Research Article

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

T.Vijaya Babu[#]* and J.S Soni[‡]

[#]Department of Mechanical Engineering, Vardhaman College of Engineering, Shamshabad, Hyderabad, India
[‡]Bharat Institute of Engineering and Technology, Ibrahimpatnam, Hyderabad, India

Abstract

WEDM 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 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 and peak current is an insignificant factor.

Keywords: WEDM, Inconel 625, Taguchi method, ANOVA, Optimization

1. 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.

Fig 1: (a) Electronica Ezee Cut NXG WEDM machine
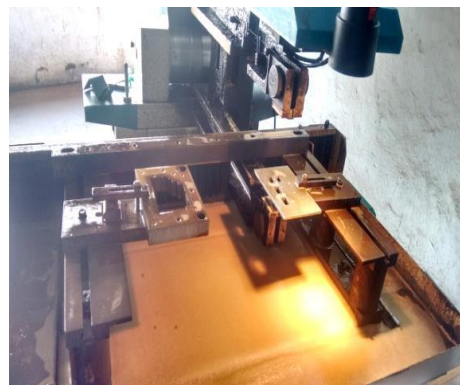
(b) Machine setup

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. 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 work piece which 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. Electrode wire is made of brass, copper or zinc coated which have good electrical conductivity with diameter

Coreponding author: **T.Vijaya Babu**

of 0.25mm. The experimental studies were performed on a ELECTRONICA EZEE CUT NXG WEDM machine in fig 1.

2. Literature survey

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. 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. 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 .Sudhakara and Prasanthi used Taguchi L27 to optimize the surface roughness of P/M Cold Worked Tool Steel. 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/cm² .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. Kanlayasiri and Jattakul found the optimal cutting condition of dimensional accuracy and surface roughness for K460 tool steel by wire EDM machine. They 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 current and offset distance is significant factor for dimension while peak current affects the surface roughness. Sharma *et al.* found the MRR, SR, recast layer, topography, micro hardness of Inconel706 for turbine disk application. 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 . 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 Md.karim Baig *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. 2A discharge current is optimum condition for higher MRR and lower Kerf Width. 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 mm³/min and lower Kerf a value of 0.375 mm .

3. Experimental detail

Theme of experiment is an attempt have made to optimize the cutting conditions 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. 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.

4.   Chemical   composition   and   mechanical properties of Inconel 625

Table 1 Chemical composition of Inconel 625

Ni	58
Cr	22
Mo	9.1
Fe	4%
Co+Nb	1
Ta	3.25
Mn	0.11
Al	0.21
P	0.01
Ti	0.33
Si	0.1

Table 2 Mechanical Properties of Inconel 625

Hardness (RB)	97
Tensile strength (Mpa)	885
Yield strength (Mpa)	758
Breaking extension	60-30
Thermal conductivity (W/mK)	9.8
Young's modulus(Gpa)	206

5. Experimental setup

Experiment were performed on a wire-cut EDM machine with specification like design fixed column, moving table type of interpolation linear & circular, power supply 3 phase, AC 415 V, 50 Hz. Inconel 625 is taken as work material of size 80X80X14 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.

6. 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 3

Table 3: processes parameters and their levels

S.No	Parameter	Levels		
		L1	**L2**	**L3**
1	Pulse On time (μs)	105	115	125
2	Pulse OFF time (μs)	35	45	55
3	Peak current(A)	120	140	160

7. Result and discussion

Table 4 Experimental procedure parameters

Expt .No	Ton	Toff	IP	Surface roughness	S/N ratio
1	105	35	120	3.263	-10.27
2	105	45	140	2.751	-8.78
3	105	55	160	1.630	-4.24
4	115	35	140	6.223	-15.88
5	115	45	160	5.980	-15.53
6	115	55	120	5.306	-14.49
7	125	35	160	7.335	-17.30
8	125	45	120	7.047	-16.96
9	125	55	140	6.696	-16.51

Response Table for Signal to Noise Ratios

Smaller is better

Level	Ton	Toff	IP
1	-7.769	-14.487	-13.909
2	-15.303	-13.761	-13.729
3	-16.928	-11.752	-12.362
Delta	9.159	2.735	1.547
Rank	1	2	3

Response Table for Means

Level	Ton	Toff	IP
1	2.548	5.607	5.205
2	5.836	5.259	5.223
3	7.026	4.544	4.982
Delta	4.478	1.063	0.242
Rank	1	2	3

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Ton	2	32.2809	16.1405	179.25	0.006
Toff	2	1.7625	0.8813	9.79	0.093
IP	2	0.1088	0.0544	0.60	0.623
Error	2	0.1801	0.0900		
Total	8	34.3323			

Surface roughness = 5.137 - 2.589 Ton_105 + 0.700 Ton_115 + 1.889 Ton_125 + 0.470 Toff_35 + 0.123 Toff_45 - 0.593 Toff_55 + 0.069 IP_120 + 0.087 IP_140 - 0.155 IP_160

It is observed that (obtained from MINITAB17 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.
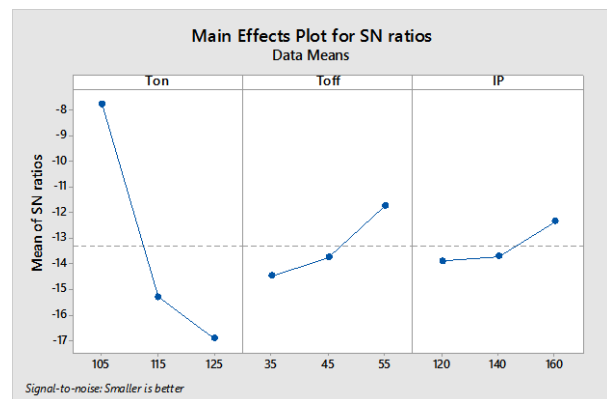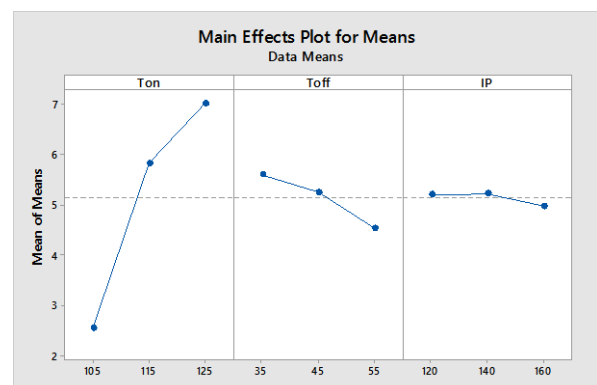

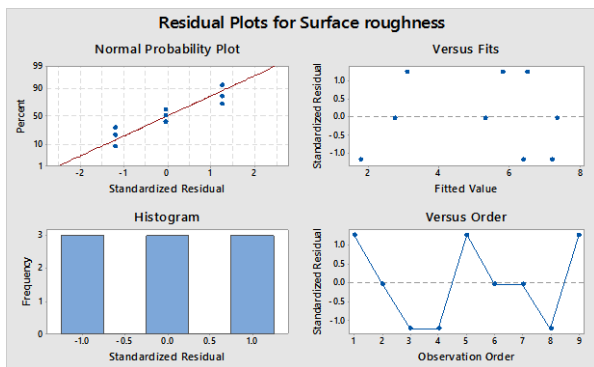**Fig 2**: Main effect plots for S/N ratios

Fig 3: Main effect plots for Means

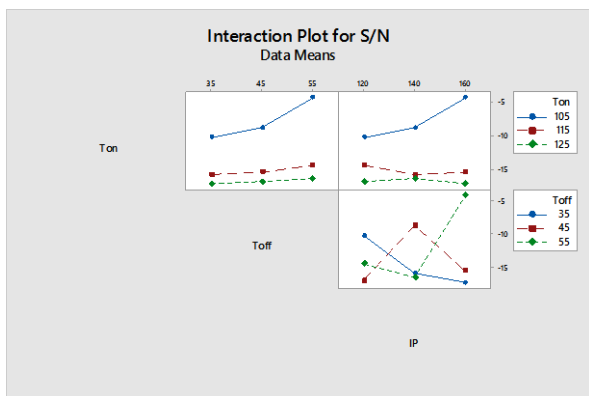**Fig 4** : Residual plots for Surface roughness

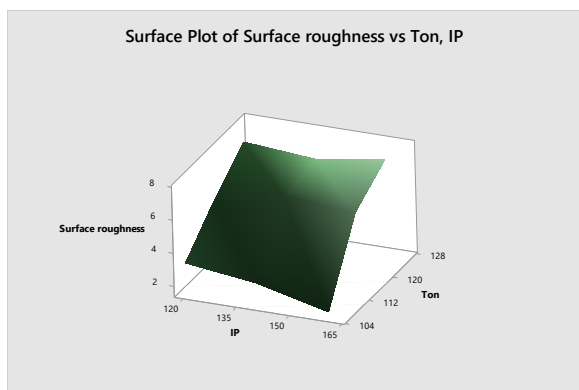**Fig 5:** Interaction plots for S/N ratios

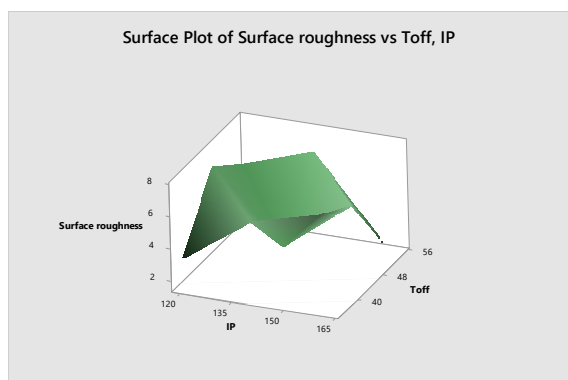**Fig 6**: Surface plots for surface roughness Vs Ton ,IP

Fig 7: Surface plots for surface roughness Vs Toff ,IP

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 .It is found that pulse on time is most significant factor (contributing 92.35%) followed by pulse off time . Surface roughness is the lower the better characteristics so pulse on time at first level and pulse off time at third level gives the optimum condition i.e. minimum surface roughness.

Conclusions

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   followed by pulse off time.
3. Peak current is insignificant factor for surface roughness.
4. Optimal setting for surface roughness which gives minimum surface roughness value.

References

T.Vijaya Babu, J.S Soni ,S.Ajaya Kumar (May2017) Effect Of Wire Edm Process Parameters On Surface Roughness Of AISI -4140 (Carbon Steel) Using Taguchi Method , International e-Journal For Technology And Research-2017 – Volume-1 , Number-2,March 2017 , pp. 1-6

T.Vijaya Babu ,J.S Soni(2016) , Investigation of Process Parameters Optimization in Die - Sinking EDM to Improve Process Performance Using Taguchi Technique ,IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , Vol.13, No.5,Ver 3, 2016, pp. 130-133

T.Vijaya Babu, J.S Soni, S. Ajaya Kumar ,(2016) An experimental investigation of machining parameters on electrical discharge machining of M-250 (Maraging) steels, International journal of engineering sciences & research technology (IJESRT) Vol.5, No.12, 2016, pp. 55-60

K. Kanlayasiri and S. Boonmung Effects of wire-EDM machining variables on surface roughness of newly developed DC 53 die steel: Design of experiments and regression model Journal of Materials Processing Technology 192–193 (2007) 459–464

JirapornPunturat, ViboonTangwarodomnukun and ChaiyaDumkum Surface characteristics and Damage of mono crystalline silicon induced by wire-EDM Applied Surface Science 320 (2014) 83–92

AdeelIkram, Ahmad Mufti, Saleem and Ahmed Raza Khan Parametric optimization for surface roughness, kerf and MRR in wire electrical discharge machining (WEDM) using Taguchi design of experiment Journal of Mechanical Science and Technology 27 (7) (2013) 2133~2141

Fuzhu Han, Jun Jiang &Dingwen Yu Influence of machining parameters on surface roughness in finish cut of WEDM

International Journal of Advance Manufacturing Technology (2007) 34:538–546

G.Ugrasen, H.V.Ravindra, Naveen Prakash and R.Keshavamurthy Process optimization and estimation of machining performances using artificial neural network in wire EDM Procedia Materials Science 6 (2014)1752 – 1760

D.Sudhakara and G.Prasanthi Application of Taguchi Method for Determining Optimum Surface Roughness in Wire Electric Discharge Machining of P/M Cold Worked Tool Steel Procedia Engineering 97 (2014) 1565 – 1576

K.Kumar and R. Ravikumar Modeling and Optimization of Wire EDM Process International Journal of Modern Engineering Research (IJMER) Vol. 3, Issue. 3, May.-June. 2013 pp-1645-1648

M.T. Antar, Soo, Aspinwall, C. Sage, Cuttell, Perez and A.J. Winn Fatigue response of Udimet 720 following minimum damage wire electrical discharge machining Materials and Design 42 (2012) 295–300

KannachaiKanlayasiri and PrajakJattakul Simultaneous optimization of dimensional accuracy and surface roughness for finishing cut of wire-EDMed K460 tool steel Precision Engineering 37 (2013) 556– 561

Priyaranjan Sharma, D.Chakradhar and S. Narendranath Evaluation of WEDM performance characteristics of Inconel 706 for turbine disk application Materials and Design 88 (2015) 558–566

SreenivasaRao and N. Venkaiah Parametric optimization in machining of Nimonic-263 alloy using RSM and particle swarm optimization Procedia Materials Science 10 (2015) 70 – 79

Md.karimBaig *et al*. Parametric optimization of WEDM for HastelloyC276, using GRA method International Journal of Engineering Development and Research ISSN: 2321-9939

E.Atzeni, Bassoli, Gatto, Iuliano, Minetola and Salmi, Surface and sub surface evaluation in coated wire electric discharge machining of Inconel alloy 718 Procedia CIRP 33, 389 – 394 (2015)

I.A.Choudhury, M. A. El-Baradie,Machinability assessment of Inconel 625 by factorial design of experiment coupled with response surface methodology, Journal of Material Processing and Technology 95, pp. 30 – 39, 1999.

M. Rahman, W. K. H. Seah and T.T. Teo 1997 The machinability of Inconel 625, Journal of Material Processing Technology, vol. 63, pp.199-204, 1997.

H. Oktem, T. Erzurumlu and H. Kurtaran, Application of response surface methodology in the optimization of cutting conditions for surface roughness, Journal of Material Processing and Technology, vol. 170, pp. 11 – 16, 2005.