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Parametric Optimization of Wire Electrical Discharge Machining (WEDM) Process Using Taguchi Method

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ABSTRACT

Wire electrical discharge machining (WEDM) is a specialized thermal machining process capable of accurately machining parts of hard materials with complex shapes. Parts having sharp edges that pose difficulties to be machined by the main stream machining processes can be easily machined by WEDM process. Technology of the WEDM process is based on the conventional EDM sparking phenomenon utilizing the widely accepted noncontact technique of material removal with a difference that spark is generated at wire and work piece gap. 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 L25 orthogonal array 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.

KEYWORDS**:** *Optimization of Process parameters, material removal rate ,surface finish, Taguchi method, WEDM.*

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I. INTRODUCTION

Electrical discharge machining (EDM) is a non-traditional, thermo-electrical process, which erodes materials from the work piece by a series of discrete sparks between the work and tool electrode immersed in a liquid dielectric medium. These electrical discharges melt and vaporize minute amounts of the work material, which are then ejected and flushed away by the dielectric. A wire EDM generates spark discharges between a small wire electrode and a work piece with de-ionized water as the dielectric medium and erodes the work piece to produce complex two and three dimensional shapes according to a numerically controlled (NC) path. Guitrau et al.[1] The main goals of WEDM manufacturers and users are to achieve a better stability and higher productivity of the WEDM process. Williams and Rajurkar et al [2] Wire electrical discharge machining manufacturers and users emphasize on achievement of higher machining productivity with a desired accuracy and surface finish. However, due to a large number of variables even a highly skilled operator with a state-of-the-art WEDM is rarely able to achieve the optimal performance. An effective way to solve this problem is to determine the relationship between the performance measures of the process and its controllable input parameters. Rajurkar and Royo et al [3] Investigations into the influences of machining input parameters on the performance of WEDM have been widely reported . Hocheng et al. [4] investigated the correlation between current and spark on-time with the crater size produced by a single spark of SiC/Al work materials. Qu et al.[5] have, through examination of literature, concluded that research has not been directed towards EDM applications in the area of newly developed engineering materials and the boundaries that limit the material removal rate (MRR). Hence, investigations were carried out to study the effect of spark on-time duration and spark on-time ratio, two important EDM process parameters, on the surface finish characteristics and integrity of the four types of advanced engineering material such as porous metal foams, metal bond diamond grinding wheels, sintered Nd-Fe-B magnets, and carbon-carbon bipolar plates.

Scott, Boyina and Rajurkar et al [6] 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 concludes that discharge current, the pulse duration and the pulse frequency are significant control factors. Tarng and Chung et al [7] used a neural network model to estimate cutting speed and surface finish using input settings as pulse duration, pulse interval, peak current, open circuit voltage, servo reference voltage, electric capacitance and table speed. Trezise et al [8] suggests that fundamental limits on machining accuracy are dimensional consistency of the wire and the positional accuracy of the work table. The detailed section of the working region of the wire electrode is shown in Fig.1. It is evident from Fig.1 that it is absolutely essential to hold the wire in a designated position against the object because the wire repeats complex oscillations due to electro-discharge between the wire and work piece. Normally, the wire is held by a pin guide at the upper and lower parts of the work piece. In most cases the wire, once used, will be discarded. However, there are problematic points that should be fully considered in order to enhance working accuracy.

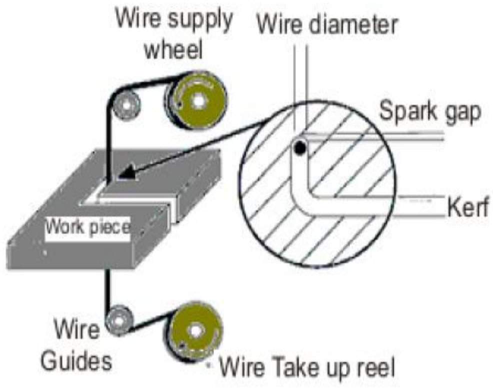


Fig.1: Details of WEDM cutting Gap.

The most important performance measures in WEDM are metal removal rate, work piece surface finish, and cutting width. Discharge current, pulse duration, pulse frequency, wire speed, wire tension, dielectric flow rate are the machining parameters which affect the performance measures. The gap between wire and work piece usually ranges from 0.025 to 0.075 mm and is constantly maintained by a computer controlled positioning system. The material removal rate (g/min) is calculated by weight difference of the specimens before and after machining. The surface finish value (µm) is obtained by measuring the mean absolute deviation, Ra, from the average surface level. In WEDM operations, material removal rate determine the economics of machining and rate of production. In setting the machining parameter, the main goal is to maximize MRR and SF (surface finish). In order to investigate the effects of various process parameters on MRR and SF and then to suggest the optimal process settings, statistically designed experiments are used in this study. The Taguchi method, a powerful experimental design tool, uses simple, effective, and systematic approach for deriving of the optimal machining parameters. Further, this approach requires minimum experimental cost and efficiently reduces the effect of the source of variation. The methodology uses Taguchi's experimental design for setting suitable machining parameters in order to effectively control the amount of removed materials and to produce complicated precise components.

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	I	II	III	IV	V
1.	Pulse On	Ms	112	116	120	124	125
2.	Pulse Off	Ms	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 %

III. EXPERIMENTAL WORK

The experiments were planned according to Taguchi's L25 orthogonal array[9] . The experiments were carried out on ELECTRONICA UNDER CUT S 1 four axis wire cut EDM machine is as shown in Fig.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 UNDER CUT S 1 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 equipment.

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

Table 4 : Processes parameters of ELCTONIKA ULTRACUT S 1 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

IV. RESULT 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 6 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

Ru	A	B	C	D	E	F	Cutting Rate	Cutting time	VMMR	Ra µm

n							mm/min	minutes	mm3/min	
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.4, 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.

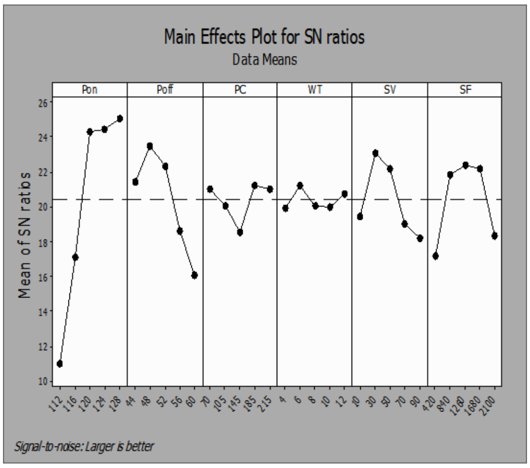


Fig.3. Response graph for S/N ratios (VMMR)

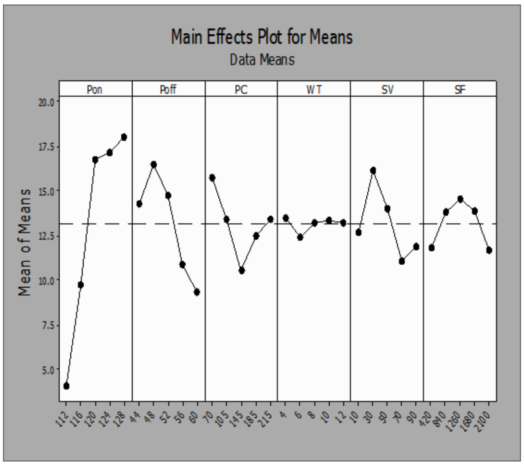
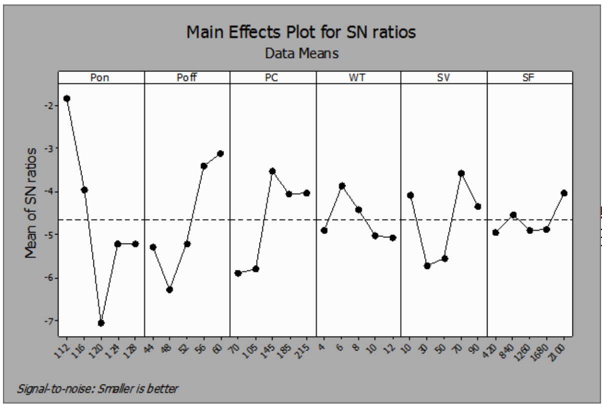


Fig.4. Response graph for means (VMMR)



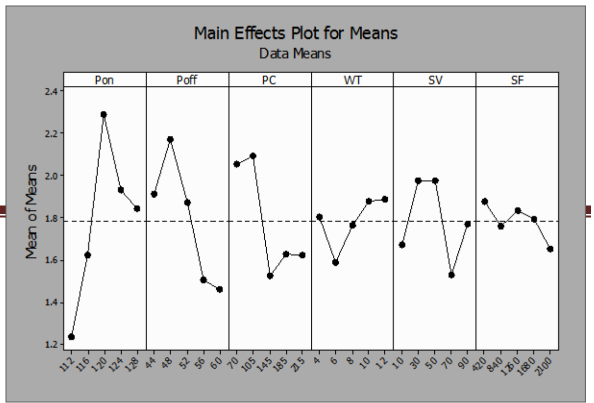


Fig.5. Response graph for S/N ratios (Ra)

Fig.6. Response graph for means (Ra)

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.

Table7 : Response table for means larger is better

Level	Pon	Poff	PC	WT	SV	SF
1	11.01	21.45	21.01	19.92	19.43	17.19
2	17.12	23.49	20.1	21.22	23.1	21.84
3	24.31	22.36	18.58	20.05	22.19	22.43
4	24.47	18.63	21.25	20.01	19.05	22.2
5	25.09	16.08	21.06	20.8	18.23	18.34
Delta	14.08	7.41	2.67	1.3	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

Table 9: Response table for means smaller is better

Level	Pon	Poff	PC	WT	SV	SF
1	-1.817	-5.274	-5.87	-4.886	-4.064	-4.94
2	-3.959	-6.263	-5.777	-3.863	-5.713	-4.533
3	-7.04	-5.2	-3.518	-4.408	-5.553	-4.884
4	-5.21	-3.403	-4.053	-5.015	-3.566	-4.867
5	-5.21	-3.097	-4.018	-5.064	-4.34	-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	Pon	Poff	PC	WT	SV	SF
1	1.234	1.914	2.056	1.802	1.672	1.876
2	1.622	2.17	2.092	1.59	1.978	1.762
3	2.29	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	1.46	1.624	1.886	1.768	1.654
Delta	1.056	0.71	0.57	0.296	0.45	0.222
Rank	1	2	3	5	4	6

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

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. 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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