International Journal of Production Engineering
Vol. 3: Issue 2
www.journalspub.com

Optimization of Machining Parameters in Electrical Discharge Machining Process of Ti-6Al-4V Alloy by Taguchi Method

Ishita Gupta, Gauri Tyagi*
Mechanical Engineering Department, Gautam Buddha University, Greater Noida, India

ABSTRACT
Electrical discharge machining (EDM) process has been made for creating holes in materials that are tough to machine, by creating sparks between the face of stationary tool electrode and workpiece. This paper depicts the effect of various input process parameters of EDM, such as discharge current, pulse on-time and pulse off-time on the respective outputs: material removal rate (MRR), tool wear rate (TWR) and average surface roughness (ASR). This process has been done on titanium grade 5 alloy.

Keywords: average surface roughness, electrical discharge machining, material removal rate, tool wear rate

****Corresponding Author***
E-mail: ishitagupta455@gmail.com

INTRODUCTION

At present, many of the advanced machining processes are widely utilized in industries, including electrical discharge machining, which has gained immense popularity in major aviation industries. Electrical discharge machining (EDM) so far is one of most widely used thermal energy-based advanced machining processes. In EDM there are two electrodes (tool electrode and workpiece electrode) separated by small gap (5–200 μm) which is called as interelectrode gap (IEG). During operation, electrical discharge occurs between two small gap electrodes in a dielectric fluid. The dielectric fluid works as an insulator between the tool and workpiece. Dielectric fluid eradicates the small quantity of heat generated by the discharges, and flushes off the discharges by-products from the IEG. As machining proceeds the number of particles in the gap increases rapidly. It is mandatory to discard the wear debris from the gap so that fresh dielectric enters for spark discharges.

In this paper, the investigation has been done on the workpiece Ti-6Al-4V alloy via Taguchi method. The various input parameters have been optimized to retrieve finest MRR, TWR and ASR values (with the main emphasis being on MRR and ASR). The stationary tool electrode that being utilized is copper (99% pure copper), which is 10mm in diameter. The drilling of Ti-alloy has been done with 3 parameters varied at 3 different levels, hence, been measured on an L9 orthogonal array. The main effects have by analyzed via ANOVA.

PAST WORK

Sultan et al. [1] studied the output effects (MRR, EWR and ASR) on EN-353 steel in a die sinking EDM process with the help of a hollow copper tool. The experiment was conducted under reverse polarity, i.e., the workpiece was connected to positive terminal and tool negative. Via the experiment, it was determined that EDM is suitable for machining the workpiece with good MRR and EWR. It was found that the effect of pulse on time and pulse off time effected the EWR the most. Also, to get low ASR peak current and pulse on time should be on low levels.

Pradhan et al. [2] performed 30 EDM experiments on AISI D2 tool steel with a 30mm copper tool in positive polarity. The lubricant being used was commercial grade EDM oil and control parameters were discharge current, pulse on time, pulse off time and discharge voltage. With the help of response surface methodology (RSM) the process parameters having the most effect on SR were determined. In conclusion, the best surface finish was found at the parameter combinations of I = 15A, Ton = 25 μs and Toff = 100 μs.

Manisha Priyadarshini et Al. [3] used grey relational Taguchi analysis to optimize EDM on Ti-6Al-4V alloy, with the help of a copper electrode. The L25 orthogonal array design was used to get the desired output parameters results with respect to each input parameter. The effects of current, duty factor and pulse-on-time on MRR, TWR and surface roughness were evaluated. The optimal EDM parameter settings were discovered.

Rahman et Al. [4] aims at optimizing the input parameters in regard to the tool wear rate in EDM. The tool being copper tungsten, and the workpiece being Ti-6Al-4V. The parameters being optimized are peak current, pulse on time and pulse off time. It was found that TWR decreases with increase of pulse on time and pulse off time and at a current value between 10 and 25 A.

Khan [5] studied the effects on MRR and TWR on aluminium and mild steel workpieces using both copper and brass electrodes. He found that highest wear ration was when EDM was being done by brass electrode on steel. The highest MRR was when EDM was being performed on aluminium by brass electrode. The MRR was lowest when copper electrodes were being used on steel. However, the TWR of copper is less than of the brass electrode.

Chattopadhyay et al. [6] developed empirical model for three parameters and three levels for rotary EDM. Based on model they have achieved near results in further experimentation. The workpiece was EN-8 (steel) and tool used was copper. Some empirical formulae were developed to evaluate MRR, TWR and SR. They also found that maximizing MRR and achieving best SR is not possible simultaneously at one combination of control parameters settings.

Patel et al. [7] determined the influence of the process parameters; gap voltage, peak current, pulse on time, pulse off time and the material of the electrode, seen on the output parameters MRR, TWR and SR. The array used to perform the experiments was L27 orthogonal array and 3 electrodes of 16 mm diameter each were used; aluminum, copper and brass. It was found that performing EDM on AISI H13 steel helps get the needed dimensional accuracy and intricacy.

EXPERIMENTAL WORK

The EDM equipment has been used on tool craft spark erosion machine (Model G30 Integrated Type). The setup has been designed keeping in view the fundamental mechanism of the process and basic functional requirements of different parts. The experimental setup is shown. The EDM setup consists of electrically conductive electrode (copper), motor, shaft, V-belt, and bearing. At one side of the shaft, the copper tool electrode is mounted, and another side V-pulley is mounted for rotation. Design of the shaft requires the selection of some input parameters like material, motor power, and motor RPM. The V-belt is used to transmit power from driver to driven pulley. In our EDM attachment, smooth power transmission is required because fluctuation in the speed affects the spark. Copper tool electrode is mounted on the shaft with the help of collar. In the EDM process the gap between both electrodes should be constant during machining. According to the requirements, the specification of the copper tool is selected, after a lot of researching. The fabricated attachment had been replaced by original tool holder of die-sinking EDM. The EDM assembly is partially dipped in dielectric with in dielectric tank. The manometers have been used to measure dielectric pressure. The dielectric fluid used in the experiment was spark erosion oil 25.

First, preliminary experiments were conducted using a copper tool electrode. The spark and machined surface was clearly observed. Current, pulse on-time and pulse off-time are the process parameters of EDD process. The operating conditions were selected as control factors. An exhaustive pilot experimentation is done to decide the parameter range for machining of titanium grade 5 alloy. The control factors (or input parameters) taken are the current (3–7 A), pulse on-time (100–200 μs) and pulse off-time (50–100 μs). The effect of these various input parameters was experimentally observed on output parameters such as MRR, TWR and ASR. Titanium was the rectangular workpiece material for experimentation. The composition of titanium grade 5 alloy is given in Table 1. Thickness of the workpiece was taken as 6 mm.

Table 1. *Composition of titanium grade 5 alloy.*

Chemical composition (%)							
O	N	H	Fe	C	Al	V	Ti
0.2	0.05	0.015	0.40	0.10	5.5 - 6.75	3.5 - 4.5	Balance

The electrode was sunk to generate a cylindrical profile on workpiece. The experiments were conducted for fixed time period, i.e., 20 minutes for set of experiments.

Reduction in the weight of the workpiece was calculated by obtaining weight difference before and after machining using electronic digital weight balance. The electronic digital weight balance is used to measure the weight of the workpiece. It has a weighing range of 0–100 g with a least count of 0.1 mg. MRR was calculated for each cutting condition using the formula:

$$MRR = (Wi - Wf) / t \quad g/min$$

where Wi is initial weight of workpiece in g (before machining), Wf is final weight of workpiece in g (after machining) and t is machining time in minutes. ASR was measured using Surface Roughness Tester. The workpiece was fitted to a device which was suitably clamped by bolts to the slots that were available on the base of the dielectric tank. The workpiece clamped within the device.

Taguchi's design was the basis of the flow of the experiment. This method is based on Orthogonal arrays and helps determine the optimal settings in which to conduct the experiment.

Orthogonal arrays assist in providing a minimum number of experiments and also the Signal-to-noise ratio (S/N ratio) which are the log function of the desired output, this helps in analyzing data and for the prediction of optimum results [8].

The 3 S/N ratios for optimization are (n being the MSNR):

i) Smaller the better

n = 10 $\log_{10}$ (mean sum of squares)

ii) Larger the better

n = 10 $\log_{10}$ (reciprocal of the mean sum of squares)

iii) Nominal is best

n = 10 $\log_{10}$ (mean sum of squares/variance)

RESULTS AND DISCUSSION

The ranking shown in the Table 2–5 show the relative contribution of the factors on multiple quality characteristics.

For MRR, the calculations for the S/N ratio have been done based on 'Larger the Better' model. For ASR and TWR the calculations were done based on 'Smaller the Better'.

n = 10 $\log_{10}$ (reciprocal of the mean sum of squares)

Table 2. *Response table for signal to noise ratios for MRR.*

Level	I (A)	Ton (µs)	Toff (µs)
1	-55.86	-51.94	-53.80
2	-60.79	-53.79	-54.76
3	-45.18	-56.10	-53.26
Delta	15.62	4.16	1.50
Rank	1	2	3

Table 3. *ANOVA for MRR.*

Source	DF	Seq SS	Adj SS	Adj MS	P
Current (A)	2	382.429	382.429	191.215	92.06
Ton (µs)	2	26.054	26.054	13.027	6.27
Toff (µs)	2	3.464	3.464	1.732	0.83
Residual Error	2	3.446	3.446	1.723	
Total	8	415.393			

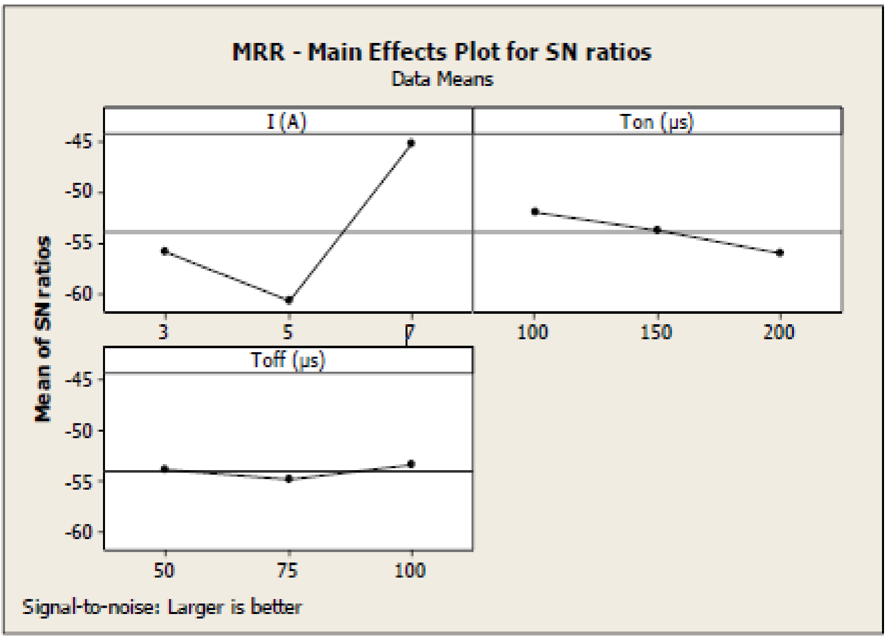

Fig. 1. *Quality characteristic MRR at different levels.*

From this it shows that the peak current (I) has the most effect on the material removal rate.

The graphical representation of factor effect on the quality characteristic MRR at different levels is shown in Figure 1.

The optimum levels of different control factors for MRR obtained are peak current at level 3 (7 A), pulse on time at level 3 (200 µs) and pulse off time at level 3 (100 µs).

Similarly, the optimum levels of TWR and ASR are calculated. The graphical representation of factor effect on the quality characteristic each at different levels are shown in Figures 2 and 3.

Table 4. *Signal to noise ratios for TWR.*

Level	I (A)	Ton (µs)	Toff (µs)
1	68.84	67.56	69.56
2	70.01	70.46	71.63
3	69.18	70.01	66.83
Delta	1.17	2.90	4.80
Rank	3	2	1

Here, pulse off time has maximum effect on TWR.

Table 5. Response table for signal to noise ratios for ASR.

Level	(A)	Ton (µs)	Toff (µs)
1	-13.03	-13.73	-13.80
2	-13.42	-13.46	-13.28
3	-14.35	-13.62	-13.73
Delta	1.32	0.28	0.51
Rank	1	3	2

Peak current has maximum effect on ASR. The graphical representation of factor effect on the quality characteristic each at different levels are shown in the following 2 figures.

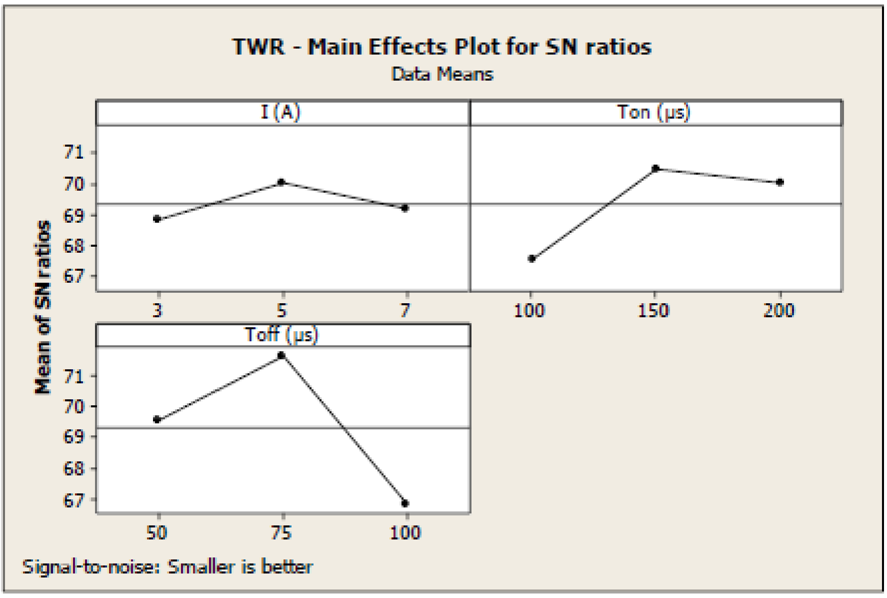

Fig. 2. *Factor effect on the quality characteristic each at different levels of TWR.*

The optimum levels for TWR for peak current is at level 2 (5A), pulse on time at level 2 (150 µs) and pulse off time is at level 2 (75 µs).

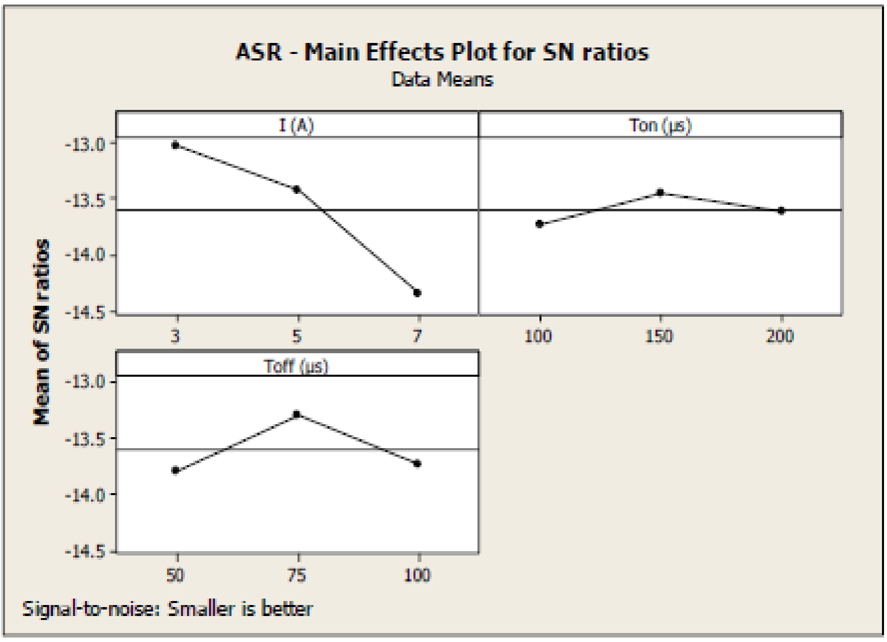

Fig. 3. *Factor effect on the quality characteristic each at different levels of ASR.*

For ASR, peak current, pulse on time and pulse off time are optimum at level 1 (3 A), level 2 (150 µs) and level 2 (75 µs), respectively.
Now to verify is the experiment has been done correctly a confirmation experiment is done.

Using the formula,

Yoptimal = Tavg + (A3avg – Tavg) + (B3avg – Tavg) + (C3avg – Tavg) + (D2avg – Tavg),

We can calculate the optimal values for each output characteristic.

We get the following values:

MRR: Yoptimal = 0.007504 g/min
TWR: Yoptimal= 0.000164 g/min
ASR: Yoptimal = 4.276 µm

Process Parameters	I	Ton	Toff	Quality Characteristic
Level No.	3	1	3	MRR = 0.007504
	2	2	2	TWR = 0.000164
	1	2	2	ASR = 4.276

Thus, by comparing the experimental and calculated results the following was observed

Quality Characteristics	Optimal Setting	Predicted & Confirmed Results		
		Predicted Value	Experimental Value	% Error
MRR	A3B1C3	0.007504	0.007850	4.610874
TWR	A2B2C2	0.000164	0.000171	4.268293
ASR	A1B2C2	4.276000	4.359000	1.941066

From the analysis of confirmation results, it can be seen that the calculated error is minute. The error between the calculated and experimental values are 4.61%, 4.26% and 1.94%, for MRR, TWR and ASR, respectively.

From the analysis, it can be justified that the experimental work has been done well and that it can be reproduced with ease.

CONCLUSION

On studying the optimization of MRR, TWR and ASR that has been done for the EDM process on the workpiece Ti-6Al-4V. The subsequent conclusions can be deducted on the basis of the results:

(1) The calculated values that are observed from optimal EDM parameters; MRR = 0.007504, TWR = 0.000164 and ASR = 4.276.
(2) The ranking as per the response table for the signal to noise ratios for MRR are as follows: Peak current, Pulse on time and Pulse off time. For TWR the order of influence is pulse off time, pulse on time and, then least, peak current. Similarly, for ASR from maximum to minimum the order is Peak current, Pulse off time and finally Pulse on time.
(3) The optimum levels of different control factors for MRR obtained are peak current at level 3 (7A), pulse on time at level 3 (200 µs) and pulse off time at level 3 (100 µs). Similarly, for optimized values for TWR; peak current is at level 2 (5A), pulse on time at level 2 (150 µs) and pulse off time is at level 2 (75 µs). Finally, for ASR; peak current, pulse on time and pulse off time are optimum at level 1 (3 A), level 2 (150 µs) and level 2 (75 µs), respectively.
(4) The optimized parameters combination for MRR, TWR and ASR are A3B1C3, A2B2C2 and A1B2C2, respectively.

REFERENCES

[1] T. Sultan, A. Kumar, R.D. Gupta. Material removal rate, electrode wear rate and surface roughness evaluation in die sinking EDM with hollow tool through response surface methodology, *Int J Manuf Eng*. 2014; 2-3: 14p.

[2] M.K. Pradhan, C.K. Biswas. Modelling & analysis of process parameters on SR in EDM of AISI D2 tool steel by RSM approach, *Int J MPES*. 2–6p.

[3] M. Priyadarshini, K. Pal. Grey-Taguchi based optimization of EDM process for titanium alloy, *J Mater Process Charact*. 2015; 2-3: 10p.

[4] M.M. Rahman, Md.A.R. Khan. Optimization of machining parameters on tool wear rate of Ti-6Al-4V through EDM using copper tungsten electrode, *J Adv Mater Res*. 2010; 2-3: 7–8p.

[5] A.A. Khan. Electrode wear and material removal rate during EDM of aluminium and mild steel using copper and brass electrodes, *Int J Adv Manuf Technol*. 2007; 2-3: 5–6p.

[6] K.D. Chattopadhyay, S. Verma. Development of empirical model for different process parameters during rotary electrical discharge machining of copper–steel (EN-8) system, *J Mater Process Technol*. 2009; 3-4: 11p.

[7] B.A. Patel, D.S. Patel, H.A. Patel. Influence of electrode material and process parameters on surface quality and MRR in EDM of AISI H13 using ANN, *Int J Recent Innov Trends Comput Commun*. 2013; 3: 11p.

[8] I. Gupta, G. Tyagi, S. Sharma, G.K. Singh, R. Kumar. Some investigations into electrical discharge drilling of Ti-alloy using Taguchi method, *Int J Electro Mech Mech Behav*. 2017.