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Optimization of electro discharge machining process parameters for Ti alloy by using Taguchi technique

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Abstract- In this study wire cut electro discharge process parameters are optimized by using Taguchi method. Process parameters considered for the study are pulse on time, pulse off time and current. Ti alloy is high tensile strength alloy which is mostly used in cold dies and tooling application that where high degree and dimensional accuracy is required. Ti alloy steel plate of rectangular shape has been used for machining operation. Performance of wire cut electro discharge machine with a molybdenum wire has been measured by surface roughness and material removal rate. In Taguchi method L9 orthogonal array has been selected. The analysis of variance (ANOVA) has been used to determine effect of each parameter on surface roughness (SR) and material removal rate (MRR). Keywords- Taguchi Method, Signal to Noise (S/N) Ratio, Optimization, Process Parameters, Material Removal Rate, Surface Roughness.

I. INTRODUCTION

Wire Electrical Discharge Machining (WEDM) is a non- traditional process of material removal from electrically conductive materials to produce parts with intricate shape and profiles. WEDM is revolutionized the tool and die, mold, punch, and metalworking and aerospace industries. It is considered as a unique adaptation of the conventional EDM process, which uses an electrode to initialize the sparking process. However, WEDM utilizes a continuously travelling wire electrode made of thin copper, brass or tungsten of diameter 0.05–0.3 mm, which is capable of achieving very small corner radii. The wire is kept in tension using a mechanical tensioning device reducing the tendency of producing inaccurate parts. The wire work-piece gap usually ranges from 0.025 to 0.05 mm and is constantly maintained by a computer controlled positioning system. In setting the machining parameters, the main goal is the minimum surface roughness. The setting of machining parameters relies strongly on the experience of operators and machining parameters tables provided by machine tool builders. It is difficult to utilize the optimal functions of a machine owing to their being too many adjustable machining parameters.

II. EXPERIMENTATION

A. Methodology of Experiment

There are several optimization techniques to develop product, process or operation. Various techniques can be applied to optimize WEDM process. Sometimes different techniques are required integrate to get statistically significant results, which can lead to better conclusions and recommendations. Some extensively used methods in developing a process or a product are Build Test Fix (BTF), Design of Experiment (DOE) and One Variable at a Time (OVAT), BTF is very primitive and unorganized approach. It is iterative method of developing a process focused on improvement from last experiment. DOE is highly efficient method of investigating the effect of parameters as it varies multiple parameters at once. As more parameters are investigated, more number of new combinations are required. DOE cannot control individual parameters and more relies on statistical data. In one variable at a time (OVAT) approach, variation is done with one variable at a time and other parameters are kept constant until the effect of one parameter is studied.

It is highly precise method to study effect of each parameter at different levels. Pulse on time (T-on), Pulse off time (T-off) and Current were identified as most predominant parameters affecting the WEDM. Based on the observation, Taguchi method has been used to optimize the process parameters. OVAT analysis has been conducted to find out effective range of parameters for optimization study. L9 orthogonal array (OA) has been selected from available designs. Standard notation for OA is given below

OA = Ln (Xm)

Where n= number of experiments, X= number of levels and m= number of parameters under study. From available designs for 3 levels 3 parameters, OA with least number of experiment required to conduct (L9) has been selected. ANOVA has been conducted to find out contribution of each parameter in the output. Minitab 19 software has been used for analysis.

B. Experimental Machine Selection

Table 1 states the specification of the WEDM used in this study. All the experiments were conducted at Sidheshwar Wirecut, MIDC Waluj, Aurangabad, M.S, India

Make and Model	**Electronica Eplus 40A**
Work Table Size	600 x 400 mm
Max. Work Piece Height	300mm
Working Table	900 x 580 mm
Max. Work piece Weight	1000 kg

Table 1 WEDM Machine Specification.

Figure.2.1 Setup Wire cut electro discharge Machine

C. Selection of material

High performance cutting tool, stamping, wood working, drawing, deep drawing, pressing tool, rolls, measuring tools. Size available in round, flat and square. Literature study indicates that research can be conducted to evaluate effect of process parameters like Pulse on time, Pulse of time and Current of wire cut electro discharge machining on surface roughness and material removal rate. Chemical composition of Ti alloy is shown in Table 2

Composition	C	Al	Fe	O
Percentage	0.1%	5.5 - 7.0%	0.25%	0.15%

Table 2 Chemical Composition of Ti alloy.

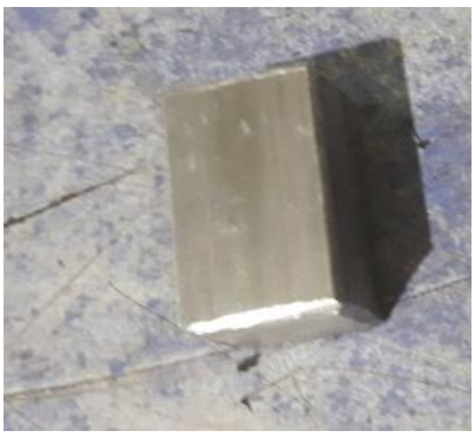

Figure 2.2 Ti alloy and a test specimen

III. RESULTS AND DISCUSSION

To get complete understanding of effects of input parameters pulse on time, pulse off time and current on output surface roughness and material removal rate, you usually assess signal to noise ratio or main effects plot for means. For this purpose, Minitab 19 statistical software has been used. Modeling of surface roughness and material removal rate has been done. ANOVA has been conducted to find out effect of each parameter on the surface roughness, material removal rate and linear regression model has been established to predict the values of surface roughness and material removal rate.

A. Experimental Result

Table 4 shows the L9 orthogonal array with measurement of material removal rate for runs one to nine. It also shows S/N ratio for all nine experiments.

Experiments	**Inputs Factors**			**Output Responses**	
Trial No.	**Pulse on time ((µs)**	**Pulse off time (µs)**	**Current (A)**	**MRR**	**S/N Ratio**
1	50	15	6	1.981	5.93769
2	50	20	9	2.159	5.37156
3	50	25	12	2.437	7.73711
4	60	15	9	2.296	7.87501
5	60	20	12	2.659	9.68600
6	60	25	6	2.140	6.60828
7	70	15	12	2.092	5.52464
8	70	20	6	1.874	5.45539
9	70	25	9	2.012	6.07256

Table 4 L9 orthogonal array with response characteristic.

The S/N ratio values are calculated with help of Minitab 19 software. It can be seen that variation in S/N ratio is minimum for all experiment.

B. Main Effects of MRR

Figure 3.1 shows the main effects plot from S/N ratios.

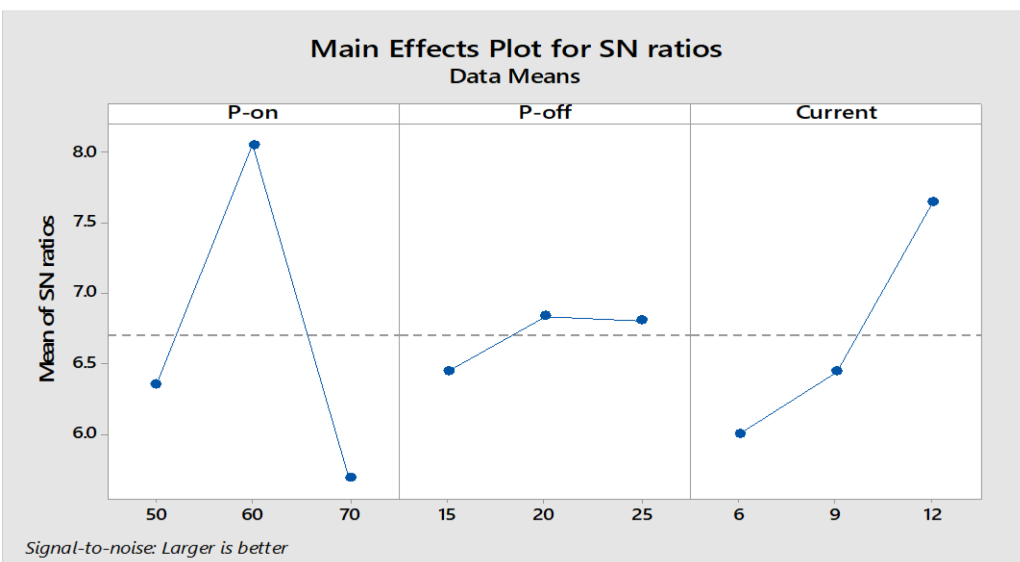

Figure.3.1 Main Effects Plot for S/N Ratio

From main effects plot for S/N ratio, parametric effect on response characteristic i.e. material removal rate can be understood. Pulse on time 60µsec at level 2, Pulse off time 20µsec at level 2, Current 12 A at level 3 gives the highest signal to noise ratio values. The levels at which highest S/N ratio obtained from S/N ratio plot taken as optimum levels setting for machine parameters.

C. ANOVA Result

ANOVA, the ratio between the variance of the cutting parameter and the error variance is called Fisher's ratio (F). It is used to determine whether the parameter has a significant effect on the quality characteristic by comparing the F test value of the parameter with the standard F table value at the P significance level. If the F test value is greater than P test the cutting parameter is considered significant. Relevance of the models is tested by analysis of variance (ANOVA). It is a statistical tool for testing the null hypothesis for planned experiments, in which several different variables are studied simultaneously. ANOVA is used to quickly analyze the variances in the experiment using the Fisher test (F test). ANOVA table shown the result of the ANOVA analysis. ANOVA analysis makes it possible to observe that the value of P is less than 0.05 in the three parametric sources. It is therefore clear that pulse on time, pulse off time and current of the material have an influence on the Ti alloy. The last column of cumulative ANOVA shown the percentage of each factor in the total variance that indicates the degree of impact on the outcome. Table 6 shows results obtained from analysis of variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
T-on	2	0.567043	0.283521	61.30	0.016	59.51
T-off	2	0.178726	0.089363	19.32	0.049	18.76
Current	2	0.197791	0.098895	21.38	0.045	20.75
Error	2	0.009251	0.004625			
Total	8	0.952811				

Table 5 ANOVA Result.

It shows that the Ton (59.51%), the Toff (18.76%) and the Ip (20.75%) have major influence on the MRR. Contribution of Ton (59.51%) is highest among all three parameters hence it is most dominating parameter while P-off is least affecting parameter.

D. Development of Regression Model for material removal rate

Regression model has been developed using Minitab software. Substituting the experimental values of the parameters in regression equation, values for material removal rate have been predicted for all levels of study parameters. Graphical representation also shows that a predicted and experimental value of material removal rate correlates with each other.

Regression Equation –

MRR = 1.84 - 0.0083 [P-on] + 0.0081 [P-off] + 0.0767 [Current]

Table number 7 gives comparison between experimentally measured and predicted material removal rate by developed mathematical equation

Sr. No.	Experimental value	Predicted value	Error %
1	1.981	2.006	1.25
2	2.159	2.273	5.09
3	2.437	2.547	4.31
4	2.296	2.153	6.80
5	2.659	2.424	9.69
6	2.140	2.047	5.54
7	2.092	2.300	9.04
8	1.874	1.881	0.37
9	2.012	2.151	6.46

Table 6 Experimental and Predicted Values of MRR

Difference between surface roughness values calculated using regression equation and experimental values for each experience found less than 10%. Hence, we can say that the regression equation developed is valid. Figure 3.2 shows the graphical representation of experimental and values calculated using regression equation.

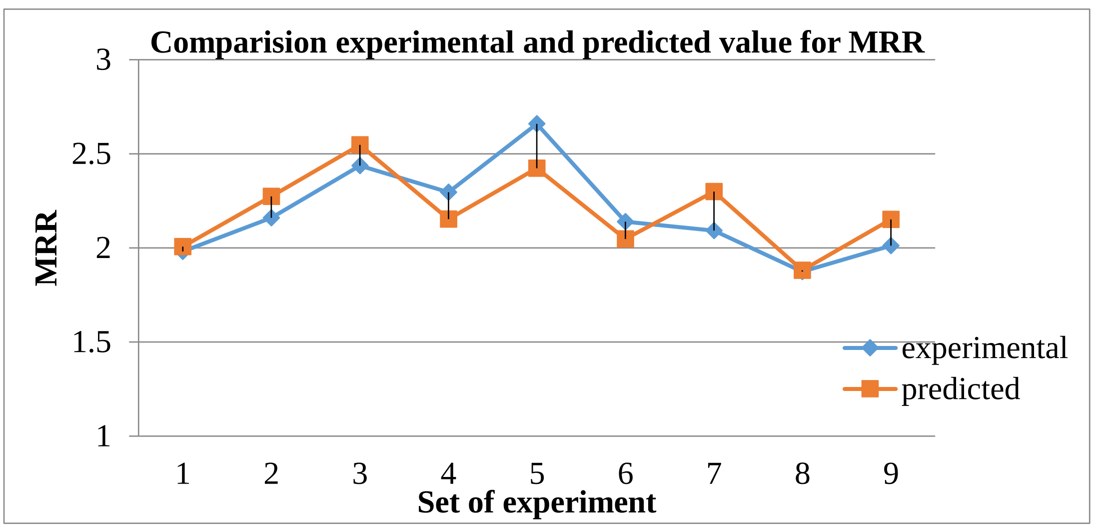

Figure 3.2 Comparison between Experimental and Predicted value of Material removal rate.

E. Confirmation Experiment Result

Table 8 shows the difference between value of material removal rate of confirmation experiment and value predicted from regression model developed.

Parameter	Model value	Experimental value	Error %
MRR (mm^3/min)	2.424	2.659	9.69

Table 7 Confirmation Experiment Result

Confirmation experiment is conducted by keeping parameters at optimum levels suggested by Taguchi method and the MRR value obtained has been compared with value predicted by the regression model keeping the parameters at same levels. It can be seen that the difference between experimental result and the predicted result is 9.69%. This indicates that the experimental value correlates to the estimated value.

F. Experimental Result

Table 4 shows the L9 orthogonal array with measurement of surface roughness for runs one to nine. It also shows S/N ratio for all nine experiments.

Experiments	Inputs Factors			Output Responses	
Trial No.	Pulse on time (μs)	Pulse off time (μs)	Current (A)	SR(Ra) (μm)	S/N Ratio
1	50	15	6	6.318	-16.0116
2	50	20	9	8.015	-18.0781
3	50	25	12	8.348	-18.4316
4	60	15	9	6.994	-16.8945
5	60	20	12	7.659	-17.6834
6	60	25	6	5.140	-14.2193
7	70	15	12	7.792	-17.8330
8	70	20	6	6.994	-16.8945
9	70	25	9	7.012	-16.9168

Table 8. L9 orthogonal array with response characteristic.

The S/N ratio values are calculated with help of Minitab 19 software. It can be seen that variation in S/N ratio is minimum for all experiment.

G. Main Effects of SR

Figure 3.3 shows the main effects plot from S/N ratios.

From main effects plot for S/N ratio, parametric effect on response characteristic i.e. SR can be understood. Ton 50μs (level 1), 20μs Toff (level 2) and 12A Ip (level 3, gives the highest signal to noise ratio values. The levels at which highest S/N ratio obtained from S/N ratio plot taken as optimum levels setting for machine parameters.

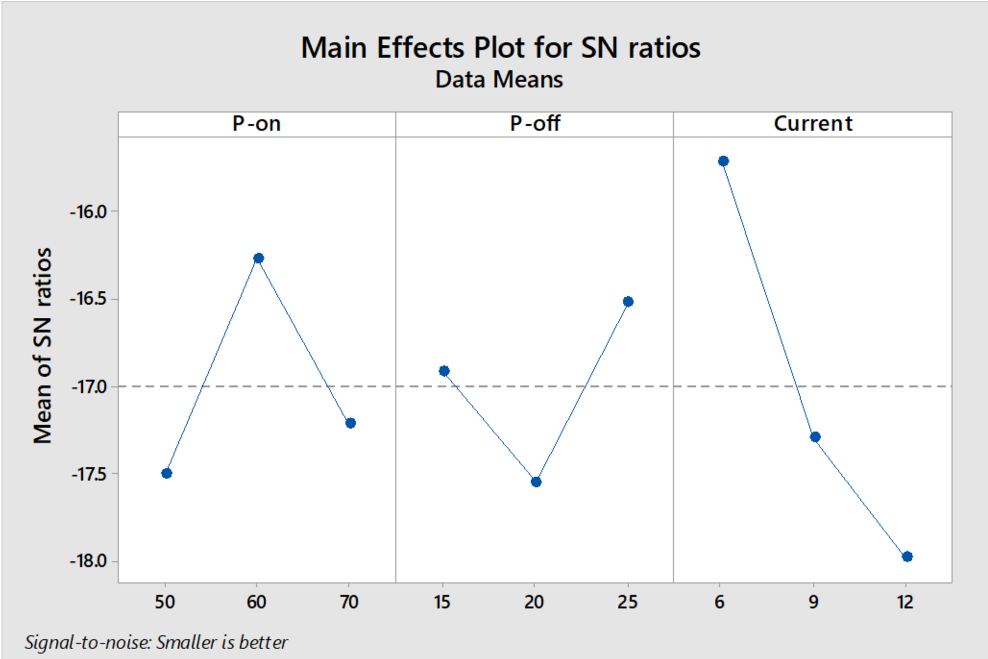

Figure.3.3 Main Effects Plot for S/N Ratio

H. ANOVA Result

ANOVA, the ratio between the variance of the cutting parameter and the error variance is called Fisher's ratio (F). It is used to determine whether the parameter has a significant effect on the quality characteristic by comparing the F test value of the parameter with the standard F table value at the P significance level. If the F test value is greater than P test the cutting parameter is considered significant. Relevance of the models is tested by analysis of variance (ANOVA). It is a statistical tool for testing the null hypothesis for planned experiments, in which several different variables are studied simultaneously. ANOVA is used to quickly analyze the variances in the experiment using the Fisher test (F test). ANOVA table shown the result of the ANOVA analysis. ANOVA analysis makes it possible to observe that the value of P is less than 0.05 in the three parametric sources. It is therefore clear that pulse on time, pulse off time and current of the SR have an influence on the Ti alloy. The last column of cumulative ANOVA shown the percentage of each factor in the total variance that indicates the degree of impact on the outcome. Table 10 shows results obtained from analysis of variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
T-on	2	1.4600	0.7300	3.51	0.053	19.07
T-off	2	3.9433	1.9716	9.47	0.022	51.51
Current	2	1.8346	0.9173	4.40	0.048	23.96
Error	2	0.4162				
Total	8	1.4600	0.7300	3.51	0.053	19.07

Table 10 ANOVA Result.

It shows that the Ton (19.07%), the Toff (51.51%) and the Ip (23.96%) have major influence on the SR. Contribution of Toff (51.51%) is highest among all three parameters hence it is most dominating parameter while Ton is least affecting parameter.

I. Development of Regression Model for Surface roughness

Regression model has been developed using Minitab software. Substituting the experimental values of the parameters in regression equation, values for surface roughness have been predicted for all levels of study parameters. Graphical representation also shows that a predicted and experimental value of surface roughness correlates with each other.

Regression Equation –

SR = 4.21 + 0.0023 [P-on] + 0.025 [P-off] + 0.200 [Current]

Table number 7 gives comparison between experimentally measured and predicted surface roughness by developed mathematical equation.

Sr. No.	Experimental value	Predicted value	Error %
1	6.318	6.935	8.89
2	8.015	7.660	4.63
3	8.348	8.385	0.44
4	6.994	7.765	9.92
5	7.659	7.248	5.67
6	5.789	5.673	9.39
7	7.792	7.146	9.04
8	6.994	7.792	7.45
9	7.012	6.796	3.17

Table 7 Experimental and Predicted Values of SR

Difference between surface roughness values calculated using regression equation and experimental values for each experience found less than 10%. Hence, we can say that the regression equation developed is valid. Figure 3.4 shows the graphical representation of experimental and values calculated using regression equation.

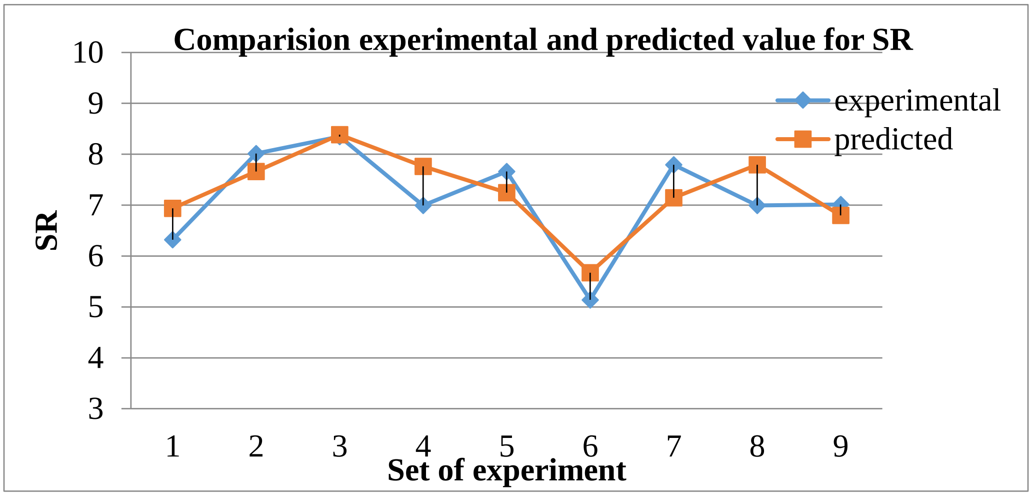

Figure 3.4 Comparison between Experimental and Predicted value of SR.

J. Confirmation Experiment Result

Table 8 shows the difference between value of surface roughness of confirmation experiment and value predicted from regression model developed.

Parameter	Model value	Experimental value	Error %
SR	6.173	5.568	9.80

Table 8 Confirmation Experiment Result

Confirmation experiment is conducted by keeping parameters at optimum levels suggested by Taguchi method and the surface value obtained has been compared with value predicted by the regression model keeping the parameters at same levels. It can be seen that the difference between experimental result and the predicted result is 9.80%. This indicates that the experimental value correlates to the estimated value.

K. Conclusions

In this study the influence of process parameters such as Ton, Toff and Ip and their optimization for Titanium alloy Steel has been studied by using Taguchi Method. Following conclusions are drawn.

1) The optimal solution obtained for MRR based on the combination of WEDM parameters and their levels is (i.e. Ton is 60 µs at level 2, P-off is 20 µs at level 2 and Ip is 12 A at level 3) and optimal solution obtained for SR based on the combination of WEDM parameters and their levels is (i.e. Ton is 60 µs at level 2, P-off is 25 µs at level 3 and Ip is 6 A at level 1).

2) ANOVA results indicate that contribution of Ton on MRR is highest followed by Toff and Ip. P-on is most dominant factor. This may be due to fact that higher the Ton, higher will be the energy applied and spark there by generating more amount of heat energy during this period.

3) Value of MRR is higher and value of SR is lower obtained in confirmation experiment. Hence, good surface finish and maximum material removed while machining can be achieved using suggested level of parameters by Taguchi method.

4) Values of MRR and SR calculated using regression model correlates with experimental values with error less than 10%. Hence the model developed is valid and experimental results of MRR and SR with any combination of WEDM parameters can be estimated within selected levels.

IV. ACKNOWLEDGMENT

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