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Evaluation of Process parameter ranks in WIRE-Electric Discharge Machining of INCONEL X750 using Brass Electrode

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Abstract- *Much of modern day machining is carried out by WEDM .In this research work an attempt has been made to analysis the effects of input parameters such as Pulse On time, Pulse Off time and Peak current, on output parameter such as material removal rate and surface roughness. The experiment was performed with different combination values of input parameter. An attempt has been made to optimize the machining conditions for MRR and surface roughness based on (L9 Orthogonal Array) Taguchi methodology. Experiments were carried out under varying pulse-on-time, pulse-off-time, and peak current. An orthogonal array, the signal-to-noise (S/N) ratio, and the analysis of variance (ANOVA) were employed to the study the MRR and surface roughness in the WEDM of INCONEL X750.*

Keywords –WEDM ,MRR

I. INTRODUCTION

The world's first WEDM was produced by the SWISS FIRM 'AGIE' in 1969. The first WEDM machine worked simply without any complication and wire choices were limited to copper and brass only. Several researches were done on early WEDM to modify its cutting speed and overall capabilities. In recent decades, many attempts were done on Wire EDM technology in order to satisfy various manufacturing requirements, especially in the precision mold and die industry. Wire EDM efficiency and productivity have been improved through progress in different aspects of WEDM such as quality, accuracy, precision and operation [1]. A schematic of a WEDM process is shown in Figure 1.1, where the wire and the work piece are immersed in a dielectric fluid.

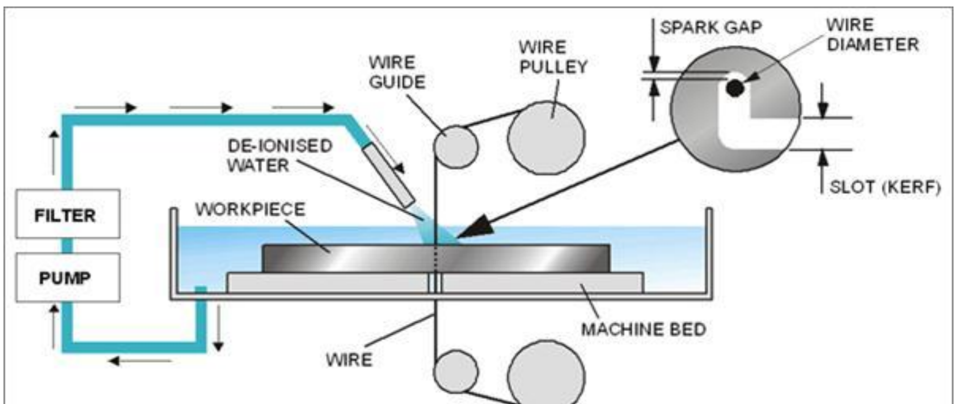

Figure 1.1 Schematic Diagram of WEDM System

Wire EDM uses electro-thermal mechanisms to cut electrically conductive materials. The material removal mechanism in WEDM is based on the melting and vaporization of material. The applied voltage creates a channel of plasma in the working gap between work piece and wire that are immersed in de-ionized water. There is a small gap between wire and work pieces that the discharge takes place with heavy flow of current in it. The area where discharge takes places is heated to extremely high temperature that leads to melting and removing of surface material. The removed particles are flushed away by the flowing dielectric fluid.

The high strength, good corrosion resistance, excellent high-temperature and cryogenic properties and weld ability attributed by Inconel alloys find wide range applications in aerospace, automobile, nuclear reactors, gas turbines and other major industrial applications. Inconel X750 is one of the most difficult-to-cut nickel based alloys. Formation of complex shapes along with reasonable speed and surface finish is very difficult by traditional machining. Wire Electric discharge machining (WEDM) is one of the most suitable non-conventional material removal processes to shape this alloy. This process is being used to machine very high harness, conductive materials such as nickel based super alloys Inconel X750. [2]

II. EXPERIMENT DETAIL

The experiments were carried out on wire-cut EDM machine of Electronica Machine Tools Ltd. housed in Advanced Manufacturing Laboratory of Mechanical Engineering Department, NIT, Kurukshetra.

Wire Edm Machine Tool

There are four basic elements of WEDM machine tool - the power supply system, the positioning system, the drive system and the dielectric system. All the four basic sub systems are distinct from conventional EDM.

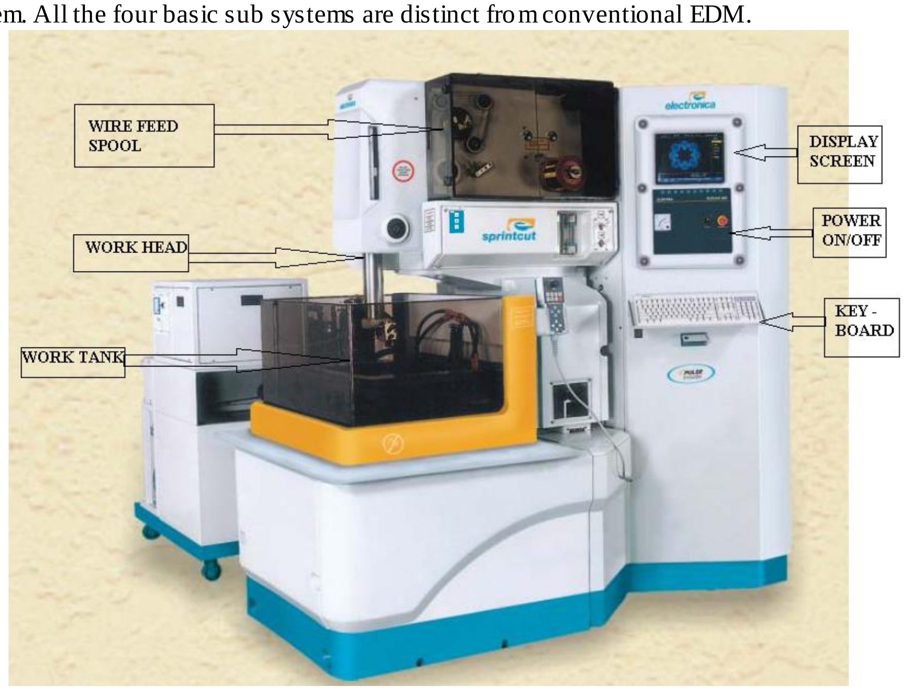

Fig. 1.2: Wire EDM Machine Tool

Technical Specifications Of Machine Tool

The experiments were carried out on a wire-cut EDM machine (ELEKTRA SPRINTCUT 734) of Electronica Machine Tools Ltd. installed at Advanced Manufacturing Laboratory of Mechanical Engineering Department, N.I.T., Kurukshetra, and Haryana, India. The WEDM machine tool (Figure 1.2) has the following specifications:

Design	Fixed column, moving table
Table size	440 x 650 mm
Max. workpiece height	200 mm
Max. workpiece weight	500 kg
Main table traverse (X, Y)	300, 400 mm
Auxiliary table traverse (u, v)	80, 80 mm

Wire electrode diameter	0.25 mm (Standard) 0.15, 0.20 mm (Optional)
Generator	ELPULS-40 A DLX
Controlled axes	X Y, U, V simultaneous / independent
Interpolation	Linear & Circular
Least input increment	0.0001mm
Least command input (X, Y, u, v)	0.0005mm
Input Power supply	3 phase, AC 415 V, 50 Hz
Connected load	10 KVA
Average power consumption	6 to 7 KVA

Process Parameters for Experiments: There are several parameters which affect the MRR of WEDM process. On the basis of literature review parameters were taken for experimentation as shown in Table 1.1.

Table 1.1 Process Parameters with their ranges

Symbol	Input Parameter	Range of Process Parameter
A	Pulse ON Time (T ON)	100 – 135 machine units (actual unit µs)
B	Pulse OFF Time (T OFF)	30 – 65 machine units (actual unit (µs)
C	Peak Current (IP)	70 – 230 Amp

Work piece Material:

The work piece material selected for the study is INCONEL X750 of 100mm×100mm× 25mm thickness.

Table 1.2 Composition of work material

Constituent	Ni	Cr	Fe	Nb	Co	Mn	Cu	Al	Ti	Si	C	S
%	70.0	14.0-17.0	5.0-9.0	0.7-1.2	1.0	1.0	0.5	0.4-1.0	2.25-2.75	0.5	0.08	0.01

Experimental Data for MRR

The experiments were conducted by selecting L-9 orthogonal array. Based on the experimental design the specimens were prepared and the value of the selected machining characteristic i.e. MRR is reported in Table 1.3.

Table 1.3 Experimental Data for MRR

Experiment No.	A	B	C	Cutting Speed (v_c) (mm/min)		$MRR = k.t.v_c$ (mm^3/min)		Average MRR (mm^3/min)	S/N Ratio
1	105	25	100	0.62	0.60	5.27	5.1	5.185	14.291
2	105	40	150	0.58	0.64	4.93	5.44	5.185	14.26
3	105	55	200	0.26	0.28	2.21	2.38	2.295	3.092
4	115	25	150	2.24	2.3	19.04	19.55	19.295	22.69
5	115	40	200	2.34	2.42	19.89	20.57	20.23	23.106
6	115	55	100	0.71	0.74	6.035	6.29	6.612	13.30
7	125	25	200	2.96	2.88	25.16	24.48	24.82	24.885
8	125	40	100	1.77	1.87	15.045	15.895	15.47	20.769
9	125	55	150	1.35	1.42	11.475	12.07	11.77	18.398
Average Mean of MRR ($\overline{T}$)								**12.26**	

Where

k = kerf width

t = thickness of the material

v_c = cutting speed

The kerf is expressed as the sum of the wire diameter and twice the wire work piece gap. The kerf (cutting width) used to find the metal removal rate determines the accuracy of the finished part. The gap between wire and work piece usually ranges from 0.025 to 0.075mm and is constantly maintained by the computer controlled positioning system.

III. EXPERIMENT RESULTS

The influence of three input parameters on MRR in WEDM process has been examined. The input parameters are pulse ON time (TON), pulse OFF time (TOFF) and peak current (IP). The experiment is performed on INCONEL X750 of thickness 25mm with brass wire of diameter 0.25mm as the tool electrode. The analysis is carried out with the help of Minitab 17 software. The results of experiments show that the pulse ON time (TON), pulse OFF time (TOFF) and peak current (IP) have significant influence on the material removal rate (MRR).

A. EFFECT OF PROCESS PARAMETERS ON MRR

The Figure 1.1 shows that MRR increases as the pulse ON time and peak current decrease from level 1 to level 2 and then from level 2 to level 3. It is also revealed from the figure that MRR decreases with increasing values of pulse OFF time.

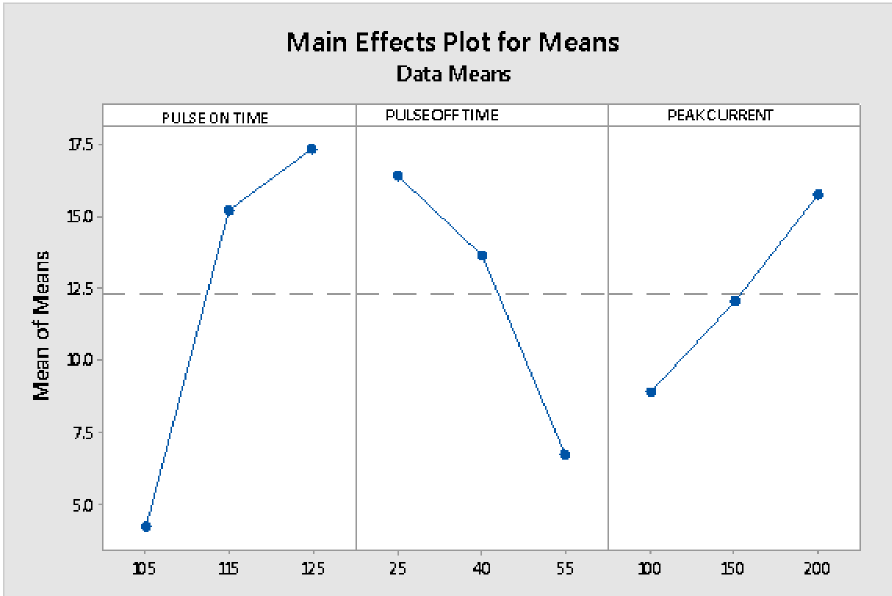

Figure 1.2: Effect of Process Parameters on MRR (Raw Data)

The Figure 4.2 also shows the same trends for S/N Data for all the three selected parameters. Tables 4.1 and 4.2 present the response values for mean and S/N ratio for MRR respectively.

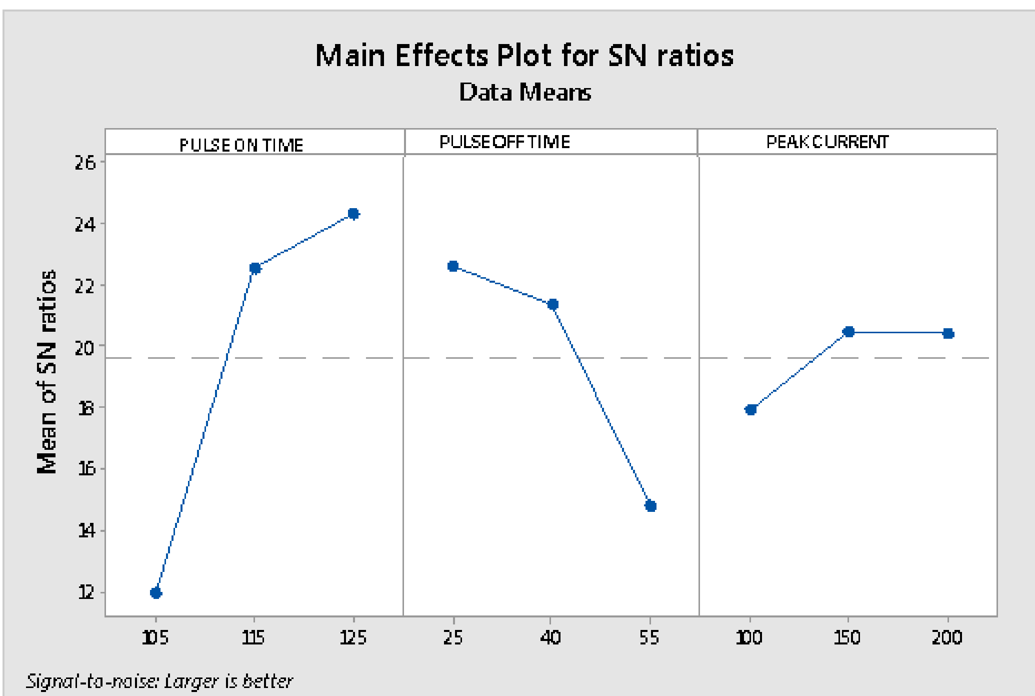

Figure 4.2: Effect of Process Parameters on MRR (S/N Data)

Table 1.4 Response Table for Means

Level	Pulse ON Time	Pulse OFF Time	Peak Current
1	4.222	16.433	8.939
2	15.229	13.628	12.083
3	17.353	6.742	15.782
Delta	13.132	9.691	6.843
Rank	1	2	3

Table 1.5 Response Table for S/N Ratios

Level	Pulse ON Time	Pulse OFF Time	Peak Current
1	11.94	22.63	17.96
2	22.54	21.40	20.47
3	24.37	14.81	20.41
Delta	12.43	7.82	2.51
Rank	1	2	3

Analysis Of Variance (ANOVA):

ANOVA is a statistical tool used to identify the significant factors affecting the response. The percent contribution of the factors on the response is also revealed in the analysis of variance.

Depending on the significance of the factors in the ANOVA, these are classified as under:

- Class I factors are those which are significant in both the ANOVAs and these affect both the mean value and the variance around the mean.
- Class II factors are those which are significant in ANOVA for S/N Data only and these affect only the variance around the mean value.
- Class III factors are those which are significant in ANOVA for raw data only and affect only the mean value.
- Class IV factors are those which are not significant in either of the ANOVAs and hence affect nothing.

Proper control should be exercised on the appropriate setting of the class I, II and III factors. However, the class IV factors may be set at some economical levels.

The ANOVAs for raw data and S/N data are reported in Tables 1.6 and 1.7 respectively. It is clear from Tables 1.6 and 1.7 that all the three factors are significant in both the ANOVAs and hence fall in the category of Class I factors affecting both the mean and variance around the mean of MRR.

Table 1.6: Analysis of variance for MRR (Raw Data)

Source	Degree of freedom (DF)	Sum of Squares (SS)	Mean Square	F Statistic	Probability (p)	Percentage Contribution
Pulse ON Time	2	298.115	149.057	1450.76	0.001	57.56
Pulse OFF Time	2	149.201	74.600	726.08	0.001	28.81
Peak Current	2	70.387	35.193	342.53	0.003	13.60
Error	2	0.205	0.103			
Total	8	**517.908**				
$F_{0.05\ (2,2)} = 19.0$						

*Significant at 95% confidence level.

Table 1.7: Analysis of variance for MRR (S/N Data)

Source	Degree of freedom (DF)	Sum of Squares (SS)	Mean Square	F Statistic	Probability (p)	Percentage Contribution
Pulse ON Time	2	203.399	101.700	14.02	0.067	55.00
Pulse OFF Time	2	143.676	71.838	9.90	0.092	38.85
Peak Current	2	8.213	4.106	0.57	0.639	2.22
Error	8	14.511	7.255			
Total	8	**369.798**				
$F_{0.05\ (2,8)} = 4.46$						

*Significant at 95% confidence level.

Selection of Optimal Levels

Table 1.4 and 1.5 clearly reveal that the third level of pulse on time (A3), first level of pulse of time (B1) and third level of peak current (C3) are the highest points in both the figures and hence represent the optimal setting of the parameters.

Estimating Optimal Performance

The optimal combination of machining parameters has already been determined. However, the final step is to predict and verify the improvement of the observed values through the use of the optimal combination level of machining parameters. The estimated mean for MRR can be calculated with the help of Equation reproduced below.

$$\eta = \overline{T} + \left(\overline{A_3} - \overline{T}\right) + \left(\overline{B_1} - \overline{T}\right) + \left(\overline{C_3} - \overline{T}\right)$$

Substituting values of $\overline{T}$, $\overline{A_3}$, $\overline{B_1}$ and $\overline{C_3}$ from tables 1.3 and 1.4

$$\eta = \mathbf{25.048} \text{ mm}^3/\text{min}$$

For calculation of CI_{CE}, the following equation has been used.

$$CI_{CE} = \sqrt{F_{\alpha(1,v)}.V_e\left[\frac{1}{R} + \frac{1}{n_{eff.}}\right]}$$

Where

$F_{\alpha(1,v)}$ = F-ratio at level of significance α (or confidence level of 1-α) against DOF of mean (always equal to one) and error DOF of v (2) = $F_{0.05\,(1,\,2)}$ = 18.5

V_e = Error variance = 0.103 (Table 1.6)

R = Number of confirmation experiments = 3

$$n_{eff.} = \textit{Effective no.of replications} = \frac{\textit{Total no.of trials or Experiments}}{1 + \textit{Total DOF associated in the estimation of mean value}}$$

$$= \frac{18}{1+8} = \frac{18}{9} = 2$$

CICE (MMR) = ±1.260

The confidence interval for MRR is 23.78 < μ_{MRR} (mm^3/min)< 26.30

IV. Conclusion

The optimal setting of process parameters is as under:

- Pulse ON Time: 121 machine units, Pulse OFF Time: 30 machine units, Peak Current: 210 amperes.
- All the process parameters significantly affect the mean value and variance around mean value of MRR at 95% confidence level.
- The percent contribution of process parameters in affecting MRR is as under:

Pulse ON Time	= 57.56%
Pulse OFF Time	= 28.81%
Peak current	= 13.60%

- The 95% Confidence Interval of MRR is 23.78 < μ_{MRR} (mm^3/min) < 26.308

Three confirmation tests were conducted at the optimal setting of process parameters and the average value of MRR was recorded. The average value of MRR achieved was 24.82 mm^3/min which lies between the predicted CI_{CE}.

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