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Optimization of process parameters for surface roughness of Inconel 625 in Wire EDM by using Taguchi method

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ABSTRACT: *WEDM is the widely adopted non convectional machining process which is mainly used for machining very hard and tough material like super alloys. Application of WEDM is mostly found in aerospace, die making etc. industries due to high accuracy and precision work. Inconel is mainly a super alloy which is mixture of nickel and chromium, which is very high melting point and strength. Due to these properties Inconel is mainly machined by WEDM. In this paper attempt was made to optimize the different process parameters like pulse on time, pulse off time and peak current for the surface roughness. Taguchi L9 orthogonal array along with ANOVA is used for optimize the different parameters so that minimum surface roughness obtained. From the experiment results found that pulse on time is the most significant factor (contributing 92.35 %) and peak current is an insignificant factor. At the end, confirmation test have conducted to verify the results.*

Keyword: *WEDM, Inconel 625, Taguchi method, ANOVA, Optimization*

I. INTRODUCTION

Inconel 625 is super alloy of nickel and chromium which is mainly used in gas turbine blades, high temperature fasteners, heat exchanger tubing, seals, combustors, steam generators as well as turbocharger rotors and seals due to its superiority mechanical and thermal properties. These super alloys are facing very difficulties for machining with convectional machining due to limitation of temperature developed in machining. To machining these super alloys non convectional machining such as electro chemical machining, electric discharge machining, ultrasonic machining etc. are used because these are capable to machining with high accuracy and excellent finishing. Wire EDM is the advancement of EDM in which wire is used as electrode [1]. WEDM is an electro–thermal machining in which a series of spark is produced between the electrode (wire) and work piece which is submerged in the dielectric fluid. During the pulse-on time or discharge period, work material is rapidly melted and vaporized to form a cut on the workpiecewhich is flashed by the dielectric fluid. Dielectric is used to cooling the cutting zone and to remove the debris from the cutting zone to ready for the next pulse discharge [2]. Electrode wire is made of brass, copper or zinc coated which have good electrical conductivity with diameter of 0.25mm. In wire EDM there is no direct contact between the work piece and electrode so that there is no mechanical stress development. The schematic diagram of WEDM is shown in figure 1.

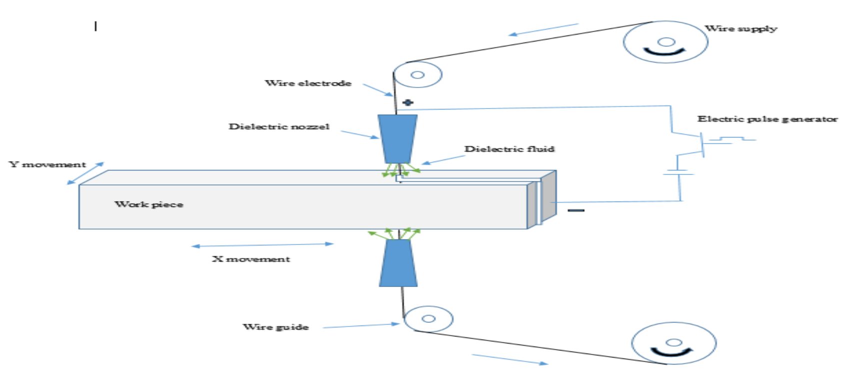

Fig. 1: Representation of WEDM process

Several researchers have attempted to optimize the different responses such as MRR, SR and Dimensional deviation. Ikram et al. used Taguchi design of experiment to optimize the surface roughness, kerf and MRR for tool steel D2. They take wire feed velocity, pulse on-time, pulse off-time, dielectric pressure, open voltage, servo voltage and wire tension as input parameter. They found that for surface roughness pulse on time and open voltage as most significant factor. Pulse on-time, wire tension and open voltage are more the significant factors for kerf [3].Han et al. determine the influence of the machining parameters (including discharge current, pulse duration, pulse interval time, sustained pulse time, polarity effect, dielectric and material) on surface roughness. They found that the surface roughness increased by decreasing both pulse duration and discharge current. They suggest that a short pulse duration combined along with a high peak value gives better surface roughness [4].Ugrasen et al. used Taguchi method along with the artificial neural network to optimize the accuracy, surface roughness and MRR. They found that for the above three responses, current is the most significant factor. They used Back propagation feed forward neural network along with Levenberg–Marquardt algorithm to build and train the network [5].Sudhakara and Prasanthi used Taguchi L_{27} to optimize the surface roughness of P/M Cold WorkedTool Steel (Vanadis-4E). They found the range optimal setting of different parameters as pulse on time = 108-128 µsec, pulse off time = 47-63 µsec, peak current = 11-13 Amperes, spark gap set voltage = 18-68 Volts, wire tension = 2-8 Grams and water pressure = 8-14 Kg/cm^2 [6].K. Kumar et al. did modelling and optimization of WEDM for surface roughness and MRR in Al-SIC. They used RSM along with Taguchi's L27 OA. They found that factors like speed, feed, Time on and Time off most significant factor for MRR and surface roughness [7].Antar et al. tried to found the fatigue behavior of Udimet 720 nickel based super alloy by using the minimum damage generator technology in wire EDM. They did comparative study between the wire EDM job and flank milled samples by using S – N curve. They conclude that at the room temperature no significant difference in fatigue life of WEDM and flank milled samples of Udimet 720 alloy [8].Kanlayasiri and Jattakul found the optimal cutting condition of dimensional accuracy and surface roughness for K460 tool steel by wire EDM machine. They used Box– Behnken design and multiple response optimization technique. They also considered cutting speed, peak current, and offset distance as input variable and dimensional accuracy and surface roughness as output variables. They found that both peak currentandoffset distance is significant factor for dimension while peak current affects the surface roughness. The optimal condition for cutting was at 2 A peak current and 772 µm offsetdistance [9]. Sharma et al. found the MRR, SR, recast layer, topography, micro hardness of Inconel 706 for turbine disk application. The proposed experimental plan was based on OFAT approach. The micro hardness and RLT have been examined using the low and high settings of servo voltage and pulse on time. EDAX analysis has been carried out to study the metallurgical changes in the machined surface. They found that pulse on time, pulse off time and servo voltage are most important factors, whereas servo feed is not important. They also found that wire feed of 6 m/min and flushing pressure of 1.96 bar gives higher MRR and SR [10]. Raoand Venkaiah hadattempt to found the effect of different parameters on MRR and SR of Nimonic-263 alloy. RSM and ANOVA are used for experiment and estimation. They developed mathematical model for MRR and SR by using RSM. They also optimize the performance of process by using Particle Swarm Optimization (PSO). They also compare the results obtained from the RSM and PSO. They found that PSO is better than RSM. They take Pon, Poff, SV and IP as input parameters. They found that for MRR, pulse on time, peak current and interactions of these are more important factors. For SR, servo voltage, pulse on time, pulse off time and interaction of Pon andPff play an important factor [11]. Ugrasen et al. in 2014 used Multiple Regression Analysis (MRA), Group Method Data Handling Technique (GMDH) and Artificial Neural Network (ANN) to forecasting effect of process variable on the process response in wire EDM [12]. Md.karimBaig et al. optimize the process parameters of wire EDM for *HastelloyC276* by using the Taguchi and Grey Relational Analysis. MRR and Kerf width are taken as response variable. They found that for MRR and Kerf Width, discharge current (IP) is more important factor. 2 A discharge current is optimum condition for higher MRR and lower Kerf Width. The next parameters that are found to be effective are Servo voltage (SV), Pulse on time (TON), Pulse off time (TOFF) in that order. Grey Relational Analysis (GRA), for finding the optimal parameters affecting both MRR and Kerf are found to be TON = 110 µs, TOFF=60 µs, IP=12A, SV=10 V, for both higher MRR value of 11.78 mm^3/min and lower Kerf a value of 0.375 mm [13].E. Atzeni et al.used zinc coated brass wire for cutting of *Inconel 718* to optimize the process parameters and obtaining modification in the surface and sub surface. SEM and EDS were used to evaluate possible variation in the surface chemical composition [14].

II. EXPERIMENTAL DETAIL

2.1 Theme of experiment

In this paper an attempt have made to optimize the cutting contidions to minimize the surface roughness based on the Taguchi method. WEDM involves many process parameters like pulse on time, pulse off time, peak current, servo voltage, wire feed rate,wire tension, dielectric pressure etc. In this paper only consider first three parameters as mentioned above.

- Pulse on time - The time for which current is applied is called pulse on time, denoted as Ton in micro second (µs).
- Pulse off time - The duration time between the two simultaneous sparks is known as the pulse off time denoted as Toff in (µs). No voltage is applied during this time.
- Peak Current - It is the maximum value of the current passing through the electrodes for the given pulse and represented by IP.

2.2 Experimental setup

Experiment were performed on a wire-cut EDM machine with specification like design fixed column, moving table type with size of the work piece 440 x 650 mm, type of interpolation linear & circular, power supply 3 phase, AC 415 V, 50 Hz. Inconel 625 is taken as work material of size 80*80*14 mm plate. Wire diameter 0.25mm made of copper is used for experiment. Wire is tensioned between upper and lower guide to obtained higher accuracy. Deionized water is taken as the dielectric fluid with 12 to 16 TDS (total dissolved solid). Surface roughness tester is used to measure surface roughness as shown in figure 2.

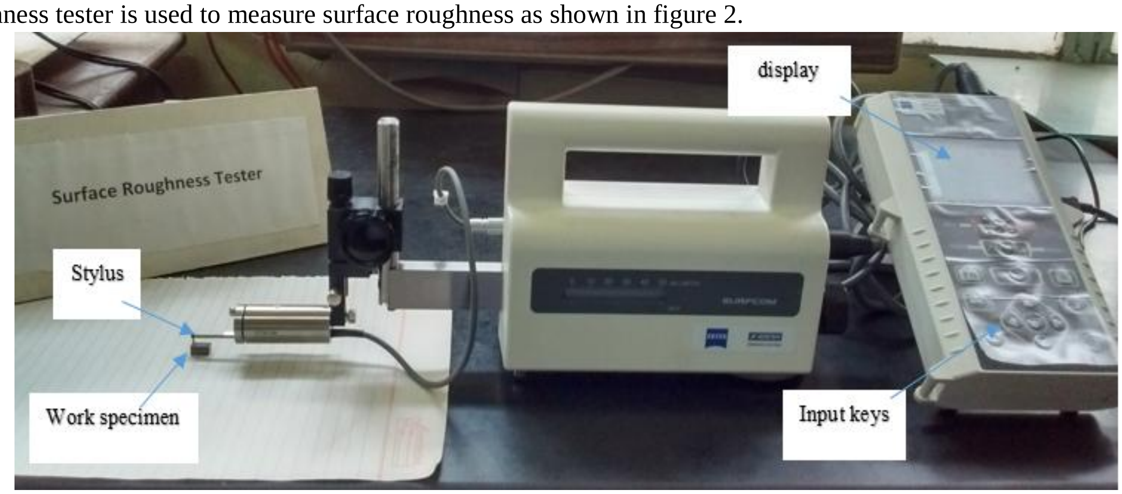

Fig. 2: Roughness Tester [Courtesy: NIT KKR]

2.3 Experimental design

Taguchi method with L9 orthogonal array and ANOVA is used for this study. Taguchi method is applied were reduce the number of trial so that cost and time minimized. In Taguchi method only perform few experiments instead of all possible setting of experiments which required in full factorial design. Each parameters at three levels are selected. The levels are taken from the previous study of literature review. The levels of selected parameters are shown in table 1.

TABLE I. Process parameters and their levels

Factors	Parameters	Levels		
		L1	L2	L3
A	Pulse on Time (µs)	105	115	125
B	Pulse off Time (µs)	35	45	55
C	Peak current (A)	120	140	160

III. Result and Discussion

The WEDM experiments were conducted to study the effect of process parameters over surface roughness. The values surface roughness obtained from the roughness tester is shown in Table 2.

TABLE II. Reading obtained from surface roughness tester

Exp. No.	Factor A Ton	Factor B Toff	Factor C IP	Surface roughness (μm)	S/N ratio
1	105	35	120	3.263	-10.2723
2	105	45	140	2.751	-8.7898
3	105	55	160	1.630	-4.2438
4	115	35	140	6.223	-15.8800
5	115	45	160	5.980	-15.5340
6	115	55	120	5.306	-14.4953
7	125	35	160	7.335	-17.3080
8	125	45	120	7.047	-16.9601
9	125	55	140	6.696	-16.5163

It is observed that from the figure 3 (obtained from MINITAB software) when pulse on time increase surface roughness also increases. This is due to increase in the discharge energy with increase in pulse on time so more strong explosion and the deeper crater created on the machined surface resulting rougher surface. It is found that with increase in pulse off time surface roughness decreases and peak current have no longer effect on the surface roughness.

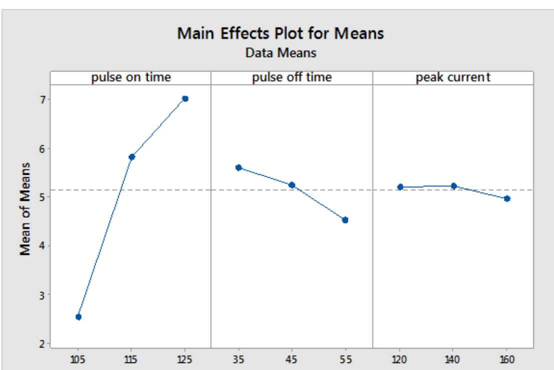

Fig. 3: Main effect plot for Mean (Surface roughness)

TABLE III. Pooled ANOVA

Source	DOF	SS	V	F	S'	P%
P_{on} A	2	32.2869	16.1405	223.55	31.709	92.35
P_{off} B	2	1.7625	0.8813	12.206	1.1847	3.406
Error	4	0.402	0.2011			4.244
Total	8					

To determine the significant parameters affecting the surface roughness Analysis of variance (ANOVA) was performed. In the present investigation, 90% confidence level or 10% level of significance is taken. From the ANOVA it is found that peak current is insignificant factor so that it is pooled shown in table 3.It is found that pulse on time is most significant factor (contributing 92.35%) followed by pulse off time (3.406 %). Surface roughness is the "lower the better characteristics" so pulse on time at first level (A_1) and pulse off time at third level (B_3) gives the optimum condition i.e. minimum surface roughness. Fig. 4 shows percentage contribution of different process variable on the surface roughness. The predicated optimal value at significant factors is calculated as follows:

$\mu = \overline{A}_1 + \overline{B}_3 - \overline{T} \quad = 2.548+4.544 -(5.136) \quad = 1.956$

$CI_{POP} = \pm [F\alpha\ (n,f_e) * V_e / n_{eff}]^{1/2} \quad = \pm [4.32*(0.2011/1.8)] = \pm 0.4826$

Where, $F\alpha\ (n,f_e) = 4.32$, $V_e = 0.2011$, $n_{eff} = 9/(1+4) = 2$

Optimum value = 1.956 ±0.4826

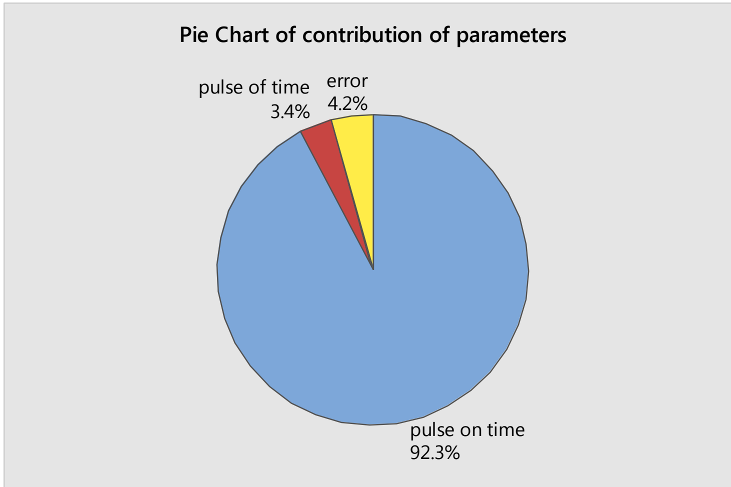

Fig. 4: Percentage contribution of process variables

IV. CONFIRMATION TEST

After successful applying the Taguchi method along with ANOVA it is found that the optimal setting of the process parameters as first level of pulse on and third level of pulse off time. To validate the result obtained perform the confirmation experiment and results obtained from confirmation test is shown in table 4.

TABLE IV. Confirmation Results

Machining characteristics	**Optimal setting of parameters**	**Predicted value by Taguchi method**	**Results obtained from confirmation experiment A_1 B_3**
Surface roughness	A_1 B_3	1.956 ±0.4826	1.85µm

V. CONCLUSION

In this experiment optimization of process parameters for surface roughness in Inconel 625 was carried out. The machining parameters are pulse on time, pulse off time and peak current. After successful application of Taguchi method and ANOVA it is conclude the following:

1. Surface roughness increases with increase on pulse on time and decrease with increase in pulse off time.
2. For surface roughness most significant factor is pulse on time (contributing 92.35 %) followed by pulse off time.
3. Peak current is insignificant factor for surface roughness.
4. Optimal setting for surface roughness is A_1 B_3 C_3which gives minimum surface roughness value.

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