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Optimization of Process Parameters of WEDM on Titanium Alloy (Ti-6Al-4V) By Using Taguchi Method

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Abstract:

The wire electro-discharge machining process is a non-traditional machining technique that utilizes electro-thermal energy to achieve precision and accuracy when machining hard and electrically conductive materials such as matrix composite metals, aluminium, and titanium alloy. Biocompatible materials, particularly titanium alloy, require a high level of surface quality to ensure compatibility, necessitating an improvement in machined surface quality. Our investigation explores the impact of machining parameters, including pulse peak current, pulse on time, and pulse off time, on surface integrity, material removal rate, and electrode consumption. By analyzing the effects of continuous traveling of wire electrodes, particularly brass wire, we aim to determine the optimal values for all parameters and assess the individual influence of each parameter on the others. We will employ Taguchi and Anova analysis to make predictions on our parameters.

Key Words: pulse peak current, pulse on time, and pulse off time, surface roughness and material removal rate etc.

Introduction

Primary and secondary manufacturing processes are two distinct categories in the field of manufacturing. The former pertains to the overall size and shape of a product, and includes forming, casting, and powder metallurgy. The latter, on the other hand, ensure greater precision in dimension and surface quality, and are achieved with material removal processes. To achieve successful WEDM machining, both the wire electrode and work material must possess electrical conductivity. These two components are submerged into a dielectric substance like kerosene or deionized water, with a gap maintained between them to create a potential difference. An electric field is established as a result, and free electrons experience an electrostatic force. The electrons are emitted from the wire electrode and accelerated towards the work material in the dielectric medium, colliding with dielectric molecules and ionizing the fluid. This generates a large concentration of ions and electrons in the area, resulting in a plasma zone. The electrons and ions move towards each other, creating a spark that converts electrical energy to thermal energy. The high-velocity electrons and ions impact the surfaces of the work material and wire electrode, resulting in heat flux or thermal energy that raises the temperature above 10000^{o} C. This intense localized heat vaporizes or melts the work material, removing it from the surface[11-12].

The process of wire-electro discharge machining (WEDM) has gained significance owing to its capability of proficiently manufacturing complex-shaped components using tough-to-work-with materials such as zirconium, nimonics, titanium, etc. This non-traditional machining technique surpasses conventional machining methods in creating intricate shapes. Furthermore, the WEDM parameters and usage of workpiece and tool material influence the resulting surface characteristics to differing extents. In 2019, A.V. S Ram Prasad conducted an experiment aimed at optimizing machining parameters to enhance the effectiveness of the WEDM process when machining Titanium alloy using 0.25mm diameter brass wire. The findings indicated that peak current and pulse on time had a significant impact on material removal rate and surface integrity, while pulse off time and machining servo voltage had a comparatively lesser effect. Increasing peak current and pulse on-time led to improving material removal rate, with high peak current being the key factor for achieving high material removal rate. In 2004, Shajan Kuriakose investigated the impact of various process parameters on the metallurgical changes observed on Titanium alloy surfaces after Wire Electrical Discharge Machining (WEDM). The experiment was conducted using zinc-coated brass wire and Taguchi's orthogonal array was utilized to analyze the results. The findings of the experiment indicated that wire-speed, wire

tension, time between two pulses, injection fluid pressure, and pulse duration were the most significant process parameters affecting the WEDM machining surfaces from a metallurgical perspective.
In 2004, Mohan and colleagues conducted a study to examine the machining characteristics of SiC/6025 Al composite using rotary EDM with a tube electrode. To evaluate the machinability, several input variables were considered, including peak current, polarity, volume fraction of SiC reinforced particles, pulse duration, hole diameter of the tube electrode, and speed of electrode rotation. In 2013, Farnaz Nau bakhsh conducted an experiment to analyze the impact of various machining parameters on WEDM of Titanium alloy. Two types of wires, brass wire, and zinc-coated brass wire, were used in the investigation. The findings of the experiment revealed that both wires significantly impacted the machining speed of Titanium alloy on WEDM when peak current, pulse gap width, and time between two pulses were considered. The machining surface integrity of titanium alloy was also significantly affected by peak current, pulse gap width, and wire tension when both wires were used on WEDM. In 2012, Basil Kuriachen conducted an experimental study to examine the effects of various process parameters on WEDM machining. The experiment used a continuous traveling wire-electrode made of brass, copper, or tungsten, with or without coating, and a thickness of 0.3 mm. The results of the experiment revealed that the most significant factors affecting surface roughness were pulse on time, pulse off time, and machining servo voltages.
In 2012, Aniza Alias conducted an experimental investigation to study the effects of the feed rate of a continuous traveling wire-electrode made of non-coated brass with a thickness of 0.25 mm in WEDM machining. The study revealed that the high feed rate was the most significant factor in determining surface integrity, while wire tension and machining servo voltages had the most influence. The high feed rate was also found to be the most significant factor in determining kerf width, with ignition pulse current, wire-speed, and wire tension having the most influence. In 2015, Amrish Raj D conducted an experimental investigation to optimize the effects of various process parameters, including pulse on and off time, wire feed rate, and machining servo-voltage, on response parameters such as surface characteristics and material removal rate on different Titanium alloy surfaces obtained from WEDM machining. The experiment was conducted according to the Box-Benkhen approach. The experiment used zinc-coated brass wire on different machining parameters, and the results showed that the surface roughness was greatly influenced by process parameters such as pulse on and off time, from an optimization point of view of the multi-parameter process.
In 2017, Siva Prasad Arikatla conducted an experimental investigation to optimize the machining parameters for the machining of Titanium alloy with WEDM. The results revealed that kerf-width is significantly increased with increased pulse on and off time, input machining power, reference wire tension, and servo machining voltage. Material removal rate is significantly increased with an increased pulse on time and peak current, but significantly decreasing with an extended increased pulse on and off time, input machining power, wire tension, and reference servo-voltage. Surface roughness is significantly increased with an increase in pulse on time and input machining power, whereas it significantly decreases with an increase in wire tension and reference servo-voltage. Uday Mahesh Chavan conducted an experimental investigation in 2018 with the aim of optimizing the influences of various machining parameters such as pulse on and off time, input machining power, and reference servo-voltage. The investigation found that material removal rate and surface roughness are significantly affected by pulse on time. An increase in pulse on time and input machining power resulted in an increase in MRR, while a decrease in pulse on time and input machining power resulted in an increase in surface roughness.
The objective of the study conducted by Danial Ghodisiyeh in 2012 was to optimize the cutting parameters of WEDM machining of titanium alloy by utilizing deionized water as a dielectric and a continuous run of zinc-coated brass wire with a diameter of 0.25 mm as an electrode. The results showed that reference peak current and pulse on time were the most dominant factors for both MRR and surface integrity. It was found that both MRR and surface integrity increase with reference peak current, which also affects the discharge energy. In 2007, Yuan-

Feng Chen and colleagues conducted a study to explore the effects of machining characteristics and surface modifications on low-carbon steel (S15C) during EDM processes utilizing semi-sintered electrodes. In 2008, Pradhan and colleagues endeavored to optimize the process parameters of micro-EDM for machining the Ti-6Al-4V superalloy. They selected metal removal rate (MRR), tool wear rate (TWR), overcut (OC), and taper as the performance criteria to validate the optimal settings of the micro-EDM process parameters. The Taguchi technique has been the primary focus of Periyanan and colleagues in 2014, optimizing the micro-wire electro discharge grinding process. Their aim was to attain the highest Material Removal Rate (MRR) possible, and they achieved this by considering the cutting parameters of feed rate, capacitance, and voltage.

In their study, Milan Kumar Das and team in 2014, aimed to identify the optimal combination of process parameters that would result in both the highest Material Removal Rate (MRR) and the most favorable surface roughness in the electro discharge machining (EDM) of EN31 tool steel. Pujari Srinivasa Rao and colleagues conducted a study in 2014 to investigate how wire EDM parameters affect aluminum alloy, given its increasing use in various industries. Using the Taguchi method, they performed a parametric analysis of wire EDM parameters to evaluate their impact on both surface roughness (SR) and material removal rate (MRR) in their current research. In 2010, Muthu Kumar and co-authors showcased the optimization of process parameters for the WEDM of Inconel800 super alloy, using the Grey-Taguchi method. They selected gap voltage, Pulse On-time, Pulse Off-time, and wire feed as the process parameters, and considered multiple performance characteristics including MRR, SR, and kerf. In 2010, Hsien–Ching Chen and colleagues proposed an optimization strategy for WEDM parameters when machining Ti-6Al-4V with multiple quality characteristics. They employed the Taguchi method and grey relational analysis to select discharge current, open voltage, pulse duration, and duty factor as process parameters, while electrode wear ratio, material removal rate, and surface roughness were used as performance characteristics.

Janardhan and colleagues (2010) examined how machining parameters affect the performance of the wire electro discharge turning process. Venkata Ramaiah and team (2013) aimed to achieve enhanced material removal rate, surface roughness, and spark gap in their study. To determine the most optimal process parameters for optimizing response measures, they employed grey relational theory.

After conducting a literature survey, it was noted that there has been limited research in the area of objective optimization for the EDM of precipitation hardening material (Ti-6Al-4V), using the Taguchi method. The effect of machining parameters on titanium has not been fully explored using WEDM with brass wire as electrode. Due to large number of process parameters, a planned set of experiments is conducted according Taguchi's L-9 orthogonal array and the effect of the parameters on the process and the workpiece has been analysed. In this paper, an attempt has been made to analyze the process parameters on the workpiece material (Ti-6Al-4V) due to WEDM process. Surface roughness, material removal and electrode consumed during machining on workpiece material machined by WEDM depending on the machining conditions.

Experimental setup, procedure and equipment

The experiments were conducted using wire-cut EDM machine (ELEKTRA SPRINTCUT 734). An experimental investigation was conducted using a CNC Wire cut EDM machine (as shown in figure 1 and 2) to carry out machining. The work-piece material used was titanium alloy (grade-5), whose chemical properties are presented in Table-1. To conduct the machining investigation, the work-piece dimensions were set to 25 mm x 10 mm, with a thickness of 10 mm in figure 3.

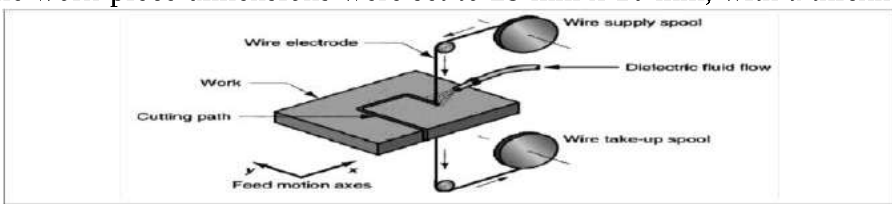


Figure 1. Diagram of WEDM Cutting

Figure 2. WEDM machine

Table 1:-Chemical Composition of Titanium Alloy (Grade -5)

Chemical Composition	Al	V	Pb	Fe	Ti
% Mass	6.61	4.20	1.09	0.11	Balance

The WEDM machine tool 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
- Generator : ELPULS-40 A DLX
- Controlled axes. : X,Y,U,V simulations/
- Interpolation : Linear & Circular
- Least input increment : 0.0001mm
- Connected Load : 10 KV

Figure 3. Sample of titanium plat

The following steps were taken during the cutting operation:

• A vertical block was used to make the wire vertical.

• The work-piece was clamped and mounted on the work table.

• A reference point was set on the work-piece to establish the work coordinate system (WCS) for programming purposes. The reference point was determined by the ground edges of the work-piece.

• A cutting program was developed to create a 12.5 mm x 10 mm square profile on the work-piece.

• The work-piece was cleaned with acetone prior to taking surface roughness measurements.

Brass electrode (wire) composition and physical properties:-

Table 2:- Chemical Composition and physical property of brass electrode

Chemical Composition	Cu	Al	Tin	P	Fe	Pb	Zn	Ni
Percentage	56.7	0.03	0.02	0.02	0.1	03	39.85	0.08
Tensile Strength				142000 PSI				
Wire Diameter				0.25 mm				

The table 3, below presents the control parameters at three distinct levels and the three response parameters considered for multiple performance characteristics in this study:

Table 3:-Response and control parameter

Response Parameters	Material Removal Rate(MM^3/MIN) Electrode Consume(Kg) Surface Roughness (µm)

Symbols	Control Parameter	Units	Level -1	Level -2	Level -3
A	Peak Current	Amp	21	22	23
B	Pulse On Time	μsec	107	110	113
C	Pulse Off Time	μsec	52	56	60

To investigate the impact of various machining parameters on the response machining parameters of cutting speed, surface roughness, MRR, and electrode consumption during WEDM of Titanium alloy grade 5 (Ti-6Al-4V), an experimental investigation was conducted using Taguchi's L-9 orthogonal array. The study utilized continuous traveling of wire with a thickness of 0.20 mm as an electrode and distilled water as a dielectric fluid. The dielectric water pressure (WP), wire tension (WT), wire feed rate (WF), and servo feed rate (SF) were maintained constant while investigating the effects of pulse peak current (IP), pulse on time (TON), and pulse off time (TOFF).

The specimens, which were 12.5mm x10mm x 10mm in size, were cut using the WEDM process with the aid of brass wire on titanium workpiece material for each combination of parameters considered according to the Orthogonal Array. All three machining parameters were varied at three levels: pulse peak current (IP) at 21, 22, and 23 amperes; pulse on time (TON) at 107, 110, and 113 μsec; and pulse off time (TOFF) at 52, 56, and 60 μsec.

In the Taguchi method, there is a focus on studying the variation in the response using the signal-to-noise (S/N) ratio, which helps to minimize the variation in quality characteristics caused by uncontrollable parameters. In this study, the quality characteristic was the metal removal rate, which follows the concept of "the larger-the-better." The material removal rate was calculated by taking the difference between the weight of the workpiece material before and after machining, and then dividing it by the machining time.

Material removal rate = removed material piece - work of or volume weight/ time machining

$$S/N_{LB} = -10 \, Log_{10} \left(\sum_{i=1}^{r} 1/y_i^2 \right) \quad (1)$$

Where n = number of tests in a trial (number of repetitions regardless of noise levels).

Yi = measured value of response (in this case response is MRR).

The regression equation for MRR is:

MRR = -0.03977 + 0.000983 Ip + 0.000179 Ton + 0.000018 Toff (2)

To measure the surface roughness, a surface roughness Rugosurf 90-G tester was utilized. The measurements were taken along the sides of each experiment. Surface roughness is an important quality parameter, and it should be minimized as much as possible. Therefore, for this study, the smaller-the-better signal-to-noise ratio was selected.

The S/N ratio for the smaller-the-better is:

$$S/N_{SB} = -10 \, Log_{10} \left(\frac{1}{n} \sum_{i=1}^{r} y_i^2 \right) \quad (3)$$

The regression equation for Surface roughness is:-

SR = -14.72 + 0.4195 Ip + 0.0726 Ton - 0.0006 Toff (4)

The electrode consume is calculated by the following equation:

Electrode consume = electrode before machining- after machining

Electrode consumption is another important quality parameter that should be minimized. Therefore, for this study, the smaller-the-better signal-to-noise ratio was selected for electrode consumption, which is the same as for surface roughness. The S/N ratio values were calculated using equation (1) and (3) with the aid of Minitab 15 software. The corresponding surface roughness values, electrode consumption values, material removal rate values, and their respective S/N ratio values are listed in Table 4.

Table 4:- Taguchi's L09 orthogonal design with quality characteristics and respective S/N ratios

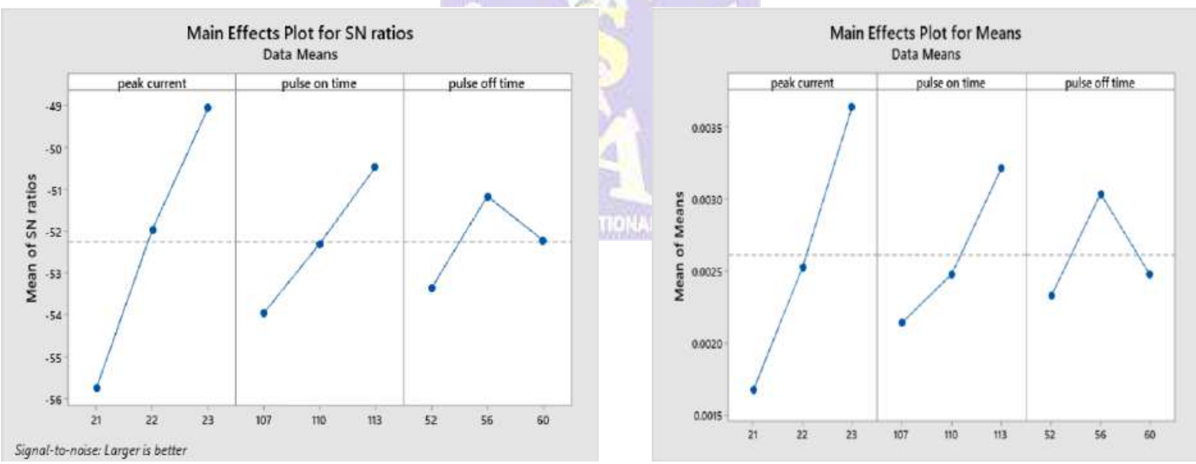
Exp. No.	IP amp	TON µsec	TOFF µsec	MRR g/min	S/N ratio	Mean	Surface Roughness µm	S/N ratio	Mean	Electro. consumed g	S/N ratio	Mean
1	21	107	52	0.001180	-58.5624	0.001180	2.004	-6.0379	2.004	0.227	12.8795	0.227
2	21	110	56	0.001813	-54.8320	0.001813	2.097	-6.4319	2.097	0.319	9.9242	0.319
3	21	113	60	0.002023	-53.8801	0.002023	2.313	-7.2835	2.313	0.755	2.4411	0.755
4	22	107	56	0.002366	-52.5197	0.002366	1.854	-5.3622	1.854	0.456	6.8207	0.456
5	22	110	60	0.002523	-51.9617	0.002523	2.354	-7.4361	2.354	0.378	8.4502	0.378
6	22	113	52	0.002693	-51.3953	0.002693	2.580	-8.2324	2.580	0.548	5.2244	0.548
7	23	107	60	0.002873	-50.8333	0.002873	2.854	-9.1091	2.854	0.391	8.1565	0.391
8	23	110	52	0.003107	-50.1532	0.003107	2.952	-9.4023	2.952	0.212	13.4733	0.212
9	23	113	56	0.004933	-46.1378	0.004933	3.125	-9.8970	3.125	0.729	2.7454	0.729

Results and Discussion

Once all the observations were collected, the S/N ratios and means were calculated, and various graphs were created for analysis using Minitab 15 software.

Material Removal Rate

Figure 4 displays the effects of variables on the material removal rate. At level 1, the current results in a low material removal rate, whereas at level 3, it results in a high material removal rate.



(a) (b)

Figure 4. Effect of control factors on MRR

When the current value changes from level 2 to 3, the MRR value increases above the overall mean value. However, at levels 1 and 2 of the pulse on current, the MRR value is below the overall mean value. When the pulse on current value changes from level 2 to 3, the MRR value increases above the overall mean value. At level 1 of the pulse off time, the MRR value is below the overall mean value. When the pulse off time value changes from level 1 to 2, the MRR value increases, but when it changes from level 2 to 3, the MRR value decreases.

Table 5:- Response table for Signal to Noise ratios

Factor / Level	Peak current (Ip)	Pulse on time (Ton)	Pulse off time (Toff)
1	-55.76	-53.97	-53.37
2	-51.96	-52.32	**-51.16**
3	**-49.04**	**-50.47**	-52.23
Delta	6.72	3.50	2.21
Rank	1	2	3

The table 5, displays the ranking of factors based on their impact on the machining characteristics. Current is ranked as the main response in the above response table, followed by pulse on time as the next main response. Pulse off time is ranked at the third position, and it has a lower impact on the machining characteristic compared to the other factors. The delta value for each factor is calculated by taking the difference between the higher and lower S/N ratio values, and the rank is determined based on these delta values. In the above table, current is ranked first because its delta value is higher than the other factors. Higher S/N ratio values for each factor in the above response table indicate the optimal level of that factor.

Table 6:- ANOVA for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution %
Regression	3	0.000008	0.000008	0.000003	10.13	0.014	85.88
Ip	1	0.000006	0.000006	0.000006	23.29	0.005	65.78
Ton	1	0.000002	0.000002	0.000002	6.99	0.046	19.73
Toff	1	0.000000	0.000000	0.000000	0.13	0.734	0.36
Error	5	0.000001	0.000001	0.000000	-	-	14.12
Total	8	0.000009	-	-	-	-	100

During the analysis of variance, it was determined that the peak current accounts for 65.78% of the contribution, followed by pulse on time at 19.73%, and pulse off current at 0.36%. The error value was calculated to be 14.12%.

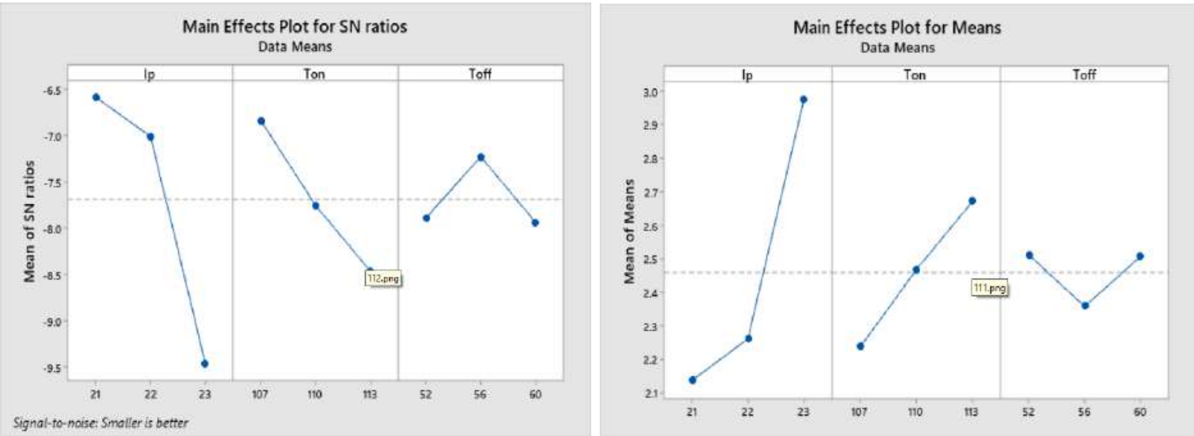
To achieve the maximum material removal rate, it is best to maintain the process variables or factors at Pulse current (Ip) of 23Amp, Pulse off current (Toff) of 56 µs, and Pulse on time (TON) of 113 µs.

Surface Roughness

The Figure 5, illustrates the impact of various factors on the surface roughness of a workpiece. When the current is at level 1, the surface roughness is high (i.e., the surface finish is good). Conversely, when the current is at level 3, the surface roughness is low. At levels 1 and 2, the surface roughness value is higher than the overall mean value. However, when the current level changes from level 2 to level 3, the surface roughness value increases above the overall mean value.

If there is a pulse in the current at levels 1 and 2, the surface roughness value is higher than the overall mean value. However, when the pulse on current level changes from 2 to 3, the surface roughness value decreases because the increased pulse-on time erodes material equally from the surface of the workpiece, resulting in a good surface finish. When the pulse-on time decreases, material removal becomes uneven due to the increased pulse-on time, resulting in a decrease in surface roughness.

At level 1 of the pulse-off time, the surface roughness value is below the overall mean value. When the pulse-off time changes from level 1 to 2, the surface roughness value increases. However, when the pulse-off time changes from level 2 to 3, the surface roughness value decreases.



(a) (b)

Figure 5. Effect of control factors on Surface Roughness

Table 7:- Response table for Signal to Noise ratios

Level \ Factor	Peak current (Ip)	Pulse on time (Ton)	Pulse off time (Toff)
1	**-6.584**	**-6.836**	-7.891
2	-7.010	-7.757	**-7.230**
3	-9.469	-8.471	-7.943
Delta	2.885	1.635	0.713
Rank	1	2	3

Table 7 presents the ranking of factors based on their influence on machining characteristics. The primary factor affecting machining characteristics, as indicated in the table, is the current, followed by the pulse-on time. The pulse-off time is ranked third and is found to have less impact on machining characteristics compared to other factors.

The delta value, calculated as the difference between the highest and lowest S/N ratio values for each factor, is used to determine the rank of each factor. Based on the delta values, the current factor is ranked first in the table, indicating that it has a greater impact on machining characteristics than other factors. In the above response, the higher values of S/N ratios for each factor indicate the optimal level of that factor.

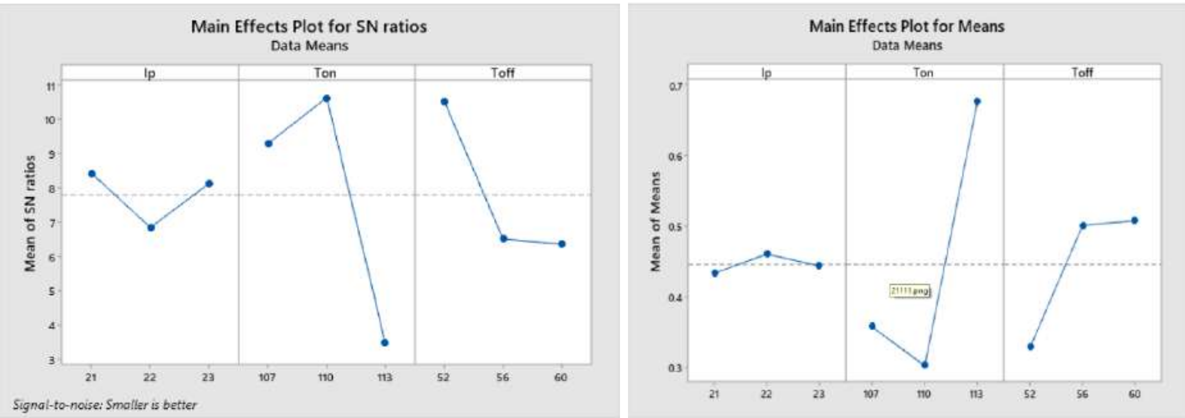
Table 8:- ANOVA for Surface Roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution %
Regression	3	1.34019	1.34019	0.44673	8.81	0.019	84.09
Ip	1	1.05588	1.05588	1.05489	20.82	0.006	66.25
Ton	1	0.28427	0.28428	0.28427	5.61	0.064	17.83
Toff	1	0.00004	0.000038	0.00004	0.00	0.979	0.00
Error	5	0.25351	0.25350	0.05070	-	-	15.91
Total	8	1.59371	-	-	-	-	100

Upon conducting an analysis of variance, it was found that the peak current has a contribution of 66.25%, while pulse-on time contributes 17.84%. The contribution of pulse-off current was found to be 0%, and the error value was 15.91%.

To achieve the minimum surface roughness, it is best to maintain the process variables or factors at Pulse current (Ip) of 21Amp, Pulse off current (Toff) of 56 µs, and Pulse on time (TON) of 103 µs.

Electrode Consumed



(a) (b)

Figure 5. Effect of control factors on Surface Roughness

The data presented in Figure 6 illustrates the impact of various variables on electrode consumption. Specifically, the graph depicts that when the current is set to level 1, electrode consumption is high, while at level 2, it is low. Levels 1 and 3 both result in electrode consumption values that exceed the overall mean value. Additionally, when the current value changes from level 2 to level 3, electrode consumption decreases.

Similarly, when the pulse on current is set to levels 1 and 2, the electrode consumption value is higher than the overall mean value. However, as the pulse current value shifts from level 2 to 3, the electrode consumption value decreases. At pulse off time level 1, the electrode consumption value is also higher than the overall mean value. However, when the pulse off time value changes from level 1 to 2, the electrode consumption value decreases. Interestingly, when it shifts from level 2 to 3, the surface roughness value also decreases.

Table 9:- Response table for Signal to Noise ratios

Factor / Level	Peak current (Ip)	Pulse on time (Ton)	Pulse off time (Toff)
1	8.415	9.286	10.526
2	**6.832**	10.616	6.497
3	8.125	**3.470**	**6.349**
Delta	1.583	7.146	4.176
Rank	3	1	2

The table 9, presents the ranking of factors based on their impact on machining characteristics. The top-ranking factor is Pulse on time, followed by Pulse off time. Pulse peak current ranks third but has a lesser impact on machining characteristics compared to other factors. Delta is calculated by determining the difference between the highest and lowest S/N ratio values for each factor. Based on the delta values, the factors are ranked. Ton is given the first rank in the above table because its delta value is higher compared to other factors.

Table 10:- ANOVA for Electrode Consumed

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution %
Regression	3	0.201182	0.201181	0.067061	3.01	0.133	64.36
Ip	1	0.000160	0.000161	0.000160	0.01	0.936	0.05
Ton	1	0.152961	0.152960	0.152961	6.87	0.047	48.94
Toff	1	0.048062	0.048061	0.048062	2.16	0.202	15.38
Error	5	0.111387	0.111389	0.022277	-	-	35.64
Total	8	0.312569	-	-	-	-	100

Upon conducting an analysis of variance, it was determined that peak current only contributed 0.05%, while pulse on time accounted for 48.94% and pulse off current accounted for 15.38%. However, it should be noted that there was an error value of 35.64%.

To achieve the minimum electrode consumed, it is best to maintain the process variables or factors at Pulse current (Ip) of 21Amp, Pulse off current (Toff) of 52 µs, and Pulse on time (TON) of 110 µs.

Conclusions

The results of this experiment revealed that optimizing control parameters such as pulse on time, pulse off time, and peak current had a significant impact on response parameters such as material removal rate, surface roughness, and electrode consumption when working with titanium plates. The following conclusions were drawn from the study:

1. The study results revealed that pulse peak current and pulse on time are the key process parameters that significantly impact the surface roughness performance of grade 5 titanium alloy (Ti-6Al-4V) in WEDM machining using brass wire. However, machining parameters such as pulse off time and servo voltage have minimal effects on the surface roughness performance when using brass wire. Increasing pulse peak current and pulse on time leads to a rise in surface roughness, while decreasing them causes a reduction in surface roughness. The maximum surface roughness is observed at maximum pulse peak current and pulse on-time values due to the resulting increase in discharge energy and larger craters. The optimal values for pulse on, pulse off, and peak current were found to be 107 µs, 56 µs, and 21 A, respectively.
2. The research findings indicated that pulse peak current and pulse on time, along with pulse off time, significantly influence the material removal rate of titanium alloy in WEDM machining using brass wire. Servo voltage has a negligible impact on material removal rates for both wires. Increasing pulse peak current and pulse on time results in a higher material removal rate, whereas decreasing those leads to a reduced rate. The highest material removal

rate is observed when pulse peak current and pulse on time are at their maximum values, and the pulse off time is minimum. This high material removal rate is due to the increased discharge energy and intensity of sparking. However, an increase in pulse off time reduces the duration of sparking, decreasing the number of discharges and resulting in a slower cutting speed. The optimal values for brass wire were discovered to be 23 A for peak current, 113 µs for pulse on, and 56 µs for pulse off time.

3. The experimental investigation revealed that pulse on-time and pulse off time are essential process parameters that significantly impact electrode consumption during WEDM machining of grade 5 titanium alloy using brass wire. Pulse peak current and servo voltage have limited effects on electrode consumption. The probability of electrode consumption increases gradually with pulse on time and decreases with pulse off time when machining with brass wire. However, the likelihood of electrode consumption decreases with a decrease in pulse on time and an increase in pulse off time. The highest probability of wire rupture occurs when pulse on time is maximum and pulse off time is minimum for brass wire. A rise in discharge energy, as pulse on-time increases and pulse off time decreases, is responsible for the higher consumption rate. However, reducing the pulse on time decreases the duration of sparking, resulting in a lower possibility of electrode consumption. The optimal values were found to be 110 µs for pulse on, 52 µs for pulse off, and 21 A for peak current, according to the experiment.

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