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Process Parametric Optimization of Wire EDM Using Taguchi Method for Inconel 718

Aqib Abdullah[1], Parul Sahu[2], Ajay Singh Rana[3]
[1]*Research Scholar, Department of Mechanical Engineering, RIMT UNIVERSITY*
[2]*Assistant Professor, Department of Mechanical Engineering, RIMT UNIVERSITY*
[3]*HOD, Department of Mechanical Engineering, RIMT UNIVERSITY*

***Abstract-** The necessity of selecting the best values for various operating factors is necessary for improving the efficiency of many non-conventional machining processes. The Wire Electrical Discharge Machining method is based on widely established non- physical contact metal erosion rate approach and is based on the traditional EDM sparking phenomena. In conductive material machining, wire electrical discharge machining (WEDM) is commonly employed. The motive of this research is to find the optimized effect of these setup factors: Pulse-on time (T_{on}), Pulse-off time (T_{off}) and Peak Current (I), which are great influenced factor among each other. These factors are controlled by the specifications while machining like Kerf (KW) and Material removal rate (MRR) and also to evaluate them. The studies followed the Taguchi's L9 orthogonal array protocol. During the creation of micro cuts in Inconel 718, the material removal rate (MRR) and cutting width (Kerf) were used as response measurements. In MRR, the pulse on time contributes the highest proportion, 67.39% followed by current and pulse off time and in Kerf, the highest percentage contribution in current is 38 % followed by pulse off time and pulse on time at 95 % confidence level. In addition, pulse on time was found to be the next major parameter for MRR, whereas peak current was shown to be the next key parameter for Kerf.*

***Index Terms**— Wire electrical discharge machine (WEDM), MRR, Kerf (cutting width), Parameter optimization, Taguchi method.*

1. INTRODUCTION AND BACKGROUND

Tough materials such as titanium, stainless steel, high strength temperature-resistant alloys, ceramics, super alloys, and others have seen an enhancement in progress and utilization in recent years [1]. Leading to enhanced technological characteristics like high structural solidity and hardness, extreme temperature, wearing away and oxidation resistance, and power-to-weight ratio, these materials are widely used in modern industry. When these materials are machined using traditional methods, difficulties like high cutting forces with elevated temperatures, quick tool wear, and enduring stresses in the work piece arise. As a result, tool-life and machining feature suffer, however machining time costs skyrocket [1,2]. Non-conventional machining is becoming increasingly popular. Wire Electrical Discharge Machining (WEDM) is a non-conventional machining technology that uses electric sparks as a heat source to remove material. It can be used to economically machine materials with low machinability, difficult jobs with complicated shapes, profiles, and sharp edges that are very challenging to machine using other conventional and non-traditional machining processes [3]. It is also used in Aerospace, automotive, die, tool manufacturing and conductive machining industries [4].

The material removal method in WEDM involves controlled erosion via a sequence of sparks. Work piece works as other electrode in which wire acts as electrode and has better electrical conductivity to minimize joule heating (I^2R) [5] and failure induced by it. A pulsed DC supply is linked to both electrodes. To focus the spark energy to an exceedingly tiny location, proper wire tension and a dielectric bath are necessary. There will be no physical changes in the deionized fluid unless the voltage and dimensions are equal to the dielectric fluid's dielectric strength. Ionization happens at this moment, and electricity flows between the positive and negative electrodes throughout the ionized column of dielectric fluid. Ionization causes the dielectric to be heated by the passage of electricity, and it eventually transforms into plasma, a gas.

Electrons in the form of sparks rapidly move through the ionized plasma under this situation. The work piece's positive ions attract the negatively charged electrode, and the electron with negative charge collides with the work piece and produces a flash spark, which melts and vaporizes a small quantity of material [6,7].

2. OBJECTIVES OF RESEARCH

1 To have a firm grasp of the WEDM procedure.
2 To investigate and analyze the effects of various controllable process parameters, such as pulse on time, pulse off time, peak current, and other uncontrollable process parameters, such as 'job height' and 'gap between job surface and wire guide', on the machining of the Inconel 718 alloy.
3 To determine the Taguchi method's capabilities in resolving the needed problem.
4 To examine the impact of changing pulse parameters on MRR and Kerf width.
5 To establish WEDM as a better alternative machining technique for low-machinability alloys.
6 Conduct a comprehensive experimental study on cutting operations using an appropriate design of experiments to investigate the impact of various controllable and uncontrollable process parameters such as pulse on time, pulse off time and peak current on performance measures such as material removal rate and kerf width.

3. MATERIAL AND METHODOLOGY

3.1 Material.

The workpiece is made of 718 nickel alloy (Inconel) and measured 58mmx27mmx5mm. The chemical configuration of the selected Inconel-718 sample was governed taking an optical spectrometer which was set up to be 17.69% Cr, 54.67% Ni, 5.12% Nb, 2.81% Mo, 0.86% Ti. A cylindrical molybdenum wire (dia. 0.3mm) were implemented as an electrodetool. The commercially deionized water was taken as dielectric fluid because of its best applications, and good di-electric strength. The Inconel alloy before and after machining is depicted in figure 1.

Fig.1. Inconel alloy before and after machining

3.2 Methodology

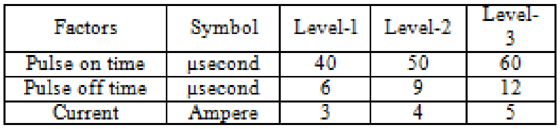
The trials were carried out using a ZHONGYUAN FDK7735 CNCWEDM machine since we have the most up-to-date technology accessible in the market and in our lab. Effects of different input parameters, such as pulse on time, pulse off time and current. In the experiment, 0.3mm diameter molybdenum wire was employed. The work piece was made of 718 nickel alloy and measured 58mmx27mmx5mm. During the experiment, one cut was made for kerf width and was repeated for 9 runs, and the same was used to calculate MRR in order to utilize the same process settings in every run. The noise factor is lowered as a result of this. Figure 2 shows the wire EDM that was utilized in the studies. . The system includes a CNC control system that uses program codes to control all of the moments (the CNC system is controlled via a key board), a power supply with anti-electrolysis circuitry, automatic wire threading, a hand-held pendant, a programmable Z-axis, a water chiller, and a filtration system. The same wire is used repeatedly, with both runs being for cutting, this is continued until the wire breaks down.

Fig.2. Wire EDM Machine

3.3 Design of experiment (DOE).

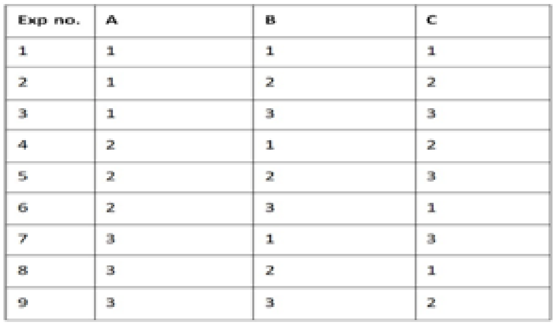
It is built on Taguchi's notion that is now being refined into a quality-improvement engineering approach known in Japan as precision engineering and in the West as robust design, which is a multidisciplinary engineering process which aims to discover the optimal accord in a material design. Taguchi's notions, like "quality," "S/N Ratio," "Orthogonal arrays Degree of Freedom," and "analysis of variance," might be synthesized in technical research. The loss function in quality is thought to be a novel way of calculating the economic benefit of enhancing system or operative protection. Orthogonal arrays are implemented to examine a large number of factors at the same time with a small amount of time and resources, resulting in a broad image that can be utilized for more thorough safety-based design and operative decision-making. The signal-to-noise ratio (SNR) is used to assess quality [8, 9]. The experiment was conducted on the L9 mixed arrays table. Three controlling factors were chosen as controlling factors, each with three levels (small, medium, and big). Table 1 shows the results.

Table 1 the degrees of machining factors



Factors	Symbol	Level-1	Level-2	Level-3
Pulse on time	µsecond	40	50	60
Pulse off time	µsecond	6	9	12
Current	Ampere	3	4	5

Table 2 L9 Orthogonal array



Exp no.	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 3 Taguchi Orthogonal Array Design L9 for both Kerf and MRR

S. No	T on	Toff	I (amps)	Kerf Width (mm)	MRR (mm^3/sec)
1	1	1	1	0.222	0.0620
2	1	2	2	0.265	0.0639
3	1	3	3	0.246	0.0586
4	2	1	2	0.233	0.0695
5	2	2	3	0.253	0.0701
6	2	3	1	0.211	0.0531
7	3	1	3	0.235	0.0855
8	3	2	1	0.253	0.0752
9	3	3	2	0.275	0.0810

3.3 MRR Analysis

Table 4 Taguchi Orthogonal Array Design L9 for MRR

T on	T off	I	MRR (mm^3/sec)	S/N Ratio
1	1	1	0.0620	-24.1522
1	2	2	0.0639	-23.8900
1	3	3	0.0586	-24.6420
2	1	2	0.0695	-23.1603
2	2	3	0.0701	-23.0856
2	3	1	0.0531	-25.4981
3	1	3	0.0855	-21.3607
3	2	1	0.0752	-22.4756
3	3	2	0.0810	-21.8303

3.4 MRR response data for signal to noise ratio for each level

Table 5 response table for signal to noise ratio (Larger the better)

Level	T on	T off	I
1	-24.23	-22.89	-24.04
2	-23.91	-23.15	-22.96
3	-21.89	-23.99	-23.03
Delta	2.34	1.10	1.08
Rank	1	2	3

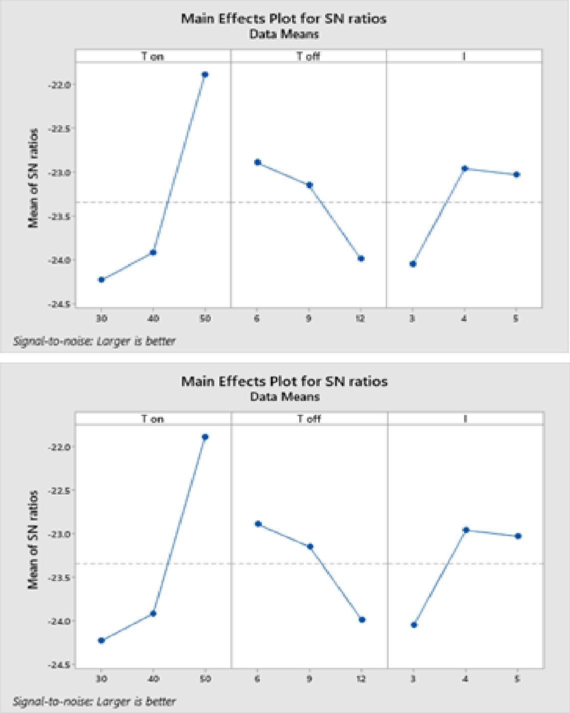


Fig. 3 Graph for S/N ratio

3.5 Analysis by variance (ANOVA).

Table 6 Analysis by variance for S/N ratio

Sources	DOF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
T on	2	9.6739	9.6738	4.8370	19.30	0.049	67.39
T off	2	1.9804	1.9804	0.9902	3.95	0.202	13.8
I	2	2.2002	2.2002	1.1001	4.39	0.186	15.32
Residual Errors	2	0.5011	0.5011	0.2506			3.5
Total	8	14.3557					

3.6 Regression

Table 7

S	R-sq	R-sq (adj)	R-sq(pred)
0.5006	96.51	86.04	0.00%

3.7 Regression Equation.

MRR = 0.0268 + 0.000953T on - 0.00136 T off - 0.00398 I

Optimum combination

$A_3B_1C_2$

Figure 4 depicts the normal probability for MRR residual plot. This diagram may be used to see if the model matches the analysis's assumptions. The data are normally distributed, and the factors are impacting the answer, as indicated by the normal probability plot. Because normalized residues are between -0.01 and 0.01, there are no outliers in the data. The residuals are distributed normally and in a straight line. As a result, the ANOVA assumptions are fulfilled, and regression analysis is effective.

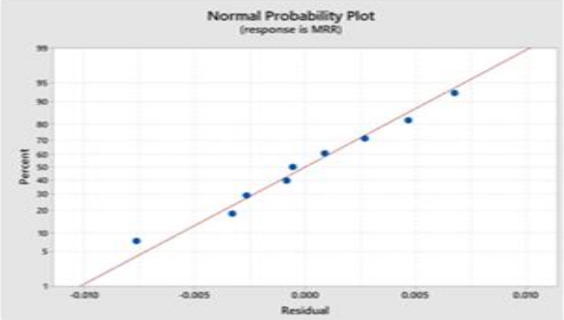


Fig. 4 Normal probability of the residuals for MRR

3.8 Kerf Width Analysis

Table 8 Taguchi Orthogonal Array Design L9 for Kerf

T on	T off	I	Kerf	S/N Ratio
1	1	1	0.222	13.0729
1	2	2	0.265	11.5351
1	3	3	0.246	12.1813
2	1	2	0.233	12.6529
2	2	3	0.253	11.9376
2	3	1	0.211	13.5144
3	1	3	0.235	12.5786
3	2	1	0.253	11.9376
3	3	2	0.275	11.2133

3.9 Kerf response data for signal to noise ratio for each level

Table 9 response table for signal to noise ratio (Smaller the better)

Level	T on	T off	I
1	12.26	12.77	12.84
2	12.70	11.80	11.80
3	11.91	12.30	12.23
Delta	0.79	0.96	1.04
Position	3	2	1

Fig. 5 graph for S/N ratio

3.91 Analysis by variance (ANOVA)

Table 10 Analysis of variance for S/N ratio

Sources	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
T on	2	0.9439	0.9439	0.4720	2.83	0.261	21.9
T off	2	1.3967	1.3967	0.6983	4.18	0.193	32.35
I	2	1.6418	1.6418	0.8209	4.92	0.169	38
Residual Errors	2	0.3339	0.3339	0.1670			7.73
Total	8	4.3163					

3.92 Regression

Table 11

S	R-sq	R-sq (adj)	R-sq(pred)
0.4086	92.26	69.06	0.00%

3.93Regression Equation

KW = 0.1707 + 0.000500T on + 0.00233T off + 0.00800I

Optimum combination

$A_2B_1C_1$

Figure 6 depicts the normal probability for Kerf residual plot. This diagram may be used to see if the model matches the analysis's assumptions. The data are normally distributed, and the factors are impacting the answer, as indicated by the normal probability plot. Because normalized residues are between -0.04 and 0.04, there are no outliers in the data. The residuals are distributed normally and in a straight line. As a result, the ANOVA assumptions are fulfilled, and the regression analysis is valid.

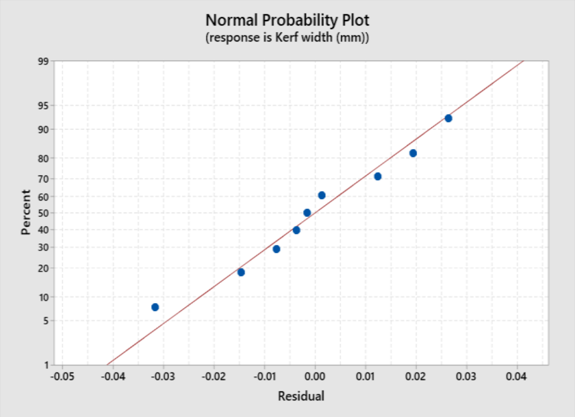


Fig. 6 Normal probability of the residuals for Kerf

3.94Confirmatory Test

The goal of a confirmation experiment is to confirm the results of the experiment. Because of confusion inside the OA columns and the occurrence of acronyms, validation is required when using OA design. For verifying the experiment/results, the average value calculated from the confirmed test (($\bar{\eta}$) is matched to pred. In general, if (($\bar{\eta}$) is within 5% of pred., we may infer that these two numbers are in excellent agreement. It shows that the model has additivity and that interaction effects cannot be dominating.

For MRR

As we know that $\bar{\eta}$ = -23.243 (from Table 4)

1. Experimental value for MRR(X_1)

(X_1) = 0.095mm^3/sec

Therefore, S/N = $-10 \log_{10}(1/X^2)$

= $-10 \log_{10}(1/0.095^2)$

= -20.401

2. Predicted value of S/N ratio

η_{pred} = -23.342+1.4542+0.452+0.3828

= -21.054

The difference between the experimental and anticipated values is just 3.1 percent, indicating that these two numbers are in good agreement. As a result, the interaction effect is not prominent.

For Kerf

As we know that $\bar{\eta}$= -12.2915 (from Table 8)

1.Experimental value for surface Roughness(X_2)

(X_2) = 0.216 mm

Therefore, S/N = $-10\log_{10}(X^2)$

= $-10 \log_{10}(0.216^2)$

= 13.2773

2.Predicted value of S/N ratio

η_{pred} = 12.2915+0.4095+0.4765+0.5501

= 13.7276

The difference between the experimental and anticipated values is just 3.28 percent, indicating that these two numbers are in good agreement. As a result, the interaction effect is not prominent.

4. CONCLUSION

The following conclusions are obtained in relation to the current investigation.

1) For optimal material removal rate (MRR), the best combination of machining parameters and their values is $A_3B_1C_2$, which stands for pulse on time (A_3), pulse off time (B_1), current (C_2).
2) The pulse on time contributes the highest proportion, 67.39%. As a result, it is the most essential and significant element influencing the MRR. The current is the next major characteristic, with a percentage contribution of 15.32%, followed by the pulse off time with a percentage contribution of 13.8%.
3) For MRR, the residuals in probability plot are distributed normally and in a straight line. As a result, the ANOVA assumptions are fulfilled, and the regression analysis is valid.
4) For minimal kerf width (KW), the best combination of machining parameters and their values is $A_2B_1C_1$, which stands for pulse on time (A_2), pulse off time (B_1) and current (C1).
5) The highest percentage contribution of current is 38 %. As a result, it is the most crucial and critical component influencing KW. The pulse off time is the next major characteristic, with a percent contribution of 32.35 percent, tracked by the pulse-on time, with a percent contribution of 21.9%.
6) For Kerf, the residuals in probability plot are distributed normally and in a straight line. It means the ANOVA assumptions are fulfilled, and the regression analysis is valid.
7) For both MRR and kerf width, there is strong agreement between ($\bar{\eta}$) and $\bar{\eta}_{pred}$, indicating that additively is included in the model and interface effects cannot be leading.

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