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Optimization of Electric Discharge Machining Process Parameters Using Taguchi Technique

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Abstract

Electro Discharge Machining is a process used for machining very hard metals, deep and complex shapes by metal erosion in all types of electro conductive materials. The metal is removed through the action of an electric discharge of short duration and high current density between the tool and the work piece. The eroded metal on the surface of both work piece and the tool is flushed away by the dielectric fluid. This paper deals with optimization of Electric Discharge Machining process parameters based on the Taguchi technique. Also the effect of peak current, pulse on time, pulse off time and Tool lift time on the EDM output responses has been studied. The output responses taken for the investigation are Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface roughness (SR). The experiments were designed by Taguchi Design of Experiments, L27 orthogonal array. These have been conducted on the Titanium super alloy utilizing copper as Tool electrode with positive polarity by taking three levels of each factor.

Keywords—Titanium super alloy, Material removal rate, Tool wear rate, Surface roughness, Design of Experiment, Signal-to-Noise ratio.

I. Introduction

Electrical discharge machining (EDM) has grown over the last few decades and successfully applied for the machining of high strength materials such as Titanium super alloys, Nickel super alloys, ceramics, composite materials etc. It is a thermal process with a complex metal removal mechanism, involving the formation of a plasma channel between two electrodes the tool and the work piece, the repetitive spark between the tool and work piece causes melting and even evaporating the electrodes to produce the finished part to the desired shape. The metal-removal process is performed by applying a pulsating on/off electrical charge of high-frequency current through the electrode to the workpiece. This removes very tiny pieces of metal from the workpiece at a controlled rate and the removed metal is carried away by the dielectric fluid passing between the tool and the workpiece. The principle of EDM is shown in Fig.1. Yusuf Keskin et al. investigated the effects of machining parameters on the surface roughness valley machined by EDM on steel using copper tool electrode. The data obtained for response measures had been analyzed using the Design of experiments method. It was observed that the surface roughness had increasing trend with an increase in the discharge duration due to the more discharge energy released during this time [1, 2]. Swarup S. Mahavatra et al. applied the Taguchi method for the optimization of wire electrical discharge machining of D2 tool steel, considering the six control factors. The analysis was made using the software MINITAB. It was aimed at the study of the effect of the factors and their interactions on the machining performances and concluded the discharge current, pulse duration and die electric flow rate are the significant factors for maximization of MRR and surface finish [3]. Rajyalakshmi et al. discussed the application of Taguchi method with fuzzy logic to optimize the machining parameters for wire electrical discharge machining of Inconel 825 with multiple characteristics and concluded that the most important factors effecting are pulse on time and servo feed [4]. Saurave Datta et al. applied the Taguchi technique coupled with grey relational analysis to optimize EDM process with multiple performance characteristics. The data collected from the Taguchi's L27 orthogonal array and it was proved that combining the Taguchi method and grey relational analysis had given the effective results and improved the efficiency [7, 8]. In this paper Taguchi method was used to investigate the effect of various parameters on EDM process responses and also to optimize the various factors to obtain maximum metal removal rate, minimum tool wear rate and maximum surface finish.

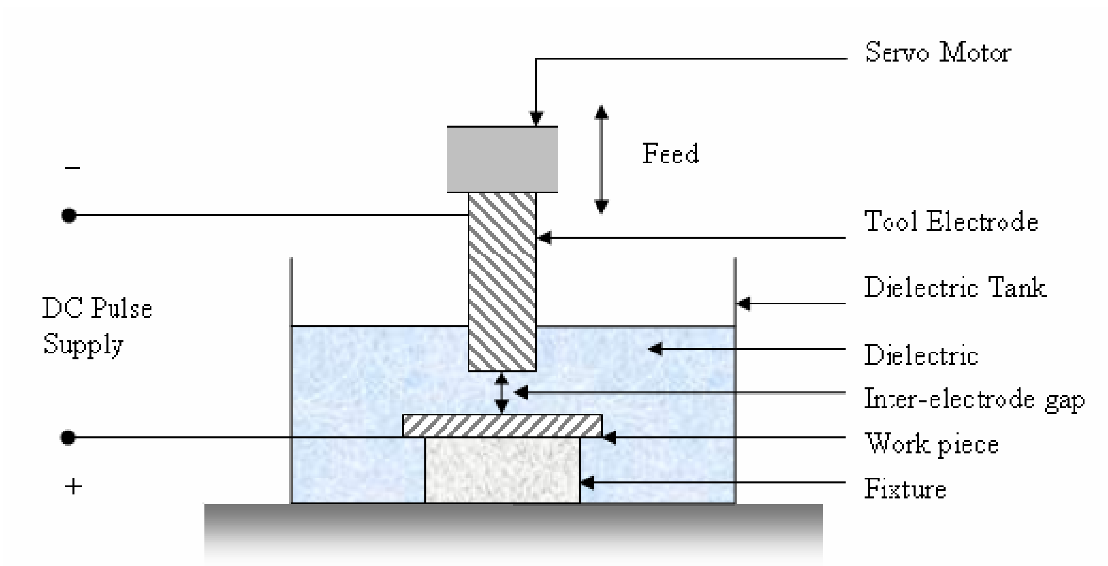

Fig.1.Principle of Electric Discharge Machining

Fig.2. Electric Discharge Machine

II.Taguchi Methodology

Taguchi method is one of the most efficient tools for the analysis of manufacturing design. The design of experiments is based on Taguchi L27 (3^4) orthogonal array was taken for conducting the experiments. The levels and notations of the process parameters are given in table 1. L27 orthogonal array has 27 rows corresponding to 27 experimental runs with 26 degree freedom on the basis of input factors. In the present work four input factors had been taken for conducting the experiments, those are Peak current (I_p), Pulse on time (T_{on}), Pulse off time (T_{off}), and Tool life time (T_{litt}). The combination of the control parameters based the orthogonal array are shown in table 2. The Signal-to-Noise (S/N) ratios has been calculated based on the Taguchi technique using the following equations [6].

$$\eta = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_i}^2}\right] \dots\dots\dots \quad (1)$$

$$\eta = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}{y_i}^2\right] \dots\dots\dots \quad (2)$$

Where, η is the S/N ratio, which is calculated from the observed values, y_i represents the experimental values of the i^{th} experiments and n is the number of replication of each experiment.The Eq.1 and Eq.2 are used for calculation of S/N ratios for “Larger the better” type characteristics and “Smaller the better” type characteristics respectively. In the present study MRR is considered as the larger the better type because of the higher MRR represents higher efficiency of the machine and TWR, SR are considered as the smaller the better type problems because of smaller the values of TWR and SR gives lower economy and better precision. Higher the S/N ratio better the performance responses.

Table 1: Selected process parameters in EDM process

Factor notation	Factor	Symbol & units	Level 1	Level 2	Level 3
A	Peak Current	I_p, Amp.	9	12	15
B	Pulse On time	T_{on}, µs	10	20	50
C	Pulse Off time	T_{off}, µs	20	50	100
D	Tool LIFT time	T_{lift}, µs	5	10	20

III. Experimental Details and Measurements

Experiments were carried out on die sinking EDM (shown in fig.2) of type Askar microns model V3525 with servo head constant gap voltage positive polarity. Commercial 30 Grade EDM Oil is used as Dielectric fluid. The investigation had been carried out on Titanium super alloys which has the hardness 104HRC. The chemical composition of work material is given in table.2. The copper electrode (99.9% of Cu) was used as tool because of higher MMR and lower cost. Machining of each experiment was carried out for 10 minutes.The MRR and TWR are calculated by measuring the weight difference of work piece and electrode before and after machining using a digital weighing balance of type AY220 with precision 0.001gm, is shown in figure 3. The MRR and TWR are calculated from the following equations [5].

$$MRR = \frac{(wp_1 - wp_2)}{T} \text{ mg/minute}$$

Where wp_1 and wp_2 are the weights of the workpiece before and after machining, T is the machining time.

$$TWR = \frac{(wt_1 - wt_2)}{T} \text{ mg/minute}$$

Where wt_1 and wt_2 are the weights of the workpiece before and after machining, T is the machining time.

The process parameters are selected based on the preliminary experiments and machine operating conditions and the experimental results of MRR, TWR and SR are tabulated in table 3. The measurements of average SR were made on HANDYSURF E 35 B. Three measurements of SR had been taken at different locations and the average value is used in the analysis.

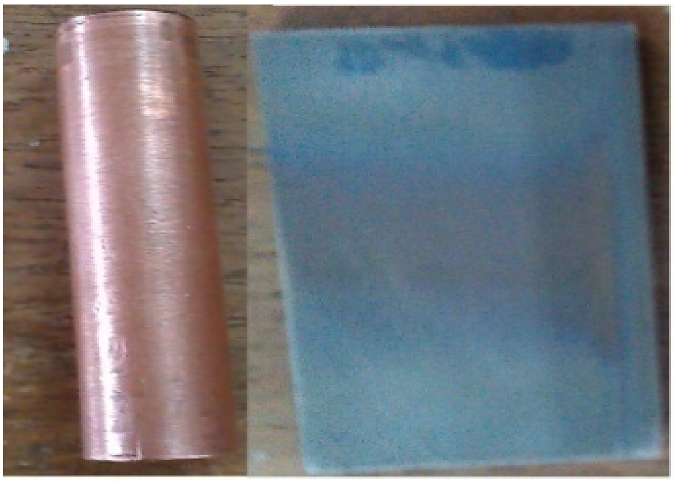

Fig.3 Tool Electrode & Work Piece

Fig. 4 Digital Weighing balance

Table.2 Chemical composition of work material.

Titanium	Al	C	Mo	Zr	Si	Fe	P	V
Base	5.5-6.8%	< 0.13%	0.5-2%	1.5-2.5%	< 0.15%	< 0.3%	0.8-2.5%	0.3%

Table 3 : Experimental results and S/N ratios

S. No.	I_p (Amp)	T_{on} (μs)	T_{off} (μs)	T_{lift} (μs)	MRR (mg/min)	TWR (mg/min)	SR (μm)	S/N ratio (MRR)	S/N ratio (TWR)	S/N ratio (SR)
1	9	5	20	5	7.2	1.2	0.7567	17.14	-1.5836	2.429
2	9	5	50	10	3.3	0.5	0.75	10.371	6.02	2.498
3	9	5	100	20	2.1	0.5	0.68	6.4	6.02	3.349
4	9	20	20	10	12.81	0.48	0.91	22.102	6.375	0.819
5	9	20	50	20	7.93	0.11	0.71	17.981	19.172	2.974
6	9	20	100	5	5.6	0.16	0.7	14.962	15.9176	3.098
7	9	50	20	20	7.8	0.19	0.79	17.841	17.721	2.047
8	9	50	50	5	10.9	0.42	1.02	20.742	7.535	-0.172
9	9	50	100	10	8	0.17	0.833	18.061	15.391	1.587
10	12	5	20	10	8.7	0.7	0.73	18.798	3.098	2.733
11	12	5	50	20	4	0.31	0.716	12.041	10.1727	2.901
12	12	5	100	5	3.5	1.13	0.936	10.882	-0.9843	0.574
13	12	20	20	20	6.5	0.69	0.986	16.254	3.223	0.122
14	12	20	50	5	11.6	0.18	0.81	21.285	14.8945	1.83
15	12	20	100	10	5.6	0.28	0.7	14.961	11.0568	3.098
16	12	50	20	5	11.8	0.41	0.936	21.19	7.7443	0.574
17	12	50	50	10	11.1	0.4	0.726	20.902	7.9588	2.782
18	12	50	100	20	4.9	0.9	0.71	13.801	0.9151	2.974
19	15	5	20	20	8	1	0.936	18.06	0	0.574
20	15	5	50	5	10.2	1.3	0.886	20.171	-2.2875	0.525
21	15	5	100	10	4.4	0.8	0.51	12.863	1.9382	5.848
22	15	20	20	5	21.2	3	0.896	26.521	-9.5424	0.953
23	15	20	50	10	17	1.7	0.683	24.301	-4.609	3.311
24	15	20	100	20	7.1	0.8	0.516	17.022	1.9382	5.747
25	15	50	20	10	10.7	0.8	1.63	20.58	1.9382	-4.243
26	15	50	50	20	8.3	0.86	0.99	18.38	1.31	0.087
27	15	50	100	5	13.9	1.3	0.786	22.86	-2.2788	2.091

IV. Analysis of Results

The signal to noise ratio for MRR were calculated based on the Eq.1 since it is the "larger the better" characteristic and for TWR and SR were calculated base on the Eq.2 because of it is the "smaller the better" characteristics. The S/N ratio for each treatment is shown in table 3. The overall mean for S/N ratio of MRR was found as 17.646 db where as the overall mean for S/N ratio of TWR and SR are found as 5.15 db and 1.892 db respectively.

Table 4.Response table for S/N ratios of MRR

Level	I_p	T_{on}	T_{off}	T_{lift}
1	16.1771	14.0802	19.8258	19.5225
2	16.6734	19.4920	18.4681	18.1080
3	20.088	19.3674	14.645	15.3091
Delta	3.9114	5.4118	5.180	4.2133
Rank	4	1	2	3

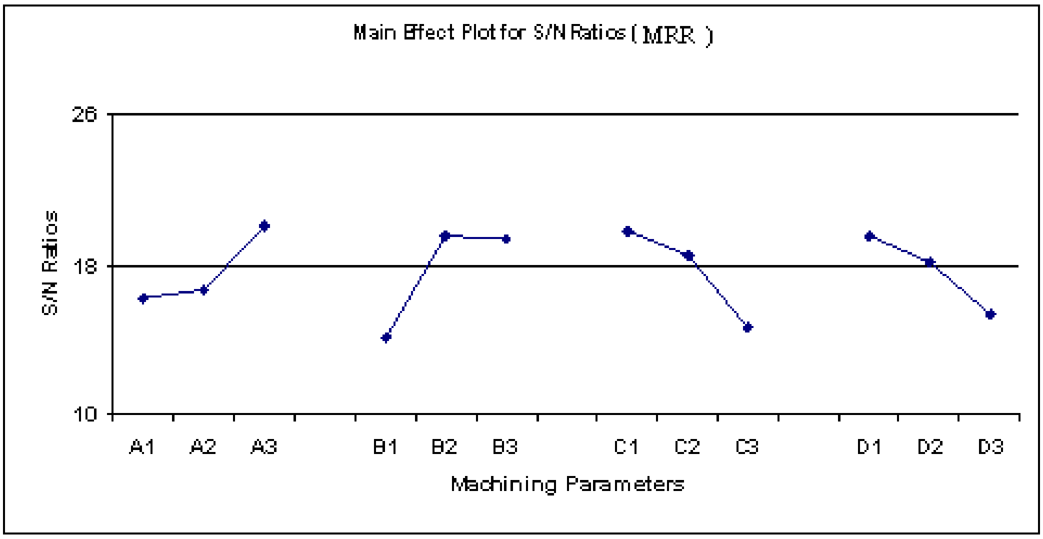

Fig.5 S/N ratio curves of the process parameters for MRR

The response tables for S/N ratios of MRR, TWR and SR are shown in tables 4, 5 and 6 respectively. The graphical representation of the effect of the four control factors on MRR, TWR and SR are shown in figures 5, 6 and 7 respectively. Referring to table 4 it is observed that the pulse on time and pulse off time are playing as the main parameters for increasing the MRR, where as peak current and tool lift time have the similar effect on the MRR. The MRR is higher in case of the 22nd run and minimum in case of 3rd run.

Table 5.Response table for means of TWR

Level	I_p	T_{on}	T_{off}	T_{lift}
1	10.2856	2.4892	3.2196	3.2694
2	6.4529	6.4717	6.6861	5.4628
3	-1.286	6.4917	5.5459	6.7193
Delta	11.522	4.0024	3.4665	3.4499
Rank	1	2	3	4

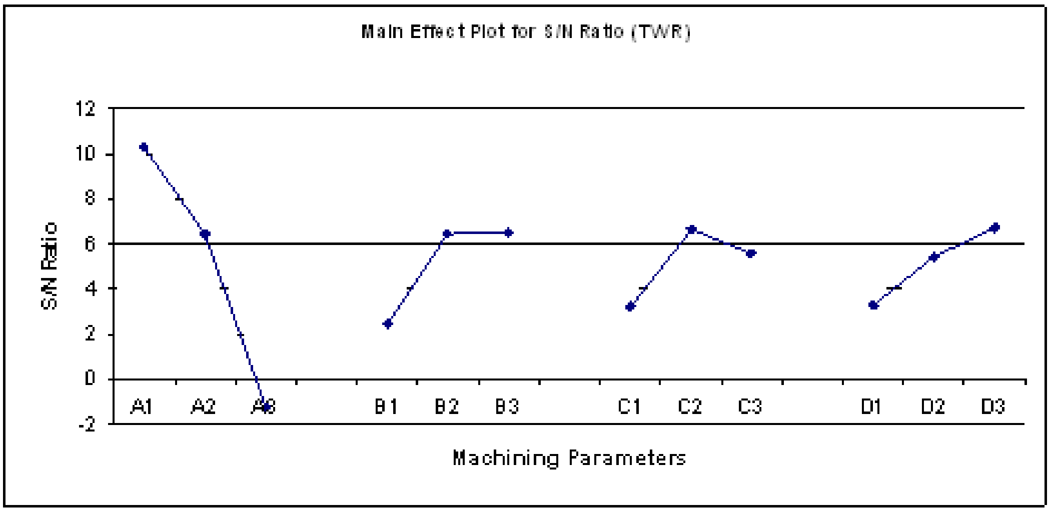

Fig.6 S/N ratio curves of the process parameters for TWR

In case of TWR, it was observed that TWR is higher for the 22nd run and least in 5th experimental run, it is also seen from the table 5 that peak current is playing as main parameter for reducing TWR, where as the tool lift time is the least influencing parameter on it. If current value is changed from low level to high level the tool wear rate increases and S/N ratio decreases from low level to high level as shown in fig 6. The pulse on time and pulse off time have the similar behavior on TWR, which decreases from low level to high level.

Referring to table 6, it is seen that the pulse off time is influencing as main factor for reducing the surface roughness, where as current is the least affecting factor. It can be seen from the main effect plots for S/N ratio that value of S/N ratio decreases as pulse on time increases from low level to high level. Similarly S/N ratio goes on decreasing when the current increases, that mean SR increases as current increases, the corresponding analysis is shown in fig.8. The larger the S/N ratio, the better is the process response, therefore, the optimal machining parameters for MRR are peaks current at level 3, pulse on time at level2, pulse off time at level1 and the tool lift time at level 1. Similarly for TWR the optimal machining parameters are peak current at level 1, pulse off time at level 3, pulse off time at level 2 and tool lift time at level 3. From the response table for the S/N ratio of SR the optimal machining parameters are selected as peak current at level 1, pulse on time at level 2, pulse off time at level 3 and the tool lift time at level 3.

Table 6.Response table for S/N ratios of SR

Level	I_p	T_{on}	T_{off}	T_{lift}
1	2.0698	2.3812	0.6675	1.3224
2	1.9542	2.4391	1.8595	2.0481
3	1.6547	0.8585	3.1517	2.3083
Delta	0.4150	1.5805	2.4842	0.9859
Rank	4	2	1	3

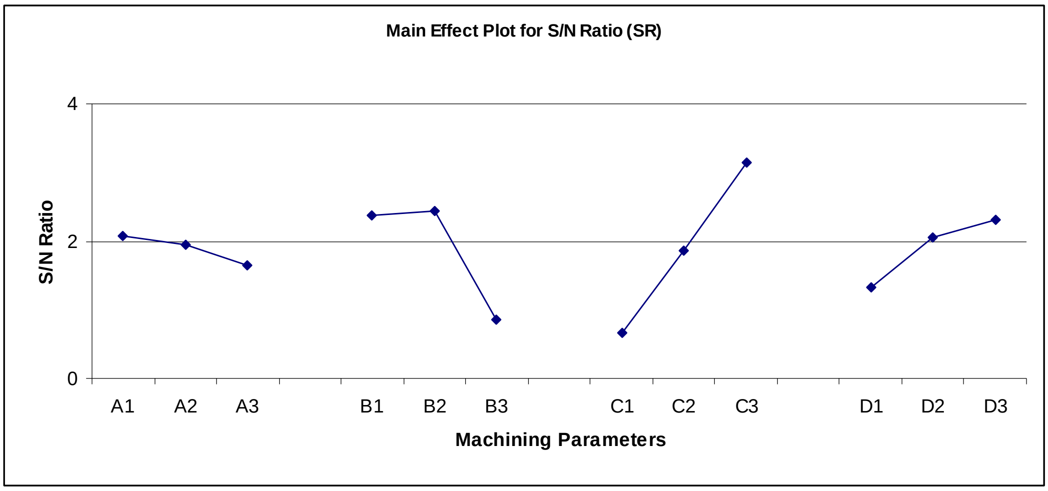

Fig.7 S/N ratio curves of the process parameters for SR

Table 10. Optimal machining process parameters and experimental results.

Response	Optimal machining parameters				Predicted	Experimental
	Ip (Amp)	Ton (µSec)	Tof (µSec)	Tuf (µSec)		
MRR (mg/min)	15	20	50	5	18.768	21.120
TWR (mg/min)	9	50	50	20	0.0178	0.0200
SR (µm)	9	20	100	20	0.5248	0.5010

IV. Confirmation test

Once the optimal levels of EDM process parameters obtained, these parameters are used to predict the corresponding value of response that represent the quality of the EDM process. Predicted response value given by the following equation.

$$\gamma_{predicted} = \gamma_m + \sum_{i=1}^{n} (\gamma_0 - \gamma_m)$$

Where $\gamma_{predicted}$ is value of response to validate the EDM process is, γ_0 is the average value of response at optimal level of the factors. γ_m is the average value of response and *n* is the number of factors finally the confirmation tests have been conducted using the optimal EDM process parameters for each response, the values are tabulated in table 10.

V. Conclusions

The following conclusions are drawn from the Analysis based on the Taguchi method.

- Increase in peak current causes MRR, TWR and SR to increases continuously.
- Increase in tool lift time causes MRR, TWR and SR to decreases continuously.
- Increase in pulse on time causes MRR, TWR to increase and SR to decrease.
- Increase in pulse off time causes MRR, SR to decrease, however, TWR to increase up to level 2, followed to decrease till level 3.
- The optional conditions for maximum metal removal rate are peak current 15Amp, Pulse on time 20 µsec, pulse off time 50 µsec, and tool lift time 5 µsec.
- The optional conditions for minimum Tool wear rate are peak current 9 Amp, Pulse on time 50 µsec, pulse off time 50 µsec, and tool lift time 20 µsec.
- The optional conditions for Maximum Surface finish are peak current 9 Amp, Pulse on time is 20 µsec, pulse off time 100 µsec, and tool lift time 20 µsec.
- It has been observed from the confirmation test results that the experimental values are better than to the predicted values; therefore, it has been proved that the Taguchi Technique is the effective method to provide the better solution for the single objective optimization problems.

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