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Optimization of WEDM Process Parameters on Titanium Alloy Using Taguchi Method

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ABSTRACT : *This paper describes an optimum cutting parameters for Titanium Grade5 (Ti-6Al-4V) using Wire-cut Electrical Machining Process (WEDM). The response of Volume Material Removal Rate (MRR) and Surface Roughness (Ra) are considered for improving the machining efficiency. A brass wire of 0.25mm diameter was applied as tool electrode to cut the specimen. The Experimentation has been done by using Taguchi's L_{25} orthogonal array (OA) under different conditions like pulse on, pulse off, peak current, wire tension, servo voltage and servo feed settings. Regression equation is developed for the VMRR and Ra. The optimum parameters are obtained by using Taguchi method. This study shows that the stated problem is solved by minimum number of experiments when compared to full factorial design.*

KEYWORDS: *Optimization of Process parameters, Titanium alloy, Taguchi method, WEDM.*

I. INTRODUCTION

Wire cut EDM has been widely adopted as a machining tool for die materials which require high strength and hardness as well as good wear resistance, while the traditional manufacturing process needs a special tool or technique with a longer process time. In WEDM, a continuously moving conductive wire acts as an electrode and material is eroded from the work piece by series of discrete sparks between the work piece and wire electrode separated by a thin film of dielectric fluid. The dielectric is continuously fed to the spark zone to flush away the eroded material and it acts as a coolant. The schematic representation of the WEDM is as shown in Figure-1.

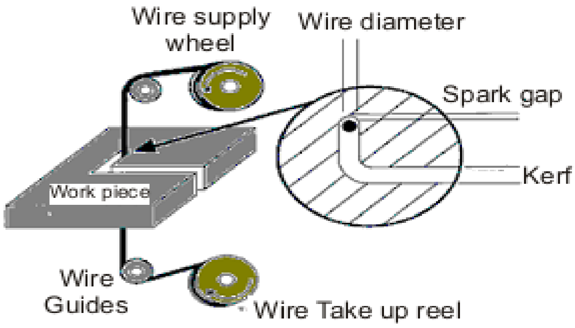

Fig.1: Schematic Representation of WEDM

Rajurkar K.P, et al, [1] used a factorial design method, to determine the optimal combination of control parameters in WEDM considering the measures of machining performance as metal removal rate and the surface finish. The study concluded that control factors are discharge current, the pulse duration and the pulse frequency. Y. S. Tarng, et al, [2] used a neural network model to estimate to the effects of parameters on the surface roughness as the response variable and machining speed. J. Prohaszka [3] in their paper they have discussed about effect of electrode material on machinability in wire electro-discharge machining that will lead to the improvement of WEDM performance. Experiments have been conducted regarding the choice of suitable wire electrode materials and the influence of the properties of these materials on the machinability in WEDM, the experimental results are presented and discussed. Y.S Liao et al.[4] derived an approach to determine machining parameter settings for WEDM process. Based on the taguchi quality design and the analysis of variance (ANOVA), the significant factors affecting the machining performance such as MRR, gap width ,surface roughness ,sparking frequency ,average gap voltage, normal ratio(ratio of normal sparks to total sparks) are determined. By means of regression analysis, mathematical models relating the machining performance and various machining parameters are established. Jose Maranon et.al [5] has investigated a new method of optimizing MRR using EDM with copper-tungsten electrodes. This paper describes an investigation into the optimization of the process which uses the effect of carbon which has migrated from the dielectric to tungsten copper electrodes.

Mustafa Ilhan et.al [6] have presented in their paper to select the most suitable cutting and offset parameter combination for the electrical discharge machining process in order to get the desired surface roughness value for the machined surface. A series of experiments have been conducted on 1040 steel material of thickness 30, 60 and 80 mm, and on 2379 and 2738 steel materials of thicknesses 30 and 60mm. S.H. Lee et al. [7] have studied the effect of machining parameters in EDM of tungsten carbide on the machining characteristics. The characteristics of EDM refer essentially to the output machining parameters such as material removal rate (MRR), relative wear ratio (RWR) and surface roughness (Ra). C. L. Lin, et al, [8] have described, the grey relational analysis based on an orthogonal array and fuzzy-based Taguchi method is applied for optimizing the multi-response process. They have used both the grey relational analysis method without using the S/N (Signal/Noise) ratio and fuzzy logic analysis in orthogonal array Table in carrying out experiments for solving the multiple responses in the electrical discharge machining process. J. L. Lin et.al [9] has studied the optimization of multiple performance characteristics of WEDM using orthogonal array. In their paper, a new approach for optimization of the EDM with multiple performance characteristics based on the orthogonal array with grey relational analysis has been studied. The performance characteristics studied are MRR, surface roughness, and electrode wear ratio.

N. Tosun et.al [10] have investigated theoretically and experimentally about the effect of the cutting parameters on size on erosion craters of wire electrode in WEDM. The level of importance of the machining parameters on the wire crater size has been determined by using analysis of variance (ANOVA). K.H. Ho, et. al, [11] in their paper have discussed about wire EDM research involving the optimization of the process parameters surveying the influence of the various factors affecting the machining performance and productivity. The paper also highlights the adaptive monitoring and control of the process investigating the feasibility of the different control strategies of obtaining the optimal machining conditions. Scott F. Miller et al, [12] in their paper have discussed about wire electrical discharge machining (EDM) of cross-section with minimum thickness and compliant mechanisms is studied. This was supported by findings from SEM micrographs of EDM surface, subsurface, and debris. R.Ramakrishnan et.al [13] in their paper have applied the Taguchi's method, which is one of the methods of robust design of experiments to optimize multi responses of the wire cut electric discharge machining operations. Experimentation is carried out using Taguchi's L16 orthogonal array method. By applying the Taguchi's method, a good improvement was obtained. Swarup S. Mahapatra et.al [14] have described in their paper about Parametric Optimization of Wire Electrical Discharge Machining (WEDM) Process using Taguchi Method. The responses measured are Surface finish (Ra) and MRR. They have used Taguchi technique for the optimization of process parameters. Orthogonal array used is L27. They have proposed some optimized parameter values for machining the work piece.

The cutting of Tungsten Carbide ceramic using electro-discharge machining (EDM) with a graphite electrode by using Taguchi methodology has been reported by Mohd Amri Lajis et al [15]. The Taguchi method is used to formulate the experimental layout, to analyze the effect of each parameter on the machining characteristics, and to predict the optimal choice for each EDM parameter such as peak current, voltage, pulse duration and interval time. It is found that these parameters have a significant influence on machining characteristic such as metal removal rate (MRR), electrode wear rate (EWR) and surface roughness (SR). The analysis of the Taguchi method reveals that, in general the peak current significantly affects the EWR and SR, while, the pulse duration mainly affects the MRR. C. Bhaskar Reddy et.al, [16] have investigated for best parameter selection to obtain maximum Metal removal rate (MRR) and better surface roughness (Ra) by conducting the experimentation on CONCORD DK7720C four axes CNC Wire Electrical Discharge Machining of P20 die tool steel with molybdenum wire of 0.18mm diameter as electrode.

From the literature several researchers have been applied the Taguchi method is used to optimize the performance parameters in WEDM process. In the Present work Titanium alloy is considered for measuring the output parameters like material removal rate, surface rough using Taguchi method.

II. EXPERIMENTAL DESIGN

Proper experimental design significantly contributes towards the accurate characterization and optimization of the process. Here, the criterion for experimental design and analysis is to achieve higher VRR along with reduction in Surface Roughness. An orthogonal array for six 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 six input variables. In the present study Table-1 represents various levels of process parameters and Table-2 represents experimental plan with assigned values.

Table 1: Levels of Various Process Parameters

S.NO	Process Parameters	Units	Level-I	Level-II	Level-III	Level-IV	Level-V
1.	Pulse On	µs	112	116	120	124	125
2.	Pulse Off	µs	60	56	52	48	44
3.	Peak Current	Amps	70	110	150	190	230
4.	Wire Tension	Kg-f	4	6	8	10	12
5.	Servo Voltage	Volts	10	30	50	70	90
6.	Servo Feed	mm/min	420	840	1260	1680	2100

Table 2: Experimental plan with assigned values

S.NO	Pulse on µs	Pulse Off µs	Peak Current Amps	Wire Tension Kg-f	Servo Voltage Volts	Servo feed mm/min
1.	112	60	70	4	10	420
2.	112	56	105	6	30	840
3.	112	52	145	8	50	1260
4.	112	48	185	10	70	1680
5.	112	44	215	12	90	2100
6.	116	60	105	8	70	2100
7.	116	56	145	10	90	420
8.	116	52	185	12	10	840
9.	116	48	215	4	30	1260
10.	116	44	70	6	50	1680
11.	120	60	145	12	30	1680
12.	120	56	185	4	50	2100

13.	120	52	215	6	70	420
14.	120	48	70	8	90	840
15.	120	44	105	10	10	1260
16.	124	60	185	6	90	1260
17.	124	56	215	8	10	1680
18.	124	52	70	10	30	2100
19.	124	48	105	12	50	420
20.	124	44	145	4	70	840
21.	128	60	215	10	50	840
22.	128	56	70	12	70	1260
23.	128	52	105	4	90	1680
24.	128	48	145	6	10	2100
25.	128	44	185	8	30	420

III. SELECTION OF MATERIAL

Titanium alloys are now the most attractive materials in aerospace and medical applications. The titanium its 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. In the present work Titanium grade 5 (Ti6Al4V) is used as work piece material and brass wire is used as electrode material. The chemical composition of the material is shown in Table -3. The variable process parameters and fixed parameters are given in Table-4 and Table-5 respectively.

Table 3**:** Chemical composition of Titanium Grade 5 Material

N	C	H	Fe	O	Al	V
0.05 %	0.08 %	0.015 %	0.40 %	0.20 %	6.75 %	4.5 %

IV. EXPERIMENTAL WORK

The experiments were planned according to Taguchi's L25 orthogonal array [17]. The experiments were carried out on ELEKTRA SPRINTCUT 734 four axis wire cut EDM machine is as shown in Figure.2. The basic parts of the WEDM machine consists of a wire Electrode, a work table, and a servo control system, a power supply and dielectric supply system. The following Fig shows the ELEKTRA SPRINTCUT 734 of wire EDM. . Therefore, the width of cut (W) remains constant. The VMRR for each WEDM operation was calculated using Eq. (1). Surface Roughness (Ra) is measured by handy surf (Mitutoyo surftest SJ-201P) equipment.

Fig. 2: CNC Wire cut EDM is used for experimentation

Table 4: process parameters of ELECTRONICA SPRINT CUT 734 CNC WEDM

Control parameters	Units	Symbol
Pulse On	µs	A
Pulse Off	µs	B
Peak Current	Amperes	C
Wire tension	Kg-f	D
Servo Voltage	Volts	E
Servo Feed	mm/min	F

Table 5: Variable and fixed parameters in WEDM

Machining Parameters	Working Range	Fixed Parameters	Value
Pulse On	115-131 machine unit	Composition of material	Ti6Al4V
Pulse off	63-45 machine unit	Work piece thickness	25mm
Peak current	70-230 Ampere	Wire electrode material	Brass wire Ø0.25mm
Wire tension	0-15 kg-f	Dielectric medium	Distilled water
Servo Voltage	0-99Volts	Wire feed	8m/min
Servo feed setting	0-2100 mm/min	Wire offset	0.00mm

Volume Material removal rate (VMRR) = Volume of the material removed / cutting time mm^3/min (1)

V. RESULTS AND DISCUSSIONS

The effect of machining parameters on material removal rate and surface roughness in machining Titanium (Ti-6Al-4V) are studied. From the results it is observed that, the pulse, pulse and peak current are the most significant factors for the performance measures. The wire tension, servo voltage and servo feed settings are less significant on performance measure. The results are obtained by analyzed using S/N Ratios, Response table and Response Graphs with the help of Minitab software. Table VI shows this experimental results then it is analyzed and obtained the optimum process parameters for MRR and Ra.

Table 6: Experimental results of output parameters

Run	A	B	C	D	E	F	Cutting Rate mm/min	Cutting time minutes	VMMR mm^3/min	Ra µm
1.	112	60	70	4	10	420	0.16	121.46	1.355	1.18
2.	112	56	105	6	30	840	0.55	33.24	4.952	1.24
3.	112	52	145	8	50	1260	0.65	30.54	5.389	1.28
4.	112	48	185	10	70	1680	0.72	29.21	5.635	1.31
5.	112	44	215	12	90	2100	0.35	59.56	2.777	1.16
6.	116	60	105	8	70	2100	0.36	60.21	2.733	1.20
7.	116	56	145	10	90	420	0.30	67.42	2.441	1.25
8.	116	52	185	12	10	840	1.35	15.02	10.959	1.52
9.	116	48	215	4	30	1260	2.21	9.12	18.049	2.11
10.	116	44	70	6	50	1680	1.88	11.40	14.439	2.03
11.	120	60	145	12	30	1680	1.72	11.56	14.239	2.01
12.	120	56	185	4	50	2100	1.64	12.15	13.548	1.93
13.	120	52	215	6	70	420	1.82	11.40	14.439	1.86
14.	120	48	70	8	90	840	2.35	7.41	22.214	2.89
15.	120	44	105	10	10	1260	2.19	8.52	19.320	2.76
16.	124	60	185	6	90	1260	1.47	13.56	12.139	1.29
17.	124	56	215	8	10	1680	1.82	10.58	15.558	1.37
18.	124	52	70	10	30	2100	2.74	7.11	23.151	2.45
19.	124	48	105	12	50	420	2.45	8.03	20.499	3.01
20.	124	44	145	4	70	840	1.73	11.25	14.632	1.54
21.	128	60	215	10	50	840	1.95	10.06	16.362	1.62
22.	128	56	70	12	70	1260	2.12	9.25	17.795	1.73
23.	128	52	105	4	90	1680	2.35	8.34	19.737	2.25
24.	128	48	145	6	10	2100	1.93	10.21	16.122	1.53
25.	128	44	185	8	30	420	2.42	8.12	20.272	2.08

VI. SELECTION OF OPTIMAL PARAMETER COMBINATION

The Experimental results shows the effect of six process parameters on material removal rate and surface roughness.Fig-4 shows the effect of Volume Material Removal Rate for the pulse on, pulse off, peak Current and Servo Voltage. From this Fig, it was observed that the VMRR increased when the pulse on time was increased due to number of discharges within a given period of time increase. In Fig.6, it shows that with an increase of pulse on time the surface quality of the machined surfaces were decreased because under longer pulse time on the electrical sparks generate bigger craters on the surface of work piece. Fig.3 and 5 shows the graphs for the S/N ratios.

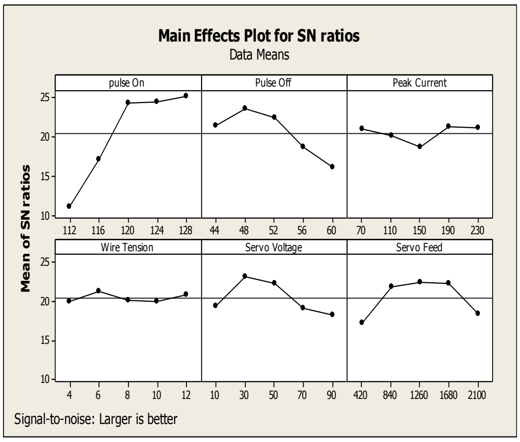

Fig. 3: Response Graphs for S/N ratios

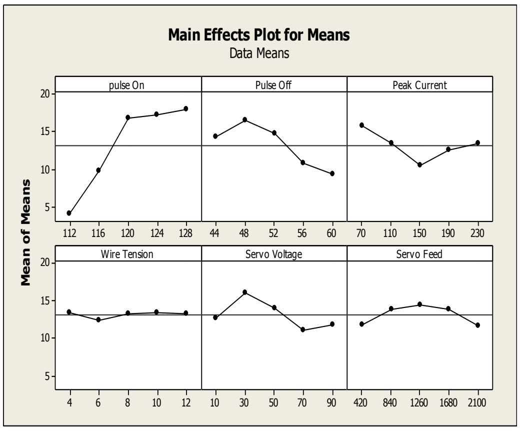

Fig. 4: Response Graphs for Means

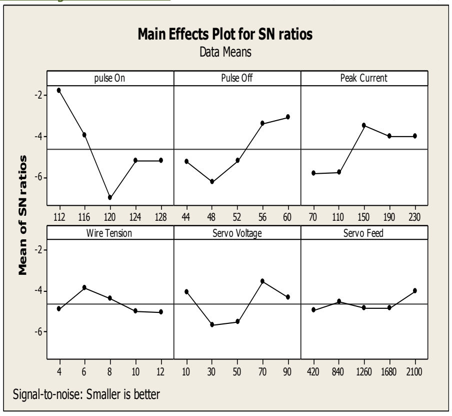

Fig. 5: Response Graphs for S/N ratios

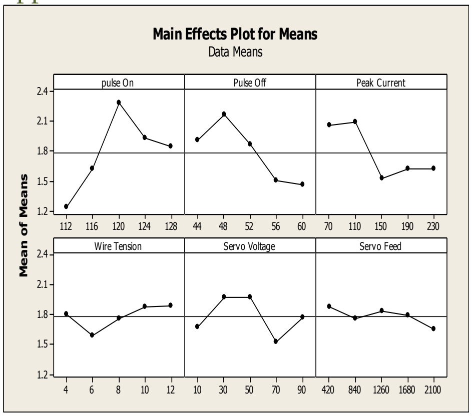

Fig. 6: Response Graphs for Means

In Taguchi Analysis the Volume Material Removal Rate versus Pulse on, Pulse off, Peak Current and Servo Voltage is carried out and average of each level is the parameter for raw data is given in Table 7 and average of each level in terms of S/N ratios are given in Table 8. Surface Rough versus Pulse on, Pulse off, Peak Current and Servo Voltage is carried out and average of each level is the parameter for raw data is given in Table 9 and average of each level in terms of S/N ratios and optimal parameter setting to obtain maximum Volume Material Removal Rate is given in Table 10. After observing all response graphs, Table 11 shows the Optimal Parameters Combination for VMRR and Ra.

Table 7: Response Table for Means Larger is better

Level	pulse On	Pulse Off	Peak Current	Wire tension	Servo voltage	Servo feed
1	11.01	21.45	21.01	19.92	19.43	17.19
2	17.12	23.49	20.10	21.22	23.10	21.84
3	24.31	22.36	18.58	20.05	22.19	22.43
4	24.47	18.58	21.25	2001	19.05	22.20
5	25.09	16.08	21.06	20.80	18.23	18.34
Delta	14.08	7.41	2.67	1.30	4.88	5.24
Rank	1	2	5	6	4	3

Table 8: Response Table for Signal to Noise Ratios

Level	pulse On	Pulse Off	Peak Current	Wire tension	Servo voltage	Servo feed
1	4.022	14.288	15.791	13.464	12.663	11.801
2	9.724	16.504	13.448	12.418	16.133	13.824
3	16.752	14.735	10.565	13.233	14.047	14.538
4	17.196	10.859	12.511	13.382	14.047	14.538
5	18.058	9.366	13.437	13.254	11.862	11.666
Delta	14.036	7.138	5.226	1.046	5.086	2.872
Rank	1	2	3	6	4	5

Table 9: Response Table for Means Smaller is better

Level	pulse On	Pulse Off	Peak Current	Wire tension	Servo voltage	Servo feed
1	-1.817	-5.274	-5.870	-4.886	-4.064	-4.940
2	-3.959	-6.263	-5.777	-3.863	-5.713	-4.533
3	-7.040	-5.200	-3.518	-4.408	-5.553	-4.884
4	-5.210	-3.403	-4.053	-5.015	-3.566	-4.867
5	-5.210	-3.097	-4.018	-5.064	-4.340	-4.012
Delta	5.223	3.165	2.352	1.202	2.146	0.928
Rank	1	2	3	5	4	6

Table 10: Response Table for Signal to Noise Ratios

Level	pulse On	Pulse Off	Peak Current	Wire tension	Servo voltage	Servo feed
1	1.234	1.914	2.056	1.082	1.672	1.876
2	1.622	2.170	2.056	1.802	1.672	1.762
3	2.290	1.872	1.522	1.764	.1.974	1.834
4	1.932	1.504	1.626	1.878	1.528	1.794
5	1.842	1.460	1.624	1.886	1.768	1.654
Delta	1.056	0.710	0.570	0.296	0.450	0.222
Rank	1	2	3	5	6	4

Table 11: Optimal Parameter Combination for MRR and Ra

Process Parameters	Optimum Level for VMRR	Optimum Level for Ra
Pulse On	128	112
Pulse Off	48	60
Peak Current	220	150
Wire Tension	6	6
Servo Voltage	30	70

DEVELOPMENT OF REGRESSION EQUATION

The objective of multiple regression analysis is to construct a model that explains as much as possible, the variability in a dependent variable, using several independent variables.

The Regression equations for VMRR and Ra

VMRR = - 69.7 + 0.889 pulse on - 0.387 Pulse Off - 0.0141 Peak Current + 0.027 Wire Tension - 0.0334 Servo Voltage - 0.00004 Servo Feed.

Ra = - 0.24 + 0.0381 pulse on - 0.0393 Pulse Off - 0.00333Peak Current + 0.0228 Wire Tension - 0.00129 Servo Voltage - 0.000098 Servo Feed.

VII. CONCLUSION

In this research, three different analyses are employed to obtain the following goals. Evaluating the effects on machining parameters on volume material removal rate, evaluating the effects on machining parameters on surface roughness and presenting the optimal machining conditions. Taguchi Analysis determines the factors which have significant impact on volume material removal rate. Equations which correlate machining parameters with material removal rate is found by regression analysis, and the optimal setting is found by S/N ratio analysis. Further research might attempt to consider the other performance criteria, such kerf, surface waviness, dimensional error as output parameters. This technique can also be applied for the various conventional machining operations and for machining of advanced materials like composites to improve the performance characteristics simultaneously. The present work was carried out by Taguchi analysis; further this work can be extended by considering any combination of fuzzy control, Grey relational analysis with Taguchi's orthogonal array technique, response surface methodology techniques.

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