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

Er. Navneet Singh Virk, Er. Mandeep Chahal

Research Scholar ,Haryana college of technology and management ,Kaithal ,Haryana, India
A.P in Haryana college of technology and management, Kaithal ,Haryana, India

Abstract: *Superalloys such as Inconel X750 are widely used in turbo machinery industry due to their outstanding mechanical properties. Inconel alloys are very difficult to machine using conventional mechanical processes like broaching, milling or grinding. Wire electrical discharge machining (WEDM) is an alternative competitive process to manufacture complex Inconel part geometries. However, surface Roughness (SR) of WEDM Inconel components is poorly understood. 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 Surface Roughness. The experiment was performed with different combination values of input parameter. An attempt has been made to optimize the machining conditions for SR 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 SR in the WEDM of INCONEL X750.*

Keywords: Surface Roughness; wire-EDM; Inconel alloy

I. INTRODUCTION

Wire Electric Discharge Machining (WEDM) is a non-traditional process of material removal from electrically conductive materials to produce parts with intricate shapes and profiles. This process is done by using a series of spark erosion. The sparks produced between the work piece and a wire electrode (usually less than 0.30 mm diameter) separated by a dielectric fluid erode the work piece to produce complex two and three dimensional shapes according to a numerically controlled pre-programmed path. The sparks produce heat and melt work piece surface to form debris which is then flushed away by dielectric pressure. During the cutting process there is no direct contact between the work piece and the wire electrode. The WEDM has become an important non-traditional machining process because it can machine the difficult-to-machine materials like titanium alloys and zirconium which cannot be machined by conventional machining processes. WEDM equipment first appeared in the early 1960s, and performed simple machining utilizing the phenomenon of electrical spark. The first five-head WEDM arrived in the United States in 1980. In today's WEDM it is possible to program wire to follow a complex path in two axes. Hence, it is possible to use this machine tool for making dies for stamping, fine blanking and extrusion as well as 2-D through holes. It is possible to tilt the wire in position other than perpendicular to X and Y axes. It is possible to perform 3-D cutting using WEDM in which two additional axes have been introduced. The drive motors which tilt the wire towards the front or back and left or right are controlled by the programmed commands in CNC WEDM.

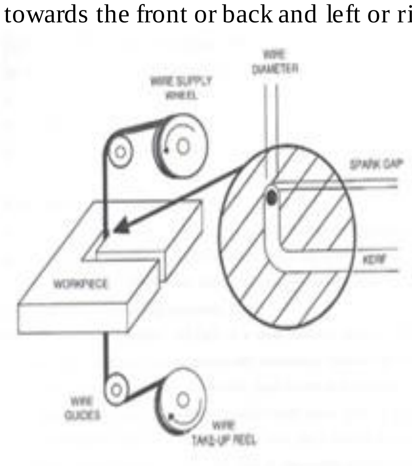

Fig. 1.1: Schematic representation of WEDM cutting process

II. EXPERIMENT DETAIL

Mechanism and Evaluation of Surface Roughness

Surface Roughness is the measure of the texture of the surface. It is measured in µm. If the value is high then the surface is rough and if low then the surface is smooth. It is denoted by Ra. The values are measured using Portable style type profilometer, Mitutoyo. The arithmetic mean of three readings is taken as the final value.

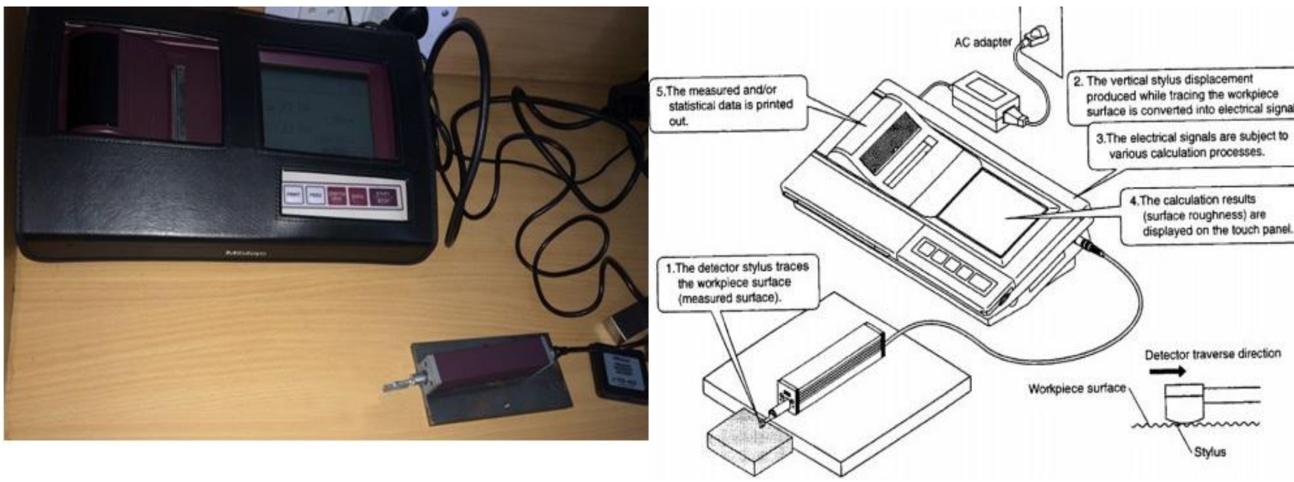

Fig. 1.2 : Mitutoyo Surface Roughness tester

Work piece Material

The work piece material selected for the study is INCONEL X750.

Table 1.1 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

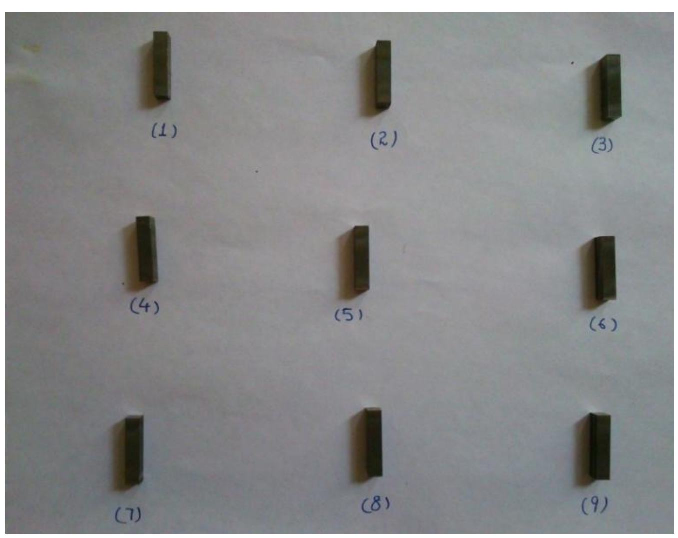

Figure 1.3 : The Specimens Shown Lying Horizontally

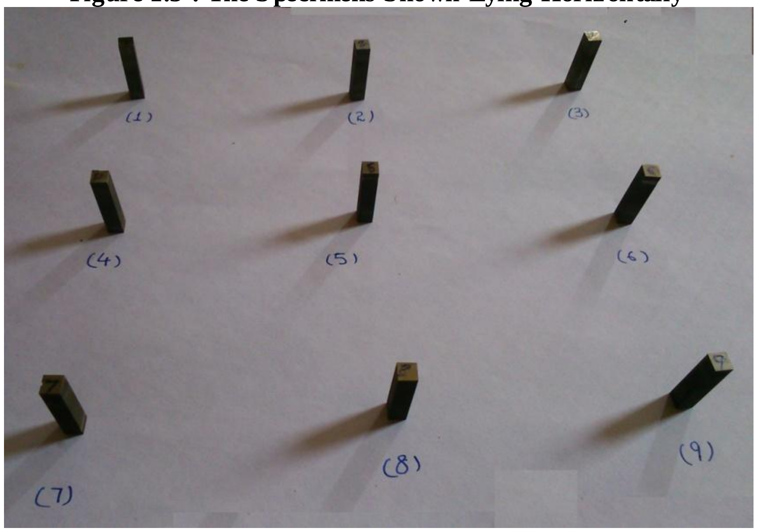

Figure 1.4: The Specimens Shown Lying Vertically.

III. EXPERIMENT RESULTS

Experimental Data for SR

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. SR is reported in Table 1.2

Table 1.2 Experimental Data for SR

Experiment No.	A	B	C	SURFACE ROUGHNESS Ra(μm)			Average SR	S/N Ratio
1	105	25	100	1.69	1.78	2.04	1.83	0.852
2	105	40	150	1.68	1.70	1.93	1.77	0.701
3	105	55	200	2.72	2.60	2.63	2.65	2.470
4	115	25	150	2.56	2.72	2.60	2.62	2.430
5	115	40	200	2.77	3.14	2.72	2.876	2.810
6	115	55	100	2.73	2.77	3.10	2.866	2.800
7	125	25	200	3.19	2.89	2.95	3.01	3.020
8	125	40	100	2.94	2.34	2.78	2.68	2.500
9	125	55	150	3.25	3.12	3.38	3.25	3.353
						Average Mean of SR ($\bar{T}$)	2.619	

Effects of Process Parameters on SR

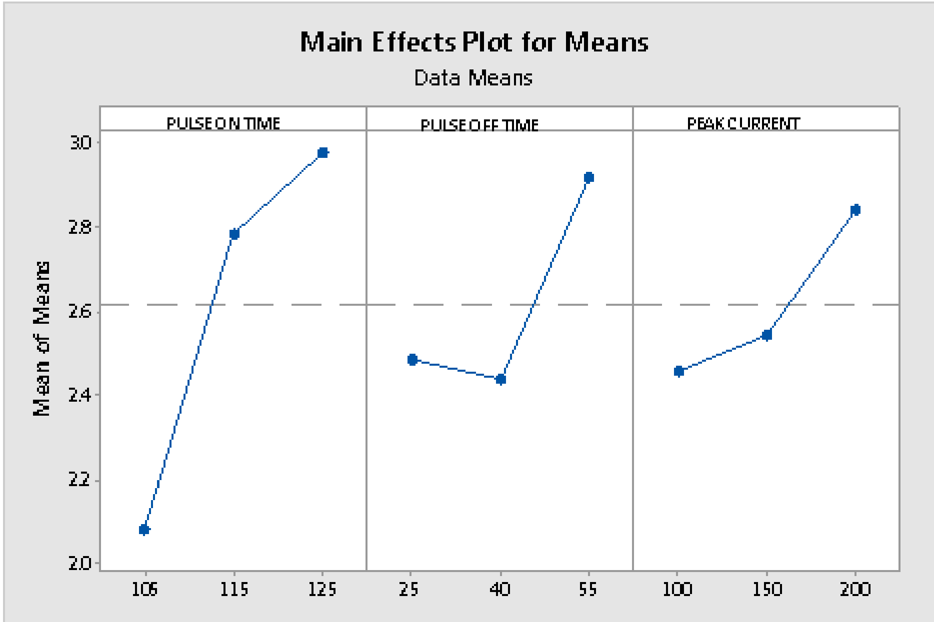

Figure 1.5: Effect of Process Parameters on SR (Raw Data)

The Figure 1.5 shows that SR increases as the pulse ON time and peak current decrease from level 1 to level 2 and then increase from level 2 to level 3. It is also revealed from the figure that SR decreases with increasing values of pulse OFF time decrease from level 1 to 2.

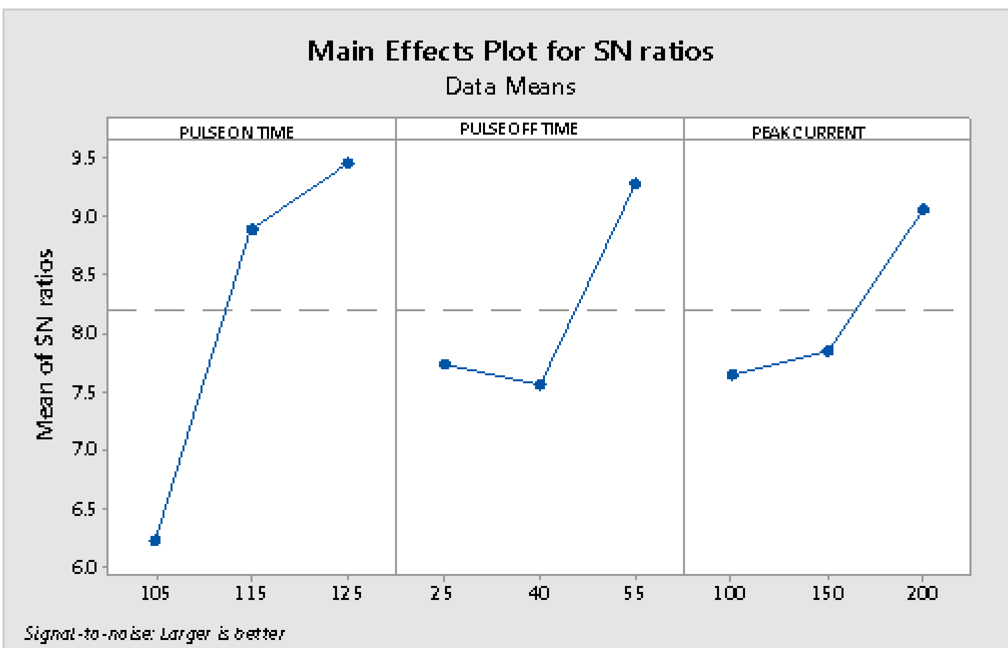

Figure 1.6: Effect of Process Parameters on SR (S/N Data)

The Figure 1.6 also shows the same trends for S/N Data for all the three selected parameters. Tables 1.3 and 1.4 present the response values for mean and S/N ratio for SR respectively.

Table 1.3 Response Table for Means

Level	Pulse ON Time	Pulse OFF Time	Peak Current
1	2.083	2.487	2.459
2	2.787	2.442	2.547
3	2.980	2.922	2.845
Delta	0.897	0.480	0.387
Rank	1	2	3

Table 1.4 Response Table for S/N Ratios

Level	Pulse ON Time	Pulse OFF Time	Peak Current
1	6.224	7.729	7.652
2	8.896	7.566	7.854
3	9.457	9.283	9.071
Delta	3.233	1.717	1.418
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 1.5 and 1.6 respectively. It is clear from Tables 1.5 and 1.6 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 SR.

Table 1.5 : Analysis of variance for SR (Raw Data)

Source	Degree of freedom	Sum of Squares	Mean Square	F Statistic	Probability (p)	Percentage Contribution
Pulse ON Time	2	1.33675	0.66837	63.81	0.015	65.98
Pulse OFF Time	2	0.42191	0.21096	20.14	0.047	20.82
Peak Current	2	0.24646	0.12323	11.76	0.078	12.16
Error	2	0.02095	0.01048			
Total	8	**2.02606**				
$F_{0.05\ (2,2)}$ =19.0						

*Significant at 95% confidence level.

Table 1.6: Analysis of variance for SR (S/N Data)

Source	Degree of freedom (DF)	Sum of Squares (SS)	Mean Square	F Statistic	Probability (p)	Percentage Contribution
Pulse ON Time	2	4.4836	2.24182	34.64	0.028	65.26
Pulse OFF Time	2	1.3660	0.68301	10.55	0.087	19.88
Peak Current	2	0.8913	0.44567	6.89	0.127	12.97
Error	2	0.1294	0.06472			
Total	8	**6.8704**				
$F_{0.05\ (2,2)}$ =19.0						

*Significant at 95% confidence level.

Selection of Optimal Levels

Tables 1.5 and 1.6 clearly reveal that the third level of pulse on time (A3), third level of pulse of time (B3) 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 SR can be calculated with the help of Eq. reproduced below.

$$\eta = \quad \overline{T} + \left(\overline{A_3} - \overline{T}\right) + \left(\overline{B_3} - \overline{T}\right) + \left(\overline{C_3} - \overline{T}\right)$$

Substituting values of $\overline{T}$, $\overline{A_3}$, $\overline{B_3}$ and $\overline{C_3}$ from tables 4.3 and 5.1

$$\eta = \mathbf{3.509}$$

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 = 0.0.01048 (Table 4.8)

R = Number of confirmation experiments = 3

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

$$= \frac{27}{1+8} = \frac{27}{9} = 3$$

CI_{CE} (MMR) = ±0.360

The confidence interval for SR is 3.149 < μ_{SR} < 3.869

Confirmation Experiments for SR

This is the final step to verify the conclusions drawn the analysis. Three confirmation tests were conducted at the optimal setting of process parameters and the average value of SR was recorded. The average value of SR achieved was 3.25 which lies between the predicted CI_{CE}.

IV. CONCLUSION

The optimal setting of process parameters is as under:

- All the process parameters significantly affect the mean value and variance around mean value of SR at 95% confidence level.
- The percent contribution of process parameters in affecting SR is as under:
  Pulse ON Time = 65.98%

  Pulse OFF Time = 20.82%

  Peak current = 12.16%

- The 95% Confidence Interval of SR is 3.149 < μ_{SR} < 3.869

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