International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2015): 6.391

Optimization of Micro WEDM Process Parameters for Machining on TI-6AL-4V Alloy

Jagdish Singh[1], Karamjit Bhambri[2]

[1]Research Scholar, SUS College of Engineering and Technology, Tangori, Distt.- Mohali, India

[2]Assistant Professor, SUS College of Engineering and Technology, Tangori, Distt.- Mohali, India

Abstract: ***This works presents the experimental investigation to determine the optimum parametric setting for the effective and efficient machining of Ti-6Al-4V alloy by using of Wire EDM process. The Taguchi method, a statistical method for experimental design, has been used to optimize the WEDM process parameters. An L_{25} orthogonal array was used to determine the S/N ratio, based on Taguchi quality design Concept, so as to indicate the significant machining parameters affecting the machining performance i.e. Material removal rate, and Surface roughness. The machining results were obtained by variation of Duty cycle at five different levels (30,40,50,60 and 70%), wire tension at five different levels (3,6,9,12 and 15kg-f) , peak current at five different levels (50,75,100,125 and 150A), and wire feed at five different levels (5,6,7,8 and 9mm/min.). It is noted that the maximum mean of material removal rate (MRR) is 59.06mm³/min and the minimum mean of surface roughness (SR) is 1.234 Ra. The optimum combination parameters for higher MRR are Duty cycle 70%, wire tension 3 kg-f , peak current 125 A, and wire feed rate 5 mm/min. The optimum combination parameters for lower surface roughness are Duty cycle 30%, wire tension 6 kg-f , peak current 125 A, and wire feed rate 8 mm/min.***

Keywords: MRR, SR, Ti-6Al-4V (Titanium alloy), Taguchi method, WEDM

1. Introduction

WEDM becomes an important non-traditional machining process due to its competency in machining of work pieces with complex geometry and hard stiffness. The material is removed by a series of discrete electrical discharges between the wire electrode and the work piece in this process. The discharges, which are highly focused by the dielectric medium, causes rise in the local temperatures of the work piece near the point of introduction. The temperatures are high enough to melt and vaporize the material in the immediate vicinity of the electrical discharges. Since, there is no mechanical contact between the work piece and the electrode, material of any hardness can be machined as long as it is electrically conductive. Ti-6Al-4V is α+β type titanium alloy which has aluminum as the alpha stabilizer and vanadium as the beta stabilizer. Ti-6Al-4V have compact hexagonal crystal structure (alpha phase) and body-centered cubic (beta) present in its microstructure at room temperature, combining strength, corrosion resistance, excellent mechanical properties for biomaterials. Fig. 1 shows details of Schematic representation of the working of WEDM process.

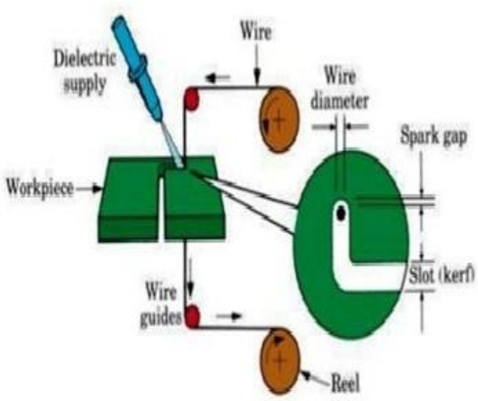

Figure 1: Schematic representation of WEDM

N. Tosun et al.[1] investigated the effect of the cutting parameters on size of erosion craters on wire electrode in WEDM using Brass wire as tool and AISI 4140 steel as workpiece and found that the increasing the pulse duration, open circuit voltage, and wire speed increases the crater size, whereas increasing the dielectric flushing pressure decreases the crater size. S. S. Mahapatra et al.[2] established the relationship between control factors and responses like MRR, SF and kerf are established by means of nonlinear regression analysis, resulting in a valid mathematical model and a genetic algorithm is employed to optimize the wire electrical discharge machining process with multiple objectives. Concluded that the WEDM process parameters can be adjusted to achieve better metal removal rate, surface finish and cutting width simultaneously. K. Kanlayasiri et al.[3] investigated the effects of machining parameters such as pulse-on time, pulse-off time, pulse-peak current and wire tension on surface roughness of DC53 die steel on wire EDM. Analysis of variance (ANOVA) technique and other quantitative testing methods was used to find out the parameters affecting the surface roughness and observed that the surface roughness of test specimen increases as pulse-on time and pulse-peak current are increased for DC53 die steel while machining on wire-EDM. A. Okada et al.[4] developed a new method for evaluation of distribution of spark location by using a high-speed video camera. The spark locations were analyzed using the recorded images, and investigated the effects of servo voltage, pulse interval time and wire running speed on the distribution of spark location. Experimentation concluded that spark distribution becomes uniform when servo voltage is high, pulse interval time is long, and wire running speed is low. A.Kumar et al.[5] studied and found that the pulse on time parameter has direct effect on MRR during machining of pure titanium. In addition to this when pulse off time is increased the MRR decreases. Balasubramanian et al.[6] studied the optimum process parameters to obtain lower SR using Grey rational analysis in machining of Inconel 718 by WEDM. The experimental result s confirms that the method used i.e. Grey relational analysis effectively improves the performance measures of WEDM process. Kuriachen Basil et al.[7] investigated the effect of voltage, dielectric pressure, pulse on-time and pulse off-time on spark gap of Ti-6AL-4V alloy and found that pulse on time and pulse off time have the more impact on the spark gap. The minimum spark gap was obtained as 0.040407mm. The developed model agrees with the conformation results by less than 6%. T. Lokeswara Rao et al.[8] studied optimum cutting parameters for Titanium alloy Grade5 using Wire-cut Electrical Machining Process (WEDM) for improving the machining efficiency. Taguchi method was used under different conditions like pulse on, pulse off, peak current, wire tension, servo voltage and servo feed settings and developed a regression equation for the MRR and SR. The optimum parameters were obtained by using Taguchi method. Manohar Pala et al.[9] studied the machining of EDM (die-sinking type) on varying discharge current, pulse on time and diameter of the electrode. Ti-6Al-4V material is machined using W-Cu electrode. The experiment is conducted with negative electrode potential and according to the L18 Orthogonal Array from Taguchi method and studied the effects of process parameters on EDM performance characteristics namely, Metal Removal Rate (MRR) and Tool Wear Rate (TWR). P. Sivaprakasam et al.[10] investigated the influence of three different input parameters such as voltage, capacitance and feed rate of micro-wire electrical discharge machining (micro-WEDM) performances of material removal rate (MRR), Kerf width (KW) and surface roughness (SR) on titanium alloy (Ti–6Al–4V) using response surface methodology (RSM) with central composite design (CCD) and Analysis of variance (ANOVA) was used to find out the significant influence of each factor. Found the significant machining results of material removal rate, Kerf width and surface roughness. G. Rajyalakshmi et al.[11] investigated the effect of process parameters such pulse on time (T_{ON}), pulse off time (T_{OFF}), peak current (I_P), wire feed (WF) on material removal rate (MRR) and surface roughness in WEDM operation and developed models to be used by the machinists to predict the MRR and SR over a wide range of input parameters and optimized multiple responses by particle swarm optimization technique. Petr Harcuba et al.[12] investigated the properties of Ti–6Al–4V alloy after surface treatment by the electric discharge machining (EDM) process. The EDM process with high peak currents proved to induce surface macro-roughness and to cause chemical changes to the surface. The chemical changes were studied by scanning electron microscopy equipped with an energy dispersive X-ray analyzer (EDX). An investigation of the biocompatibility of the surface-treated Ti–6Al–4V samples in cultures of human osteoblast revealed that the samples modified by EDM provided better substrates for the adhesion, growth and viability of MG 63 cells than the TiO2 coated surface. EDM treatment can be considered as a promising surface modification to orthopedic implants.

2. Selection of Material

Titanium alloys are used extensively in aerospace, such as jet engine and airframe components, because of their excellent combination high specific strength (strength to weight ratio) and their exceptional resistance to corrosion at elevated temperature. Titanium alloys are used in different medical applications including surgical implants, such as hip balls and sockets (joint replacement) that can stay in place for up to 20-30 years use in orthodontic wires, dental implants that can remain in place for over 30 years In the present work Ti-6Al-4V alloy is used as work piece material, zinc coated brass wire ϕ 0.25mm is used as electrode material and Distilled water is used as Dielectric medium. The chemical composition of the material is shown in Table 1.

Table 1: Chemical composition of Ti-6Al-4V alloy

Element	*Al*	*Fe*	*V*	*C*	*Ti*
%	5.75	0.28	3.9	0.08	Remaining

3. Experimental Design

It was essential to select proper machining parameters for effective machining of Ti-6Al-4V alloy. The criterion for experimental design and analysis is to achieve higher VMRR along with reduction in Surface Roughness i.e. Optimization of the process. The experiments were planned according to Taguchi's L25 orthogonal array [13] for four controllable parameters is used to construct the matrix of five levels of controllable factors. The L25 orthogonal array contains 25 experimental runs at various combinations of four input variables. In the present study Table-2 represents various levels of process parameters and Table-3 represents experimental plan with assigned values.

Table 2: Process Parameters and Their Levels to be used in WEDM

Coded Factor	*Input Parameters*	*Levels*				
		1	*2*	*3*	*4*	*5*
A	Duty Cycle (DC) %	30	40	50	60	70
B	Wire Tension Kg-f	3	6	9	12	15
C	Peak Current (IP) A	50	75	100	125	150
D	Wire Feed Rate mm/min	5	6	7	8	9

Table 3: Experimental plan with assigned values

RUN	*A*	*B*	*C*	*D*
1	30	3	50	5
2	30	6	75	6
3	30	9	100	7
4	30	12	125	8
5	30	15	150	9
6	40	3	75	7
7	40	6	100	8
8	40	9	125	9
9	40	12	150	5
10	40	15	50	6
11	50	3	100	9
12	50	6	125	5
13	50	9	150	6
14	50	12	50	7
15	50	15	75	8
16	60	3	125	6
17	60	6	150	7
18	60	9	50	8
19	60	12	75	9
20	60	15	100	5
21	70	3	150	8
22	70	6	50	9
23	70	9	75	5
24	70	12	100	6
25	70	15	125	7

4. Experimental Work

The experiments were conducted using the CNC Wire Electrical Discharge Machine model Electronica (ELPLUS 40A DLX) is as shown in Figure-2. The experiments were conducted by varying WEDM machining parameters like Duty cycle, wire tension, peak current and wire feed, while the other parameters like Composition of material, Workpiece thickness, Wire electrode material, Dielectric medium and Servo Voltage are kept constant. Surface Roughness (Ra) is measured by ITI- surface roughness tester equipment. The VMRR for each WEDM operation was calculated using Eq. (1).

$$\text{VMRR (mm3/min)} = \text{Volume of the material removed / cutting time} \quad (1)$$

Figure2: CNC WIRE EDM Setup for machining

5. Results and Discussions

The metal removal rate, and Surface roughness has been measured for each experiment to study the effects of duty cycle, peak current, wire tension and Wire feed rate on performance during machining.

Table 4: Experimental results of VMRR and SR

RUN	*A*	*B*	*C*	*D*	*Volume (5x5x6) = 150 mm^3*	*Machining Time (min)*	*MRR (mm^3/min)*	*SR (μm)*
1	30	3	50	5	150	8.13	18.45	1.726
2	30	6	75	6	150	11.15	13.45	1.493
3	30	9	100	7	150	18.14	8.27	1.541
4	30	12	125	8	150	32.13	4.67	1.245
5	30	15	150	9	150	49.15	3.05	1.643
6	40	3	75	7	150	14.36	10.45	2.371
7	40	6	100	8	150	31.19	4.81	1.429
8	40	9	125	9	150	5.49	27.32	1.866
9	40	12	150	5	150	7.34	20.44	1.912
10	40	15	50	6	150	23.08	6.5	1.596
11	50	3	100	9	150	4.21	35.63	2.368
12	50	6	125	5	150	5.28	28.41	2.04
13	50	9	150	6	150	7.49	20.03	2.368
14	50	12	50	7	150	37.36	4.01	3.142
15	50	15	75	8	150	5.21	28.79	2.194
16	60	3	125	6	150	7.52	19.95	2.986
17	60	6	150	7	150	4.26	35.21	2.326
18	60	9	50	8	150	8.42	17.81	2.245
19	60	12	75	9	150	7.15	20.98	2.516
20	60	15	100	5	150	9.53	15.74	2.97
21	70	3	150	8	150	2.54	59.06	2.627
22	70	6	50	9	150	16.27	9.22	1.804
23	70	9	75	5	150	17.3	8.67	1.98
24	70	12	100	6	150	5.16	29.07	2.117
25	70	15	125	7	150	3.39	44.25	2.278

The effect of machining parameters i.e. Duty cycle, peak current, wire tension and wire feed rate on MRR is evaluated using ANOVA. After analyzing the experimental data from the test, Minitab software was used for finding the optimum value from the parameters being taken in this experimentation. Also later Signal to Noise ratio (S/N ratio) is evaluated using the Minitab software and effect of parameters like Duty cycle, peak current, wire tension and wire feed rate on MRR is represented by plots

Table 5: Response Table of Signal to Noise Ratios for MRR (Larger is better)

Level	*A*	*B*	*C*	*D*
1	17.86	27.63	19.59	24.66
2	21.04	23.10	23.47	24.03
3	25.48	23.38	23.25	22.93
4	26.46	21.47	26.02	23.33
5	27.13	22.40	25.66	23.04
Delta	9.27	6.16	6.43	1.73
Rank	1	3	2	4

Table 6: Response Table of means for MRR (Larger is better)

Level	*A*	*B*	*C*	*D*
1	9.578	28.708	11.198	18.342
2	13.904	18.220	16.468	17.800
3	23.374	16.420	18.704	20.438
4	21.938	15.834	24.920	23.028
5	30.054	19.666	27.558	19.240
Delta	20.476	12.874	16.360	5.228
Rank	1	3	2	4

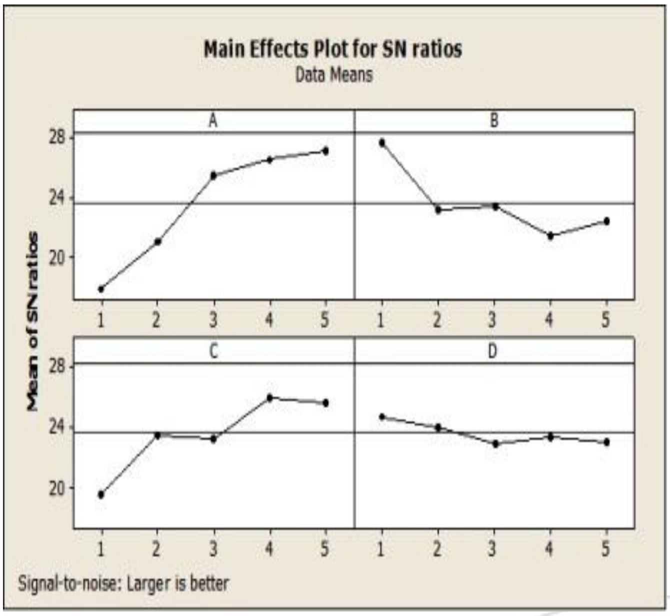

Figure 3: Response graphs of S/N ratios (MRR)

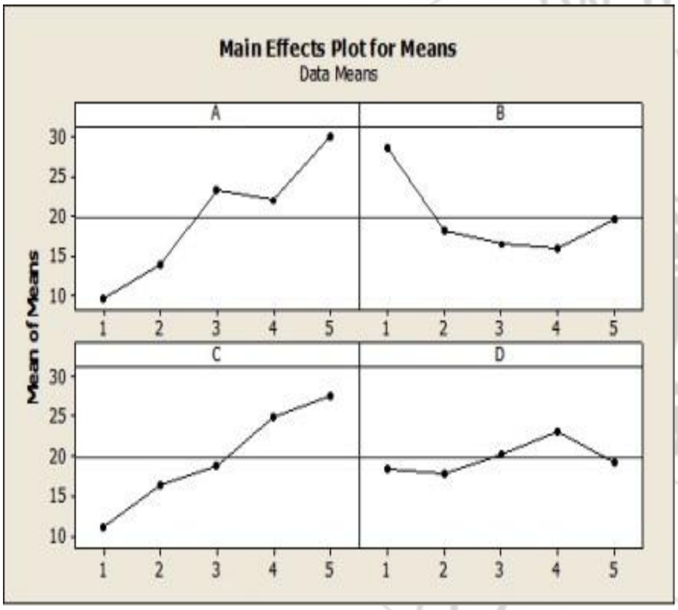

Figure 4: Response graphs of Means (MRR)

Material removal rate (MRR) increases with the increase of Duty cycle and peak current, decreases with the increase of wire tension while the wire feed rate has least effect on MRR Fig. 5 represents the relative interactions effects of different process parameters of WEDM at different levels on MRR.

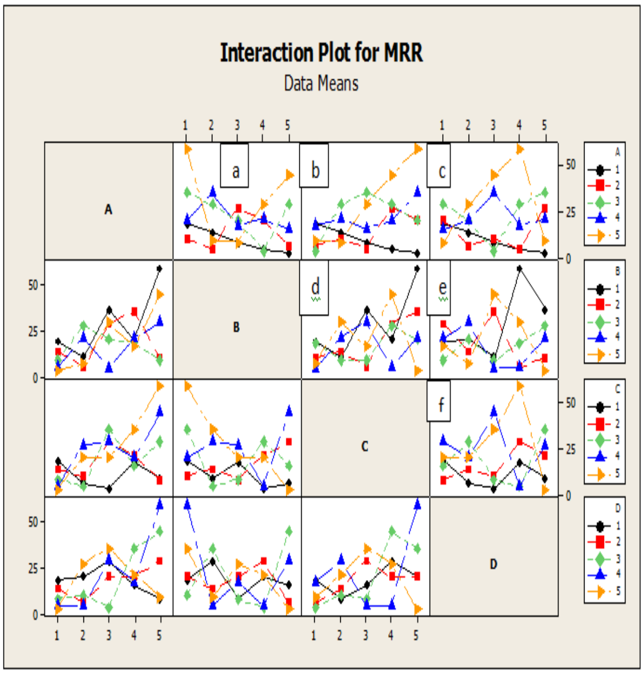

Figure 5: Interactions effect of process parameters of WEDM on MRR

As in case of MRR similarly the effect of machining parameters i.e. Duty cycle, peak current, wire tension and wire feed rate on SR is evaluated using ANOVA. After analysis of data Minitab software was used for finding the optimum value from the parameters being taken in this experimentation and Signal to Noise ratio (S/N ratio) is evaluated, hence the effect of parameters like Duty cycle, peak current, wire tension and wire feed rate on SR is represented by plots

Table 7: Response Table of Signal to Noise Ratios for SR (Smaller is better)

Level	*A*	*B*	*C*	*D*
1	-3.652	-7.567	-6.240	-6.442
2	-5.159	-5.100	-6.374	-6.270
3	-7.614	-5.959	-6.145	-7.173
4	-8.365	-6.446	-6.092	-5.468
5	-6.714	-6.432	-6.653	-6.151
Delta	4.713	2.467	0.561	1.705
Rank	1	2	4	3

Table 8: Response Table of means of Signal to Noise Ratios for SR (Smaller is better)

Level	*A*	*B*	*C*	*D*
1	1.530	2.416	2.103	2.126
2	1.835	1.819	2.111	2.112
3	2.423	2.000	2.085	2.332
4	2.609	2.187	2.083	1.948
5	2.161	2.136	2.175	2.040
Delta	1.079	0.597	0.092	0.384
Rank	1	2	4	3

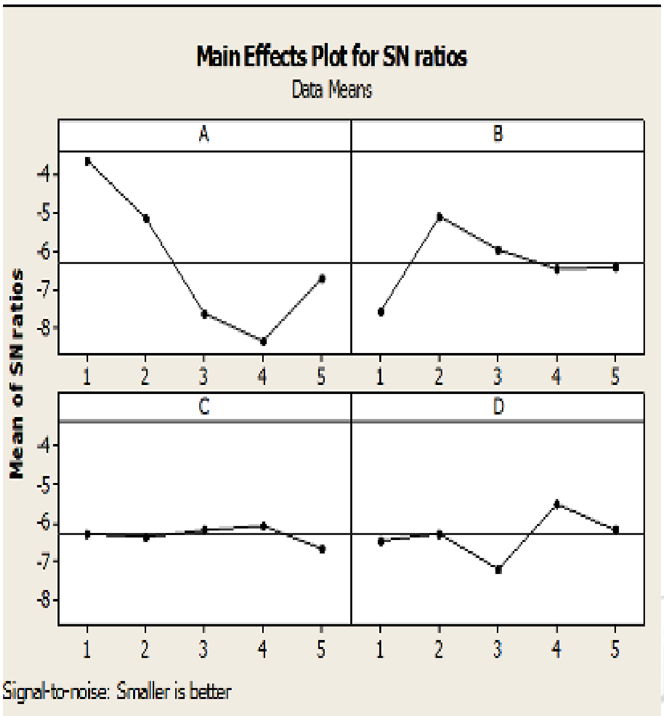

Figure 6: Response graphs of S/N ratios (SR)

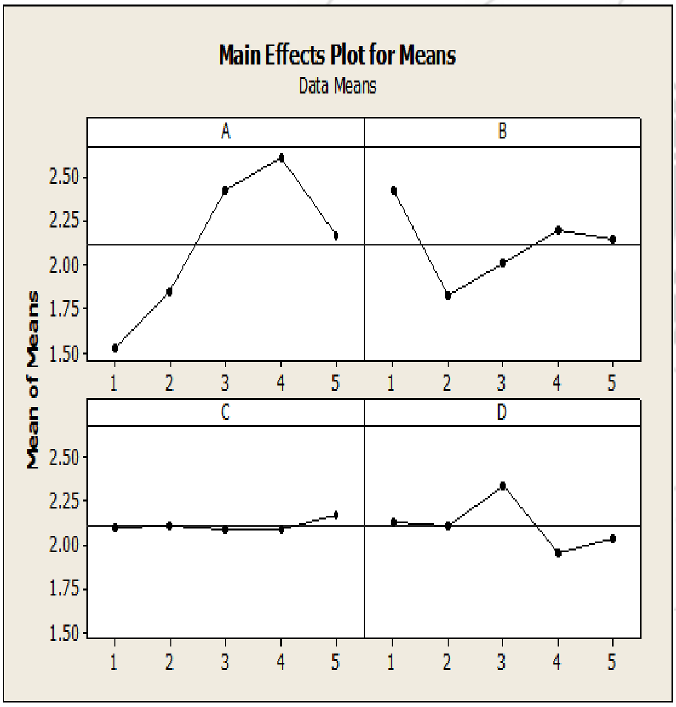

Figure 7: Response graphs of Means (SR)

Surface roughness (SR) increases upto level4 and then decreases with the increase of Duty cycle, Surface roughness decreases upto level 2 and then increases with the increase of Wire Tension. Surface Roughness slightly increases after level4 with increase in Peak Current, Surface Roughness decreases from level1 to level2 and than increases from level2 to level3 then again decreases from level3 to level4 and then increases with the increase in Wire feed rate. Fig. 8 represents the relative interactions effects of different process parameters of WEDM at different levels on SR.

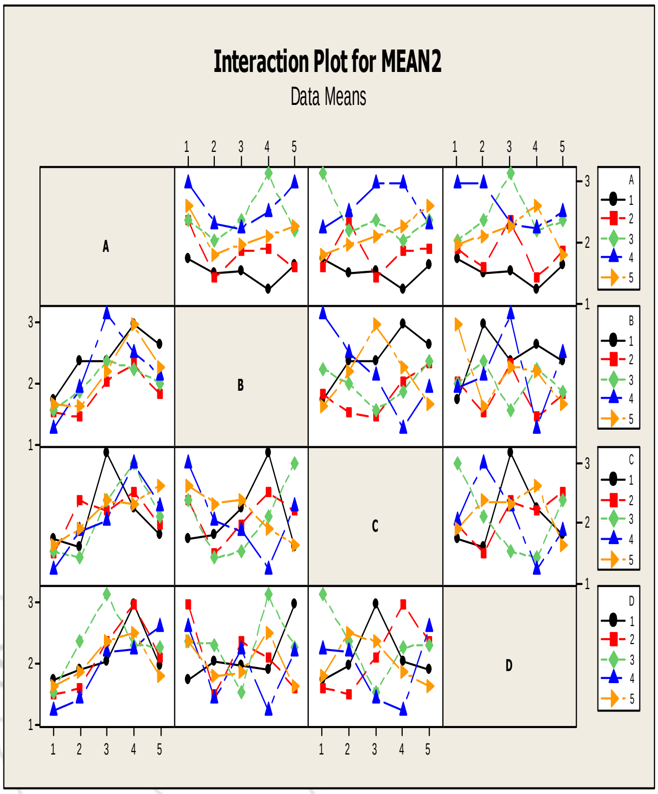

Figure 8: Interactions effect of process parameters of WEDM on Surface Roughness (SR).

6. Conclusion

1) The maximum mean of material removal rate (MRR) is 59.06 mm3/min which is at Duty cycle 70%, wire tension 3 kg-f , peak current 150 A, and wire feed rate 8 mm/min.
2) The optimum combination parameters for machining of Ti-6Al-4V alloy using WEDM for higher MRR are Duty cycle 70%, wire tension 3 kg-f , peak current 125 A, and wire feed rate 5 mm/min.
3) The minimum mean of surface roughness (SR) is 1.245 Ra which is at Duty cycle 30%, wire tension 12 kg-f , peak current 125 A, and wire feed rate 8 mm/min.
4) The optimum combination parameters for machining of Ti-6Al-4V alloy using WEDM for lower surface roughness are Duty cycle 30%, wire tension 6 kg-f , peak current 125 A, and wire feed rate 8 mm/min.

References

[1] N. Tosun, C. Cogun, H.Pihtili, (2003), "The effect of cutting parameters on Wire crater sizes in Wire EDM", International journal of Manufacturing Technology (21) pp. 857–865.

[2] S.S.Mahapatra, Amar Patnaik, (2006), "Optimization of wire electrical discharge machining (WEDM) process parameters using Taguchi method", International journal of Manufacturing Technology, pp. 911–925.

[3] K. Kanlayasiri , S. Boonmung (2007), "An investigation on effects of wire-EDM machining parameters on surface roughness of newly developed DC53 die steel", Journal of Materials Processing Technology 187–188 ,26–29.

[4] A. Okada ,Y. Uno , M. Nakazawa , T. Yamauchi (2010), “Evaluations of spark distribution and wire vibration in wire EDM by high-speed observation”, CIRP Annals - Manufacturing Technology ,59- 231–234.

[5] A. Kumar, V. Kumar, P. Kumar, (2011), “Effect of machining parameters on MRR during CNC WEDM of Pure Titanium”, Proceedings of the Fifth International Conference on Advances in Mechanical Engineering, pp. 541–545.

[6] S.Balasubramanian, S.Ganapathy, (2011), “Grey Relational Analysis to determine optimum process parameters for wire electrical discharge machining (WEDM)”, IJEST, Vol. 3 No.1 Jan ISSN: 0975–5462.

[7] Kuriachen Basil, Dr. Josephkunju Paul, Dr. Jeoju M.Issac ,(2013), “Spark Gap Optimization of WEDM Process on Ti-6Al-4V”, International Journal of Engineering Science and Innovative Technology (IJESIT), Volume-2, Issue-1, ISSN: 2319-5967.

[8] T. Lokeswara Rao, N. Selvaraj, (2013), “Optimization of WEDM Process Parameters on Titanium Alloy Using Taguchi Method”, International Journal of Modern Engineering Research (IJMER), Vol. 3, pp-2281-2286, ISSN: 2249-6645.

[9] Manohar Pala, K.Viswanatha Sarma, D.Sakthivel,(2015),“Experimental Investigation of Machining of Ti-6Al-4V through EDM using Copper Tungsten Electrode and Modeling of Machining Parameters using Artificial Neural Network”, (IJAERS). ISSN: 2349-6495.

[10] P. Sivaprakasam , P. Hariharan , S. Gowri , (2014), “Modeling and analysis of micro-WEDM process of titanium alloy (Ti–6Al–4V) using response surface approach”, Engineering Science and Technology, an International Journal, Volume 17, Issue 4, Pages 227–235.

[11] G. Rajyalakshmi, Koushik.Thatipally, Kalyan.Tammu,(2015),“ Parametric Optimization in WEDM using Particle SWARM Optimization Technique”, Proceedings of 34th IRF International Conference, Pune, India, ISBN: 978-93-85465-73-4.

[12] Petr Harcuba, Lucie Bačáková, Josef Stráský, Markéta Bačáková, Katarína Novotná, Miloš Janeček,(2012), “Surface treatment by electric discharge machining of Ti–6Al–4V alloy for potential application in orthopaedics”, Journal of the Mechanical Behavior of Biomedical Materials Volume 7, Pages 96–105.

[13] Peace SG (1993) , “Taguchi methods: a hands on approach”, Addison-Wesley, New York

Author Profile

Jagdish Singh received the B.Tech. Degree in Mechanical Engineering from Punjab Technical University in 2010 and started pursuing M.Tech. in Production Engineering from Punjab Technical University in 2011. He is now working as Assistant Professor in Mechanical Engineering Department at Doaba Institute of Engineering and Technology (DIET), Kharar Distt.- Mohali.