Performance of Wire-EDM Parameters on Machining Characteristics of Titanium Alloy (Ti6Al4V) using Taguchi Method

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***Abstract*—The effect of wire electrical discharge machining (wire-EDM) parameters on machining characteristics of Titanium Alloy (Ti6Al4V) is studied. 0.2mm diameter of electrolytic brass wire having composition ratio Copper and Zinc 60:40 was selected as wire electrode. The experiment was done using SODICK VZ500L wire-EDM machine. Orthogonal arrays design of Taguchi method was applied to design the experimental matrix and the data was analyzed using analysis of variance (ANOVA). It is found that the most significant parameter affected material removal rate (MRR) is servo voltage followed by pulse duration, while pulse interval shows the less significant factor. The validation of optimum parameter has been done for MRR and it is found that after optimization process, the MRR can reach up to 0.044g/min, which is a 4.76% increased as compared to maximum MRR result from initial experiment. Surface roughness (Ra) reduces to 4.35% meanwhile kerf width (Kw) slightly increases to 0.036% after conformation run of the optimization combination process parameters. Pulse duration of input parameter of gives the most significant impact to RA and Kw. Thus, it shows that the results of wire-EDM on Ti6Al4V are particularly useful for industrial practitioners and researchers to determine the best combination of parameters which lead to optimize the machining performance.**

Keywords—wire-EDM; titanium alloy; taguchi method; machining characteristics

I. INTRODUCTION

Wire electrical discharge machining (wire-EDM) is a modification of electric discharge machining which has been widely used for a long time in producing mould, die and other machine parts of conductive materials. Capability of cutting variety of conductive materials with intricate shapes makes it important in the market [1]. Some researchers have studied machining in critical area such as cutting at narrow slot [2], thin part [3] and pocketing having sharp edge [4], however, wire-EDM is the most preferred method rather than using conventional machining [5]. It was known that Titanium alloys, i.e., Ti6Al4V, have relatively high melting temperature, low thermal conductivity and high electrical resistivity as compared to metal. It also has been classified as difficult to machine by conventional machining method [6]. Therefore, selection of optimum machining parameters is challenging task in wire-EDM due to the presence of a large number of process variables and stochastic process mechanism. It was noticed that various wire-EDM machining parameters influence material characteristics such as material removal rate, kerf width and surface roughness. The setting possible combination of those parameters was difficult to produce optimum surface quality. Thus, the application of statistic techniques was widely used in an accessing in machining performance such as using response surface method [7], full factorial [8] and Taguchi method [9]. Therefore, a comprehensive study using design of experiment (DOE) of the effect of wire-EDM parameters such as pulse duration, pulse interval, servo voltage and ignition pulse current on the machining characteristic is greatly significant and could be necessity [10]. In this study, the effect of machining parameters on machining characteristics, i.e., MRR, RA and Kw, of Titanium alloy (Ti6Al4V) in wire-EDM is investigated. Further, the design of experiment using Taguchi method was used for optimization parameters and the percentage contribution response of machining characteristic of Ti6Al4V was analyzed by ANOVA analysis.

II. EXPERIMENTAL SET-UP

Titanium alloy (Ti6Al4V) was used as a workpiece material for this study and electrode brass wire with diameter of 0.2mm was selected as electrode. Bridge Port milling machine having maximum speed 4200rpm was used to prepare the workpiece samples. The size of Ti6Al4V workpiece was 60mm (width) x 260mm (length) x 4mm (height) as shown in Figure 1. SODICK VZ500L having 4-axis CNC wire-EDM machine was used to perform the machining process and the machining parameters were selected such as pulse duration, pulse interval, servo voltage and ignition pulse current as the parameters set-up. De-ionized water was used as dielectric fluid while machining characteristics to be investigated were material removal rate (MRR), surface roughness (Ra) and kerf width (Kw). Mitutoyo weighing scale was used to get the weight of workpiece for calculation of MRR.

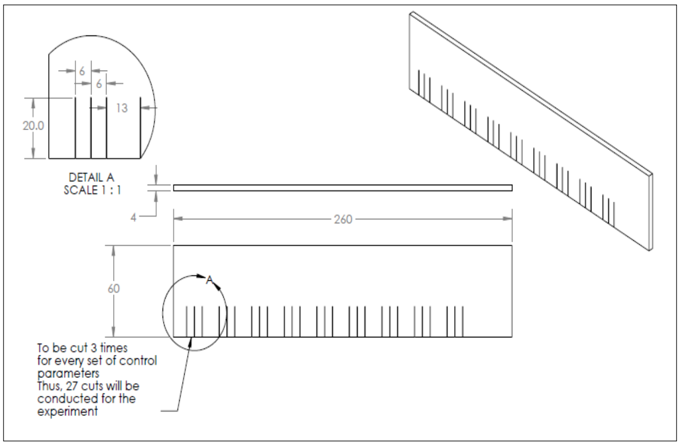

Fig. 1. Cutting method of workpiece

With the help of Minitab software version 16 to analyze the result, orthogonal arrays of Taguchi method was selected and analysis of variance (ANOVA) was employed to evaluate the data. Table 1 shows the selected parameters performed for this study with working levels. The range of experimental parameters value between low and high was decided according to capability of SODICK VZ500L wire-EDM machine. Four factors with three levels were performed in this experiment. In this paper, the pulse duration, pulse interval, servo voltage, and ignition pulse current were represented by A, B, C, and D respectively.

TABLE I. PARAMETERS SETTING FOR WIRE-EDM

Parameters	**Units**	**Level**		
		Low (-1)	***Medium (0)***	***High (+1)***
Pulse duration[a]	μs	0.5	0.6	0.7
Pulse interval[b]	μs	10	15	20
Servo voltage[c]	V	30	40	50
Ignition pulse current[d]	A	8	16	24

a. *Pulse duration (A),*
b. *Pulse interval (B),*
c. *Servo voltage (C)*
d. *Ignition pulse current (D)*

The equation of Taguchi method is stated in Equation 1.

$$N = 3^k \qquad (1)$$

Where, N denotes as the number of preparation samples and k denotes as the number of factors, i.e., pulse duration, pulse interval, servo voltage, and ignition pulse current, being investigated in this experiment and 3 is the level of experiment, i.e., low (-1), medium (0) and high (+1). There were 9 operation runs and 3 repetitions on each operation run were performed for this experiment with total 27 operation runs. The ANOVA analysis was employed in order to indicate the percentage of contribution on each factor.

III. Results and Discussions

A. Experimental Result

Table 2 shows the experimental result of material removal rate (MRR), surface roughness (Ra) and kerf width (Kw) that was collected using orthogonal arrays of Taguchi method. The measurements of weight were taken by using weighing scale while the time of machining process was taken from the screen monitor of wire-EDM machine after each machining process. It is found that sample no. 2 shows the highest MRR with 0.042g/min while sample no. 3 shows less MRR with 0.031g/min. The MRR value was determined using Equation 2.

$$MRR = \frac{wa - wb}{tm}\ (g/min) \qquad (2)$$

Where; *wa* = material weight before machining, *wb* = material weight after machining and *tm* = machining time.

TABLE II. EXPERIMENTAL DATA OF MRR, RA AND KW

Run	**A**	**B**	**C**	**D**	**MRR (g/min)**	**Ra (μs)**	**Kw (mm)**
1	0.5	10	30	8	0.038	2.40	0.282
2	0.5	15	40	16	0.042	2.34	0.279
3	0.5	20	50	24	0.031	2.07	0.277
4	0.6	10	40	24	0.040	2.97	0.267
5	0.6	15	50	8	0.037	2.82	0.272
6	0.6	20	30	16	0.040	2.76	0.277
7	0.7	10	50	16	0.039	3.21	0.276
8	0.7	15	30	24	0.041	3.13	0.274
9	0.7	20	40	8	0.040	3.16	0.276

B. Analysis result of material removal rate (MRR)

Explanation of the result analysis is described by the graph and percentage of contribution value. It is determined that each of selected parameter influenced all the responses based on the percentage of contribution value. S/N ratio for MRR after analyzed using Minitab Software Version 16 is shown in Table 3. Further, Figure 2 shows the S/N response graph of MRR with initial setting the larger is better. From the graph which is plot from data from Table 3, it shows that the optimum parametric combinations are pulse duration 0.7μs at Level 3, pulse interval 15μs at Level 2, servo voltage 40V at Level 2, and ignition pulse current 16A at Level 2. It shows that servo voltage is dominant factor affecting MRR. Result after validation on combination optimization of these four parameters increases the MRR for 4.76%. Some researchers had agreed that servo voltage influenced MRR. When servo voltage increases, the spark discharges more energy to facilitate the action of melting and vaporization. Therefore, advancing the large impulsive force in the spark gap, in which increasing the MRR [11,12].

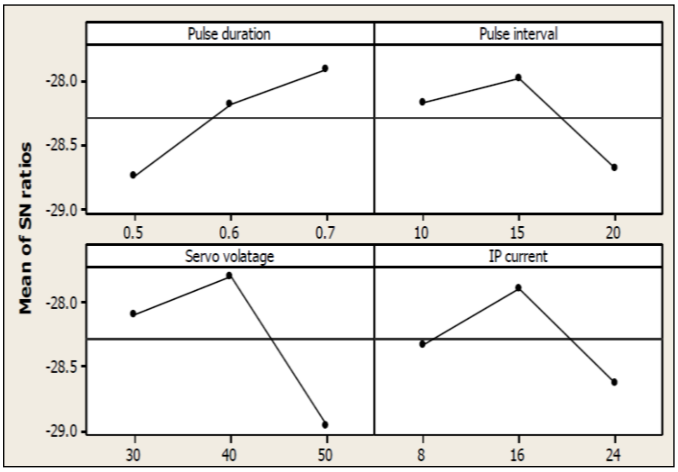

Fig. 2. Signal to noise graph for MRR

TABLE III. RESPONSE OF S/N RATIO FOR MRR

Level	A	B	C	D
1	-28.75	-28.18	-28.09	-28.33
2	-28.19	-27.98	-27.79	-27.9
3	-27.91	-28.69	-28.96	-28.63
Delta	0.84	0.71	1.17	0.73
Rank	2	4	1	3

In order to study the percentage significance of the parameters affected the quality characteristic of interest, i.e., MRR, ANOVA analysis was performed. The summary of the result percentage is indicated using R-Sq as shown in Table 4. Considering the value of percentage that shows the significant factors influenced MRR, it can be determined that servo voltage is the highest percentage with 45.04%. For all ANOVA analysis in this paper, the percentage of R-Sq value where the parameter shows the highest percentage, it means that the nearly value with 100% is the most significant factor

TABLE IV. ONE-WAY ANOVA FOR MRR

Level	A	B	C	D
Rank	2	4	1	3
R-Sq (%)	22.15	16.32	45.04	16.49

C. Analysis result of surface roughness (Ra)

The S/N response graph of RA is shown in Figure 3 with initial setting the smaller is better. It shows that the optimum parametric combinations are pulse duration 0.5µs at level 1, pulse interval 20µs at level 3, servo voltage 50V at level 3 and ignition pulse current 24A at level 3. From this result, it can be noted that the lowest value of RA can be achieved with pulse duration is setting at low level meanwhile pulse interval, servo voltage and ignition pulse current are setting at high level. Result after validation on combination of optimum parameters reduces the RA for 4.35%.

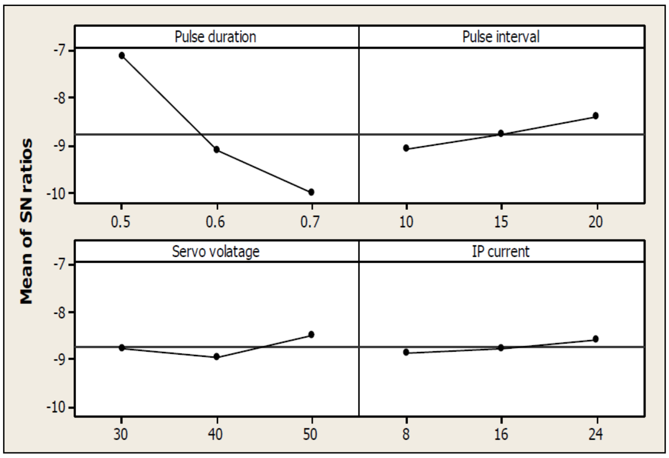

Fig. 3. Signal to noise graph for RA

Similar to table 4, the summary of the RA using ANOVA was identified is shown in Table 5. Considering the value of percentage that shows the significant factors influenced RA, it can be determined that the pulse duration is the highest percentage with 93.41% followed by pulse interval with 4.31%, servo voltage with 1.72% and ignition pulse current with 0.57%. Result of this experiment shows that when longer of pulse duration time touches on the workpiece, the good surface of workpiece can be found.

TABLE V. ONE-WAY ANOVA FOR RA

Level	A	B	C	D
Rank	1	2	3	4
R-Sq(%)	93.41	4.31	1.72	0.57

D. Analysis result of kerf width

The S/N response graph of kerf width is shown in Figure 4 with initial setting the nominal is the best. It shows that the optimum parametric combinations are pulse duration 0.7µs at level 3, pulse interval 20µs at level 3, servo voltage 50V at level 3 and ignition pulse current 24A at level 3. From this result, it can be noted that the appropriate value can be achieved with pulse duration, pulse interval, servo voltage and current are setting at high level. Result after validation on combination these parameters increases the kerf width for 0.036%.

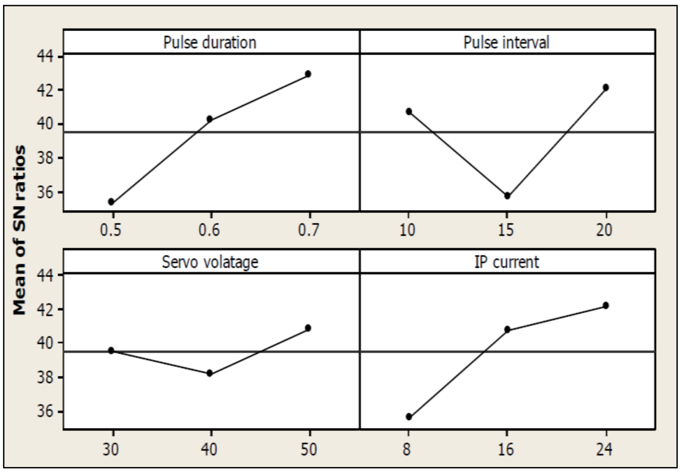

Fig. 4. Signal to noise graph for Kw

Similar to table 5, the summary of the Kw using ANOVA was identified is shown in Table 6. Considering the value of percentage that shows the significant factors influenced Kw, it can be determined that the pulse duration is the highest percentage with 37.09% followed by ignition pulse current with 30.53%, pulse interval with 28.03% and servo voltage with 4.35%. The cutting of Kw on the slot of workpiece needs more energy since the cutting must moving through solid area therefore it needs more combination parameters of pulse duration, pulse interval and ignition pulse current.

TABLE VI. ONE-WAY ANOVA FOR KW

Level	**A**	**B**	**C**	**D**
Rank	1	3	4	2
R-Sq(%)	37.09	28.03	4.35	30.53

IV. CONCLUSIONS

In this study, the performance of wire-EDM parameters on machining characteristic that were material removal rate, surface roughness and kerf width of titanium alloy was investigated. The servo voltage contributes the most significant factor for material removal rate, while pulse duration contributes the most significant factor for surface roughness and kerf width. It can be concluded that a storage spark with higher energy is produced when increasing current, subsequently more heat is generated and substantial quantity of heat utilized in material removal. Meanwhile, high quality surface can be achieved when low current with long pulse duration time are selected.

ACKNOWLEDGMENT

The authors wish to thank Universiti Teknikal Malaysia Melaka (UTeM) for technical and providing facilities for this experiment to be conducted sucessfully. The authors also gratefully acknowledge UTeM for supported under the research project FRGS/1/2014/TK01/UTEM/02/3.

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