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Investigating the effects of process parameters on MRR in WEDM using Molybdenum wire

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Abstract: The goal of this research work was to create guideline for Wire Electrical Discharge Machining (WEDM) of Titanium Alloy (Ti6 Al4V), using Molybdenum wire as a cutting tool. The Ti alloy possesses excellent bio compatibility to human beings, especially with tissues or bones. In general, the material of wire (electrode) is taken as brass/copper in WEDM. But in this work, Molybdenum wire is used. The main goal of this research work was to investigate the effect of various process parameters on material removal rate (MRR) while machining Ti6AL4V work piece on WEDM using Molybdenum wire. The important process parameters are pulse on time (Ton), pulse off time (Toff), peak current (IP), servo voltage (SV) and wire feed rate (WF). The optimum process parameters for maximum material removal rate (MRR) were to be determined experimentally using DOE, use of Taguchi method. The analysis of results (i.e. parametric contribution of each process parameter on MRR) was determined by ANOVA using SPSS software (Statistical Package for Social Sciences). The optimum process parameters were determined, from the graphs generated between S/N ratios to each design factors. At last, the specimen (work piece) was machined at optimum process parameters to find the improvement in MRR with acceptable surface finish (max. 3.5 μm).

Keywords: Wire electrical discharge machining (WEDM), material removal rate (MRR), ANNOVA, Taguchi method.

I. Introduction

Wire Electric Discharge Machining (WEDM) is extension of EDM. It was introduced in late 1960s', and has revolutionized the tool and die, mold, and metal-working industries. The WEDM uses a thin metallic wire to cut a programmed contour in a work-piece and capable of machining all electrically conductive materials. In Wire EDM the spark always takes place in the dielectric of de-ionized water. The electrolyte acts as a coolant and flushes away the eroded metal particles. With WEDM technology, complicated difficult-to-machine shapes can be easily cut. The high degree of accuracy and the fine surface finish make WEDM valuable. It is the key process for surface modification in extrusion die and blanking punches, manufacturing industries, where material is removed by controlled erosion through a series of electric sparks. Now days, WEDM is an important machine tool to produce complex and intricate shapes of components in areas such as tool and die making industries, automobile, aerospace, nuclear, computer, and electronics industries.

II. Basic Principle of Wire EDM Process

Electrical discharge wire cutting, more commonly known as wire-EDM (WEDM), is a spark erosion process used to produce complex two-and three-dimensional shapes through electrically conductive work-pieces by using a thin wire electrode. The material is removed by means of a series of recurring electrical sparks irrespective of mechanical properties such as hardness, strength, and toughness. There is never any mechanical contact between the electrode and work-piece.

Table 1: Comparison between Brass and Molybdenum Wire

Sr. No	Molybdenum Wire	Brass Wire
1.	High Tensile Strength (950 Mpa)	Low Tensile Strength (310 Mpa)
2.	High Melting Point (2623°C)	Low Melting Point (900°C)
3.	Low Coefficient of Thermal Expansion (5×10^{-6} m/mk)	High Coefficient of Thermal Expansion (18×10^{-6} m/mk)
4.	High Brinell Hardness (1500 Mpa)	Low Brinell Hardness No (60)
5.	Minimum dia. of Wire is 0.1 mm	Minimum dia. Of wire is 0.25 mm
6.	Suitable for High speed machining	Suitable for Low speed machining
7.	Suitable for semi-finish work	Suitable for highly finish work
8.	Acceptable Electrical Resistivity Coefficient ($5.2 \times 10^{-8} \Omega \text{ m}$)	Electrical Resistivity Coefficient ($5.9 \times 10^{-8} \Omega \text{ m}$)
9.	Thermal Conductivity ($138 \text{ Wm}^{-1}\text{K}^{-1}$)	Thermal Conductivity ($115 \text{ Wm}^{-1}\text{K}^{-1}$)
10.	Used for multi-passes, very high life	Used only for single pass, less life

III. Literature Review

Several researchers have made many attempts to improve the performance characteristics of WEDM like surface roughness, cutting speed, dimensional accuracy and material removal rate. WEDM is an essential operation for generating very complicated shapes with high level of accuracy in several manufacturing processes. The right selection of wire is a very important task for optimum output. But the full potential utilization of this process is not completely solved because of its complex and stochastic nature and more number of variables involved in this operation. Spedding and Wang [1] Developed mathematical models to predict material removal rate and surface finish while machining D-2 tool steel at different machining conditions. It was found that there is no single combination of levels of the different factors that can be optimal under all circumstances. Y.F.Luo *et. al.* [3] investigated that wire rupture in Wire Electrical Discharge Machining (WEDM) process was a serious problem. A solution in the form of a new computer-added pulse discrimination system was developed on the basis of voltage waveform characteristic. Also, proposed an index to monitor wire rupture and its relation with machining parameters and metal removal rate (MRR). Kozak *et al* [7] presented a study of wire electric discharge machining (WEDM) of low conductive materials and found that total electrical resistance between work-piece and tool (wire electrode) vary during machining, depending upon the clamping position. This change in resistance caused a change in material removal rate (MRR) and average surface roughness that lead to the poor quality of products. Ramasawmy *et.al* [11] described the multi objective optimization of the WEDM process using parametric design of Taguchi methodology. It was identified that the pulse on time and ignition current intensity has influence more than the other parameters. Mahapatra and Patnaik [13] developed relationships between various process parameters and responses like MRR, SR and kerf by means of non-linear regression analysis and then employed genetic algorithm to optimize the WEDM process with multiple objectives. H.Singh and R.Garg [16] investigated the effects of various process parameters of WEDM to reveal their impact on MRR of hot die steel (H-11), using one variable at a time approach. Ravindranadh B. *et al* [19] presented the influence of machining parameters on surface roughness and material removal rate of high strength armour steel using wire cut electrical discharge machining (WEDM). Results show that pulse-on time, pulse-off time, spark voltage were found significant variables to material removal rate (MRR) and surface roughness (SR) of the material. After a comprehensive study of the existing literature, it was concluded that the effect of process parameters on Titanium alloy has not been fully explored on WEDM with Molybdenum wire as an electrode.

IV. Design of Experiments

Design of Experiments (DOE) is a powerful statistical technique, to study the effect of multiple variables simultaneously. It is used to find out the relationship between the different factors affecting a process and output of that process. After analysis, the results of these experiments are helpful to identify the optimal conditions, most dominating factors, least dominating factors and the possibility of interactions and synergies between factors. The experimental methods proposed by Taguchi involves orthogonal arrays to organize the process parameters and their levels to determine the factors most affecting the product quality with minimum numbers of experiments, thus saving of time and resources

(A) Selection of Orthogonal Array

In present experimental work, seven process parameters with two levels and three levels ($2^1 \times 3^7$) have been decided. It was desirable to have three minimum levels of process parameters to reflect the true behavior of output parameters of study. Taguchi recommends orthogonal array (OA) for lying out of experiments. To design an experiment is to select the most suitable OA and to assign the parameters and interactions of interest to the appropriate columns. The use of linear graphs and triangular tables suggested by Taguchi makes the assignment of parameters simple.

Table 2: Range and Level of Machining Parameters

Machining parameters	Levels		
	1	2	3
	Low	Medium	High
Coolant Pressure (bar) 'A'	1	---	4
Pulse On Time, (μ s) 'B'	110	115	120
Pulse Off Time, (μ s) 'C'	50	55	60
Peak Current, (IP) (amp) 'D'	2	4	6
Servo Voltage, (SV) (v) 'F'	60	80	100
Wire Feed, (WF) (m/min) 'F'	10	15	20
Wire Tension (WT) (gm) 'G'	1200	1300	1400

(B) Material of Work Piece

The material of the component (work-piece) was Titanium alloy (Ti6Al4V). It has excellent bio compatibility, especially when direct contact with human tissue or bone. The density of Ti6Al4V was taken $4.3 \text{ cm}^3/\text{gm}$. The

chemical composition of the work-piece material is given in Table 3. The six specimens were prepared for experimental purpose. The size of each specimen was 50 mm×50 mm×4 mm.

Table 3: Chemical Composition of Ti Alloy

	Al	V	C	N	O	H	Fe	Y	Others	Ti
Min.	5.5	3.5	--	--	--	--	--	--	--	
Max.	6.76	4.4	0.08	0.5	0.2	0.0125	0.3	0.005	0.1	Balance

(C) Material of Electrode (Wire)

The Eco-Wire EDM machine was loaded with Molybdenum wire, 0.18 dia., supplied by M/s Wangpin Machine Tool Accessories Co., Ltd, situated at Hongkong, (Head Office), China. The chemical composition of Molybdenum wire is given in Table 4.

Table 4: Chemical Composition of Molybdenum Wire

Mo	C	N	O	Fe	Ni	Si
≥99.35	<0.006	<0.002	<0.003	<0.003	<0.002	<0.002
Remarks: 0.2% – 0.6% of doped element in Mo which is not treated as impurity content						

V. Experimentation

From the selected L18 array, nine experiments were to be conducted at minimum coolant pressure and rest nine experiments for maximum coolant pressure. The value of each experiment is the average of three experiments conducted at each setting. All the experiments were conducted for each combination of design factors as per selected L18 orthogonal array accordingly.

(A) Metal Removal Rate Calculation

The recorded values of the loss of mass and machining time of work piece for all the eighteen experiments were used for calculation for metal removal rate (MRR), see Table 5. The relation for calculation of MRR is as below:

$$\text{Loss of Mass (g)} = \text{Mass [before experiment]} - \text{Mass [after experiment]} \quad (1)$$

$$\text{Volumetric Material Loss (cm}^3\text{)} = \text{Loss of mass (g)} / \text{Density of Material (g/cm}^3\text{)} \quad (2)$$

$$\text{Material Removal Rate (mm}^3\text{/min)} = \text{Volumetric material loss (mm}^3\text{)}/\text{Machining Time (min.)} \quad (3)$$

(B) Calculation of S/N Ratio

The experimental observations were further transformed into a signal-to-noise (S/N) ratio. Taguchi method was used to analyze the result of response of machining parameters for “Higher is Better” criteria. The Signal to Noise ratio is the ratio of signal to noise where signal represents the desirable value and noise represents the undesirable value. The S/N Ratio is statistic and denoted by η with a unit of db. The higher observed value shows the better machining performance in case of MRR, it is referred to Quality Engineering. It is termed as “Higher is the Better” (HB). The S/N ratio for all eighteen experiments was calculated as shown in Table 5.

Table 5: Material Removal Rate and S/N Ratio Calculation

Experiment No	Mass Before Machining	Mass After Machining	Loss of Mass	Machining Time (Min.)	Volumetric Material Loss (cm ³)	MRR (mm ³ /Min)	S/N Ratio db
1.	42.610	41.51	1.10	22.33	0.2483	12.21	21.73
2.	41.10	40.450	1.06	18.70	0.2392	12.79	22.14
3.	40.450	39.370	1.08	17.42	0.2437	13.99	22.92
4.	42.100	41.050	1.05	12.57	0.2372	18.86	25.51
5.	41.050	39.855	1.19	12.63	0.2697	21.36	26.59
6.	39.855	38.775	1.08	13.73	0.2437	17.76	24.99
7.	42.820	41.700	1.12	12.28	0.2528	20.59	26.27
8.	41.700	40.640	1.06	12.47	0.2392	19.19	25.70
9.	40.640	39.490	1.15	14.93	0.2595	17.39	24.80
10.	42.720	41.630	1.09	15.63	0.2460	15.74	23.94
11.	41.630	40.510	1.12	18.68	0.2528	13.53	22.57
12.	40.510	39.330	1.18	21.77	0.2663	12.24	21.99
13.	41.850	40.650	1.20	21.37	0.2708	12.67	21.89
14.	40.650	39.290	1.36	12.20	0.3069	25.16	28.08
15.	39.290	38.170	1.12	12.78	0.2528	19.78	26.24
16.	42.520	41.340	1.18	17.38	0.2663	15.32	23.71
17.	41.340	40.020	1.32	12.38	0.2979	24.07	27.34
18.	40.020	38.600	1.42	11.92	0.3205	26.89	28.68

VI. Results and Discussion

All experiments were conducted to study the effect of process parameters over the output response characteristic with the process (design) parameters and interactions assigned to columns. The experimental results for MRR are given in Table 5. All eighteen experiments were conducted using Taguchi Method to investigate the effect of process parameters on the output parameter MRR. In present study all the designs, plots and analysis have been carried out using Statistical Package for Social Sciences (SPSS) software. Finally, according to Taguchi Method, the significant parameters (factors) were found by using Analysis of Variance (ANOVA) Technique, which represents the relationship between machining parameters and the process performance.

(A) Effect of Various Parameters on MRR

The significance weightage of each design factors was seen from the ANOVA and F-Test. But to know how much each factor was affecting the S/N Ratio, the interactive graphs were plotted for each factors and the optimum value of each factor was found out as shown in window by choosing appropriate menu options in SPSS software.

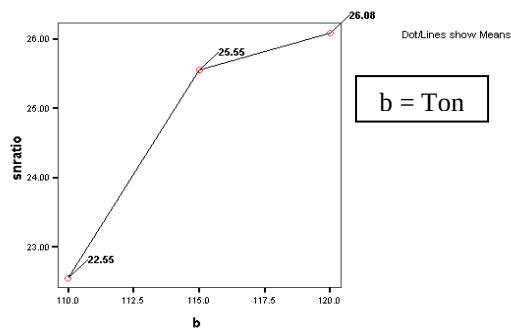


Fig. 1: Effect of 'Ton' on MRR

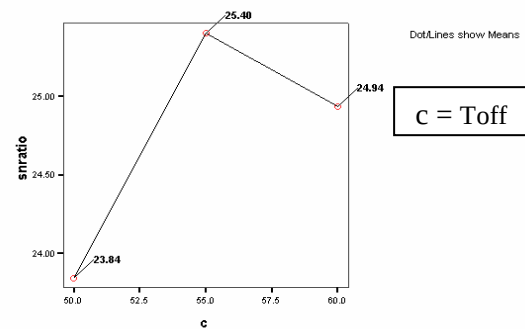


Fig. 2: Effect of 'Toff' on MRR

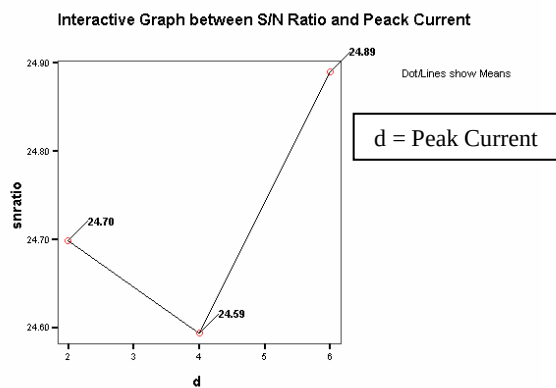


Fig. 3: Effect of 'Peak Current' on MRR

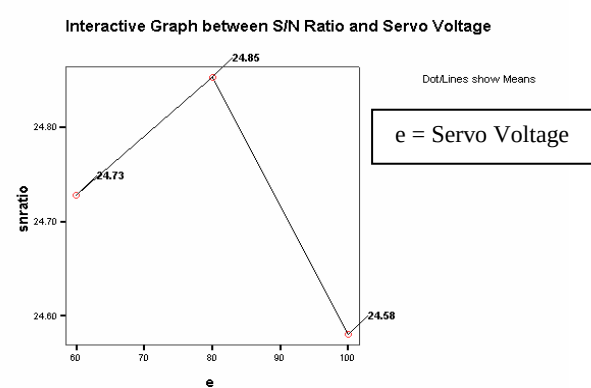


Fig. 4: Effect of 'Servo Voltage' on MRR

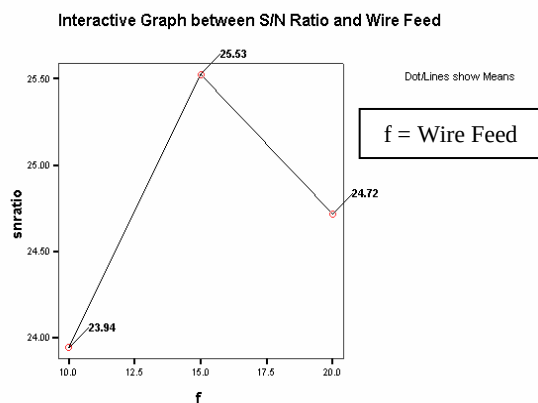


Fig. 5: Effect of 'Wire Feed' on MRR

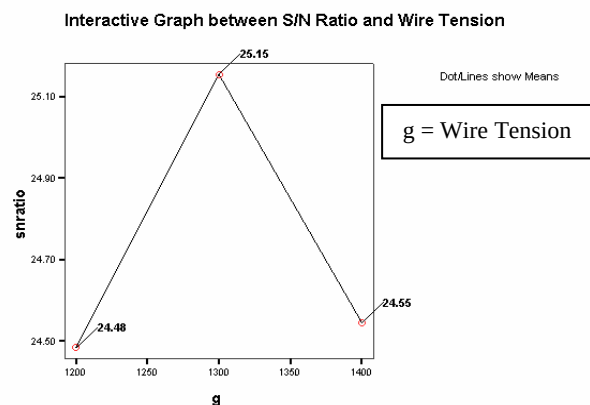


Fig. 6: Effect of 'Wire Tension' on MRR

(B) Analysis of Results

The results found from S/N response graphs generated by SPSS software for all design factors, it was concluded that the selected seven design factors at Level A3, B3, C2, D3, E2, F2, and G2 were found the suitable set of parameters for the maximum MRR. It was observed that the optimal process parameters for highest MRR are quite different.

VII. Conclusion

On the basis of the experimental results, the calculated S/N ratio (db), the analysis of ANOVA using SPSS software, F test values and confirmation test, the following conclusions are drawn for the effective machining of Ti alloy work-piece on Eco Wire CNC EDM machine, using Molybdenum wire:

Pulse on time (Ton) is the most significant influencing machining parameter having direct effect on metal removal rate (MRR) in the machining of Ti alloy and maximum MRR was obtained at Ton 120 μ sec. Pulse off Time (Toff) is the second most significant influencing machining parameter and optimal value of Toff was found at 55 μ sec for maximum MRR.

It was also concluded that for rough and high-speed cutting (for higher MRR), the optimal wire feed rate of Molybdenum wire was 15 m/min for Ti alloy work-piece. And the optimal wire tension was found 1300 gms. It was concluded that for rough and high-speed machining, the optimal value of servo voltage is 80 volts.

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