629	7.72	0.014
Current	2	120.535	60.267	11.74	0.004
Bed Speed	2	53.390	26.695	5.20	0.036
Error	8	41.062	5.133		
Total	17	329.341			

Table 5: Analysis of Variance for MRR

Level	Voltage	Pulse on	Pulse off	Current	Bed speed
1	20.03	20.57	21.27	18.3	19.2
2	21.56	19.43	20.76	19.9	21.6
3	---	21.21	19.18	22.8	20.2
Delta	0.73	1.77	2.09	4.48	2.45
Rank	5	4	3	1	2

Table 6: Response Table for S/N Ratios

The regression equation for material removal rate is MRR = -3.42 + 0.0531 voltage + 0.0714 pulse on - 0.571 pulse off + 1.58 current + 0.00908 bed speed

Table 6 represents the response table for material removal rate. The ranks and delta values for various parameter in the table show that pulse on has the greatest effect on material removal rate and is followed by pulse off, current, voltage and bed speed in that order.

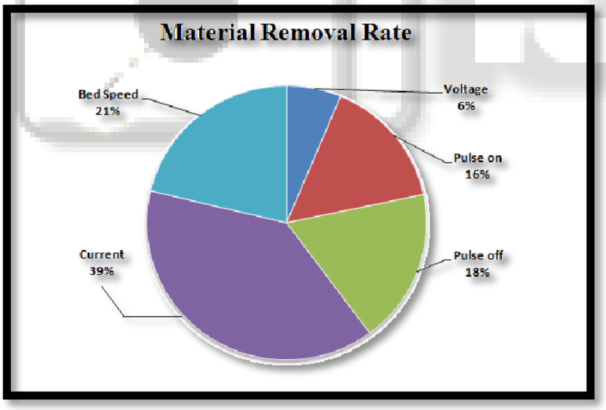

Fig. 5: Percentage contribution by process on Material Removal Rate

Thus it is observed from the above figure that Current contributes the most that is 39% followed by Bed Speed (21%), Pulse off (18%), Pulse on (16%) and Voltage (6%) in that order to achieve better Material Removal Rate in machining Inconel 800.

C. Studies Related To Surface Roughness:

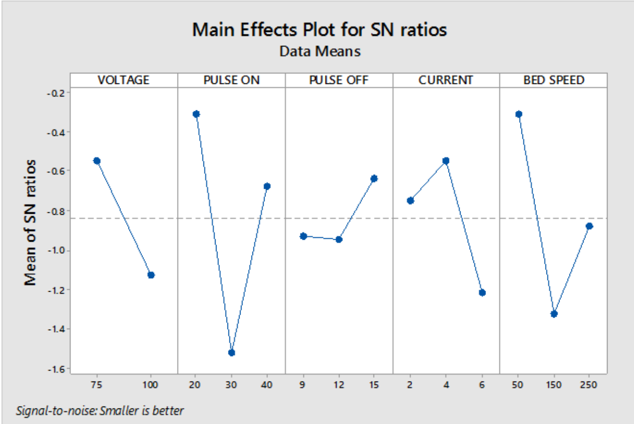

Fig. 6: Signal to noise ratio graph for surface roughness (Ra)

Figure 6 shows the Effect of process parameters on main surface roughness. For achieving better surface roughness while machining Inconel 800 are Voltage: 100 volts, Pulse on time: 30µs, Pulse off time; 12 µs, Current; 6 amp, Bed Speed; 150µm/s.

Source	DF	Adj. SS	Adj. MS	F-Value	P-Value
Voltage	1	0.021	0.021	0.59	0.463
Pulse On	2	0.076	0.038	1.04	0.396
Pulse OFF	2	0.006	0.003	0.09	0.912
Current	2	0.020	0.010	0.28	0.763
Bed Speed	2	0.055	0.027	0.76	0.500
Error	8	0.293	0.036		
Total	17	0.474			

Table 7: Analysis of Variance for Surface Roughness

Level	Voltage	Pulse on	Pulse off	Current	Bed speed
1	-0.546	-0.312	-0.928	-0.748	-0.307
2	-1.126	-1.522	-0.947	-0.545	-1.325
3		-0.675	-0.634	-1.216	-0.876
Delta	0.5795	1.2103	0.3126	0.6713	1.0179
Rank	4	1	5	3	2

Table 8: Response Table for S/N Ratios

The regression equation for surface roughness is
Ra = 0.759 + 0.00278 voltage + 0.00198 pulse on - 0.0055 pulse of + 0.0142 current + 0.000398 bed speed

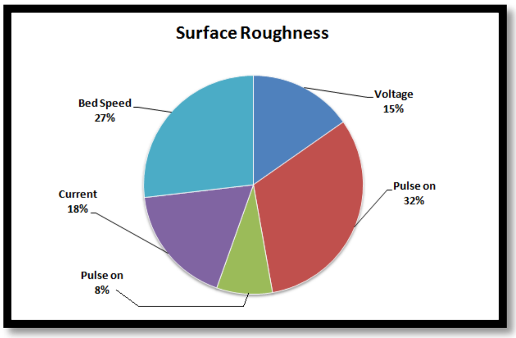

Fig. 7: Percentage contribution by process parameters on Surface Roughness

Thus it is observed from the above figure that pulse on contributes the most that is 32% followed by Bed Speed (27%), Current (18%), Voltage (15%) and Pulse on (8%) in that order to achieve better surface finish in machining Inconel 800.

D. *Artificial Neural Network Predictions:*

By using artificial neural network for feed forward back propagation network we can predict the response data as mentioned in the table . in feed forward back propagation network TRAINGDX as training function and LEARNGDM as learning function for 10 hidden layers and training the ann tool for around 50 times the predicted values of MRR and surface roughness were obtained.

Exp. No.	Material Removal Rate (mm^3/min)	Surface Roughness (µm)
1	7.9418	0.9743
2	9.3111	0.8984
3	10.5392	0.9396
4	8.0205	1.213
5	13.0726	1.0622
6	10.3325	1.1098
7	10.0606	1.0212
8	17.4924	1.1670
9	6.6266	1.0153
10	18.7453	1.4124
11	7.5952	1.1357
12	8.952	1.2098
13	8.4807	0.9961
14	9.1571	1.2942
15	9.2582	1.3974
16	21.8617	1.3497
17	8.9553	1.1928
18	8.408	1.1162

Table 9: Prediction of the Machining Performances by Artificial Neural Network

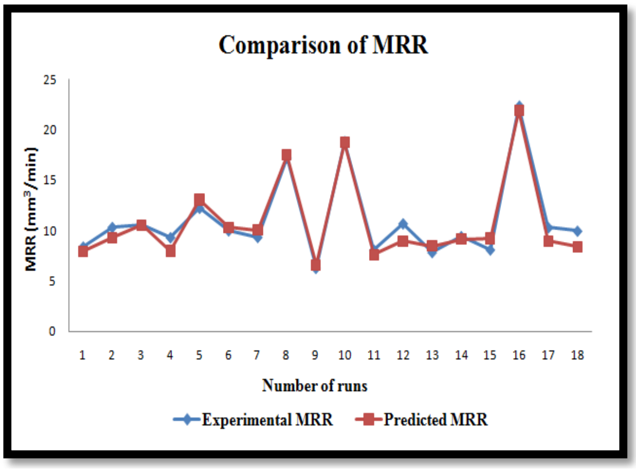

Fig. 8: Comparison of experimental and predicted values of MRR

Figure 8 shows the Comparison of experimental and ANN predicted Material Removal Rate and it is clearly observed from the figure that the measured material removal rate is correlating well with the predicted material removal rate. The maximum and minimum deviations are 19.30% and 0.18% respectively.

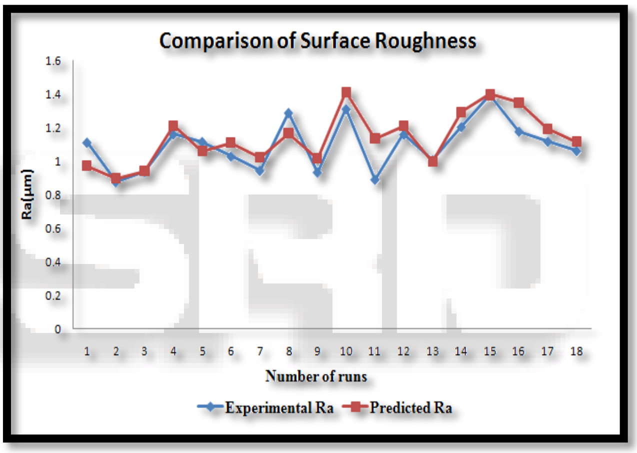

Fig. 9: Comparison of experimental and predicted values of Surface Roughness

Figure 9 shows the Comparison of experimental and ANN predicted Surface Roughness and it is clearly observed from the figure that the measured material removal rate is correlating well with the predicted material removal rate. The maximum and minimum deviations are 21.45% and 0.27% respectively.

V. CONCLUSION

Inconel 800 was the workpiece material and taguchi L18 orthogonal array was used to conduct the experiment. S/N ratio and ANOVA analysis were carried out. Artificial Neural Network was used for the prediction of the machining characteristics.

Based on the analysis the following conclusion were drawn

1) Using taguchi method MRR and Ra were optimized individually.
2) Current was the most influential parameter which significantly affects the material removal rate (MRR). The bed-speed, pulse-off, pulse on and voltage were less influential parameters.

3) According to proposed levels of factors used in this work to maximize MRR can be achieved by selecting combination of parameters, Voltage: 100 volts, Pulse on time: 40µs, Pulse off time: 9 µs, Current: 6 amps, Bed Speed: 150µm/s
4) Pulse on was the most influential parameter which significantly affect the surface roughness (Ra). The Bed speed, pulse off, voltage and pulse off were less influential parameters.
5) To obtain minimum surface roughness the optimum condition were Voltage: 100 volts, Pulse on time: 30µs, Pulse off time; 12 µs, Current; 6 amp, Bed Speed; 150µm/s.
6) The comparison of the measured MRR with predicted MRR and measured surface roughness with predicted surface roughness. It is clearly observed that the measured values are correlating well with the predicted values.