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OPTIMIZATION AND MODELING FOR MATERIAL REMOVAL IN A NONCONVENTIONAL PROCESS ON TITANIUM ALLOY

Md. Ashikur Rahman Khan[1,*], **M. M. Rahman**[2] and **Md. Bellal Hossain**[3]

[1]*Department of Information and Communication Technology, NSTU, Bangladesh*
[2]*Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia*
[3]*Department of Computer Science and Telecommunication Engineering, NSTU, Bangladesh*

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ABSTRACT

Although there are many nonconventional techniques, electrical discharge machining (EDM) is a most important process where no direct contact of tool and workpiece. Electrical discharge machining is a relatively modern machining process having distinct advantages over other machining processes. Proper selection of the machining parameters is vital role for machining performance in terms of higher material removal rate, better surface finish, and lower electrode wear ratio. This paper was investigated the influence of machining characteristics of EDM process in terms of peak current, pulse on time and pulse off time on titanium alloy of Ti-6Al-4V. A mathematical model is developed using response surface method (RSM) and optimum machining settings in favor of material removal rate (MRR) is evaluated and design of experiments (DOE) method are implemented. Analysis of variance (ANOVA) has been performed to verify the fit and adequacy of the developed mathematical models. The acquired results yield that the material removal rate increases with ampere and pulse on time and while decreasing tendency is observed with increasing pulse off time. These results lead to desirable MRR and economical industrial machining by optimizing the input parameters.

Keywords: *Electrical Discharge Machining, Material removal rate, Nonconventional process, Response Surface Methodology, Titanium Alloy.*

1. INTRODUCTION

The usage of titanium and its alloys is increasing in many industrial and commercial applications because of these materials' excellent properties such as a high strength–weight ratio, high temperature strength and exceptional corrosion resistance (Hascalık and Caydas, 2007). The most common titanium is the α+β type two phase Ti–6Al–4V alloy among several alloying types of titanium. In aerospace industry, titanium alloys have been widely used because of their low weight, high strength or high temperatures stability (Fonda *et al.,* 2008). Titanium and its alloys are difficult to machine materials due to several inherent properties of the material (Rahman *et al.*, 2010). Owing to their poor machinability, it is very difficult to machine titanium alloys economically with conventional machining process (Rahman *et al.*, 2006).

Non conventional Machining is a recent development in machining techniques. It is based on unconventional machining techniques using ultrasonic machining, electrochemical grinding electrochemical machining, electrical discharge machining, electron beam machining, plasma arc machining etc. Conventional machining involves the direct contact of tool and workpiece, whereas unconventional machining does not require the direct contact of tool and workpiece. The electrical discharge machining is a well-established machining choice for manufacturing geometrically complex or hard material parts that are extremely difficult-to-machine by conventional machining processes (Ho and Newman, 2003). Its unique feature of using thermal energy to machine electrically conductive parts regardless of hardness has been its distinctive advantage for manufacturing of mold, die, automotive, aerospace and surgical components (Ponappa *et al.,* 2010). Thus, titanium and titanium alloy, which is difficult-to-cut material, can be machined effectively by EDM (Yan *et al.,* 2005). Proper selection of the machining parameters can result an effective machining performance (Lin *et al.,* 2002). Several researches have been carried out for improving the process performance and for detection optimum parameters as follows. A study has been carried out to develop a mathematical model for optimizing the EDM characteristics on matrix composite Al/SiC material (Habib, 2009). They used response surface methodology to determine the optimal setting of the EDM parameters such as the metal removal rate, electrode wear ratio, gap size and the surface finish. The effect of the thermal and electrical properties of titanium alloy Ti–6Al–4V on EDM productivity has been detected (Fonda *et al.,* 2008). They stated that the duty factor is a vital EDM condition parameter and is an easy means of changing the energy application to the workpiece. The results indicate that as the duty factor increases, the internal workpiece temperature also increases which causes poor EDM productivity and quality. The optimal duty factor in terms of productivity and quality was found at around 7%. Tomadi *et al.* (2009) were carried out the optimum machining conditions for machining Tungsten Carbide with a Copper Tungsten as electrode. For material

* Corresponding Author: ashik.nstu@yahoo.com

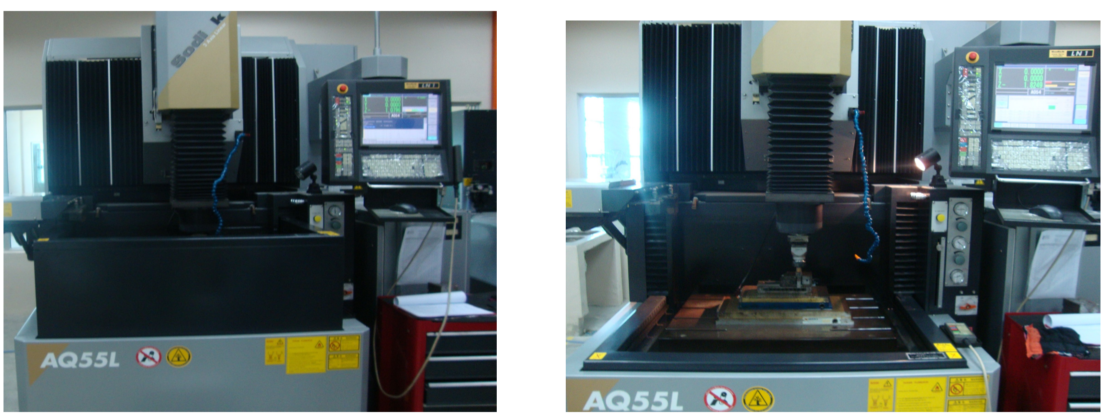
removal rate pulse on time is the most influential, followed by voltage, peak current, and pulse off time. In order to obtain optimum circumstances high values of peak current and voltage to get high MRR should be used. To investigate the relationships and parametric interactions between the variables on MRR using response surface methodology experiments have been conducted on AISI D2 tool steel with Cu electrode (Prodhan and Biswas, 2008). It was acquired that discharge current, pulse duration, and pulse off time significant effect on the MRR. Their observation illustrates that the highest MRR values appeared at the higher ampere and pulse on time and at the lower pulse off time. Research have been attained to assess the effect of three factors-tool material, grit size of the abrasive slurry and power rating of ultrasonic machine on machining characteristics of titanium (ASTM Grade I) using full factorial approach for design and analysis of experiments (Kumar *et al.,* 2008). It has been investigated that the surface finish obtained in USM is better than many of the other non-traditional techniques. It has been reported that the MRR depend on the tool material.

Optimal selection of process parameters is very much essential as this is a costly process to increase production rate considerably by reducing the machining time. Thus, the present paper emphasizes the development of models for correlating the various machining parameters such as peak current (I_P), pulse on time (t_i) and pulse off time (t_o) on the most dominant machining criteria i.e. MRR. Machining parameters optimization for the titanium alloy material Ti-6Al-4V has been carried out using the techniques of DOE and RSM. Also the effect of input parameters on the characteristic of machining such as material removal rate on Ti-6Al-4V has been analyzed.

2. RESEARCH METHODOLOGY

2.1 Experimental Set Up

Pulse on time (t_i) refers the duration of time (μs) in which the current is allowed to flow per cycle (Puertas and Luis, 2003). Pulse off time (t_o) is the duration of time (μs) between the sparks. The experiments are carried out utilizing a numerical control programming electrical discharge machine known as ‘‘LN power supply AQ55L”. The EDM has the provisions of movement in three axes such as longitudinal (X-axis), lateral (Y-axis) and vertical direction of electrode (Z-axis) and has also a rotary U-axis. In this effort, titanium alloy (Ti-6Al-4V) was selected as the workpiece material and cylindrical copper electrode were employed to machine the workpiece. The machining was usually carried out for a fixed time interval. The listing of experimental parameters is also scheduled in Table 1. The weight of the workpiece before and after machining was measured by a digital balance (AND GR-200) with readability of 0.1mg. The experimental setup is shown in Fig. 1. The schematic diagram of the electrical discharge machining process is presented in Fig. 2.



(a) EDM at machining state (b) EDM tank and workpiece

Figure 1: Experimental setup of electrical discharge machining.

The amount of metal removed was measured by taking the difference in weights of the workpiece before and after electrical discharge machining. The MRR is expressed as the weight of material removed from workpiece over a period of machining time in minutes (Wu *et al*., 2005; Khan *et al.,* 2012b). The MRR was calculated by the formula as expressed in (1) (Lin *et al.,* 2002; Khan *et al.,* 2012a).

$$MRR = \frac{1000 \times W_w}{\rho_w \times T} \text{ mm}^3/\text{min} \qquad (1)$$

where, W_w is the weight loss of the workpiece in gm; ρ_w is the density of the workpiece material (Density of Ti-6Al-4V is 4.37 g/cm^3); T is the machining time in minutes.

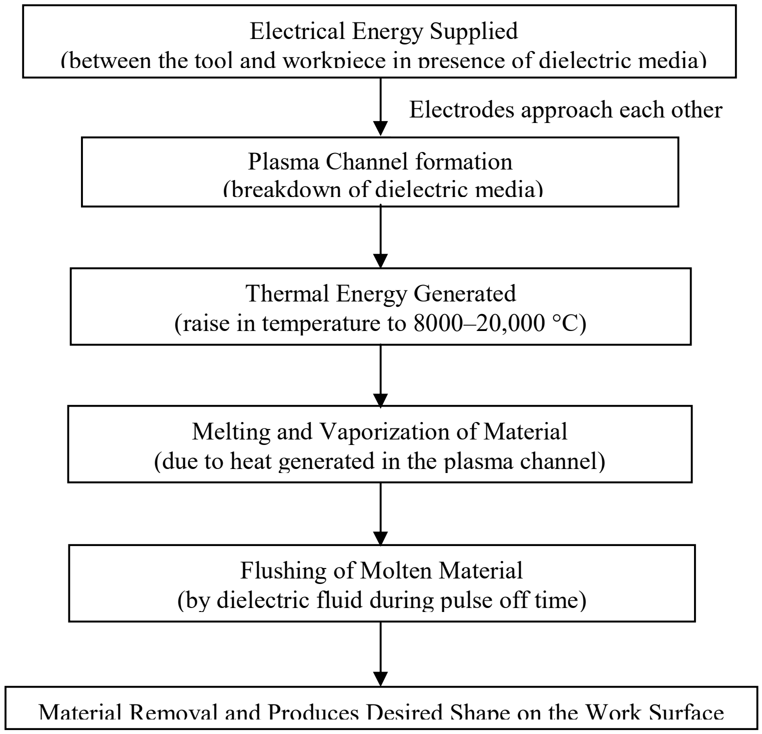


Figure 2: Schamatic diagram of the electrical discharge machining process.

Table 1: Experimental settings

Working parameters	Description
Work piece material	Ti-6Al-4V
Size of work piece	22 mm × 22 mm × 20 mm
Electrode material	Copper
Size of electrode	ϕ 19 mm × 50 mm (length)
Electrode polarity	Positive
Dielectric fluid	Commercial Kerosene
Applied voltage	120 V
Servo voltage	70 V
Flushing pressure	1.75 MPa
Machining time	30 minutes

Table 2: Machining Parameters and Their Levels

Designation	Process parameters	Levels		
		-1	0	1
X_1	Peak current (A)	2	16	30
X_2	Pulse on time (μs)	10	205	400
X_3	Pulse off time (μs)	50	175	300

2.2 Design of Experiment

The main objective of the experimental design is to study the relations between the response as a dependent variable and the various parameter levels. It provides a prospect to study not only the individual effects of each factor but also their interactions. The design of experiments for exploring the influence of various predominant EDM process parameters e.g. peak current, pulse on time and pulse off time on the machining characteristics of MRR modeled. In the present work experiments were designed on the basis of experimental design technique using response surface design method. The coded levels for all process parameters used are displayed in Table 2. The set of designed experiments to obtain an optimal response utilizing box-behnken type of design is presented in Table 3.

Table 3: Set of Designed Experiments for Different Parameters

Expt. No.	Peak current (A)	Pulse on time (μs)	Pulse off time (μs)	Expt. No.	Peak current (A)	Pulse on time (μs)	Pulse off time (μs)
1	0	0	0	9	0	1	-1
2	1	1	0	10	-1	-1	0
3	1	0	-1	11	0	0	0
4	-1	0	1	12	0	1	1
5	0	-1	1	13	1	0	1
6	0	0	0	14	1	-1	0
7	-1	1	0	15	0	-1	-1
8	-1	0	-1				

3. MODELLING

In statistics, response surface methodology explores the relationships between several explanatory variables and one or more response variables. The main idea of RSM is to use a set of designed experiments to obtain an optimal response. In this work, RSM is utilized for determining the relations between the various EDM process parameters with the various machining criteria and exploring their effects on the MRR. To carry out this objective second order polynomial response surface mathematical model can be developed. In the general case, the response surface is described by an equation of the form (Mason *et al.,* 2003):

$$Y=C_0+\sum_{i=1}^{n}C_i x_i+\sum_{i=1}^{n}C_{ii}x_i^2+\sum_{i=1}^{n-1}\sum_{j=2}^{n}C_{ij}x_i x_j \qquad (2)$$

where, Y is the corresponding response (e.g. MRR) yield by the various EDM process variables and the x_i (1,2, . . . , n) are coded levels of n quantitative process variables, the terms C_0, C_i, C_{ii} and C_{ij} are the second order regression coefficients. The second term under the summation sign of this polynomial equation is attributable to linear effect, whereas the third term corresponds to the higher-order effects; the fourth term of the equation includes the interactive effects of the process parameters. In this research, Eq. (2) can be rewritten according to the three variables used as:

$$Y=C_0+C_1x_1+C_2x_2+C_3x_3+C_{11}x_1^2+C_{22}x_2^2+C_{33}x_3^2+C_{12}x_1x_2+C_{13}x_1x_3+C_{23}x_2x_3 \qquad (3)$$

where: x_1, x_2 and x_3 are peak current (I_p), pulse on time (t_i) and pulse off time (t_o) respectively.

The experimental data are analyzed through analysis of variance of response surface method. The analysis of variance of this model is shown in Table 4. The adequacy of the above proposed model has been tested by the analysis of variance (ANOVA). The variance is the mean of the squared deviations about the mean or the sum of the squared deviations about the mean divided by the degrees of freedom. The usual method for testing the adequacy of a model is carried out by computing the F-ratio of the lack of fit to the pure error and comparing it with the standard value. The values of P (<α-level) in the analysis ascertain that the regression model is significant. Therefore, at least one of the terms in the regression equation makes a significant impact on the mean response. The P-values of the residual error (0.071 for MRR) is not less than α-level (0.05). The results of the analysis justifying the closeness of fit of the mathematical model are enumerated. Finally, the mathematical model is developed using the results of ANOVA. The equation of the fitted model for MRR is represented in (4):

Table 4: Analysis of Variance for MRR

Source of variation	Degree of freedom	Sum of squares	Mean squares	F-ratio	P
Regression					
Linear	3	5.54672	1.84891	36.54	0.000
Quadratic	9	6.01552	0.66839	38.08	0.000
Error					
Linear	11	0.55656	0.05060	28.99	0.034
Quadratic	5	0.08775	0.01755	13.15	0.071
Total					
Linear	14	6.10328			
Quadratic	14	6.10328			

$$MRR = 0.808257 + 0.779585 I_p + 0.282756 t_i - 0.075071 t_o + 0.123259 I_p^2 - 0.081933 t_i^2 - 0.003843 t_o^2 + 0.302213 I_p t_i - 0.03079 I_p t_o + 0.055620 t_i t_o \qquad (4)$$

4. RESULTS AND DISCUSSION

4.1. Optimization

An attempt is fulfilled to estimate the optimum machining setting to build the best possible MRR and surface finish within the experimental constraints. The obtained optimum values of the parameters are shown in Table 5. Optimum machining parameter combinations for MRR characteristics are also tested as shown in Table 6 through confirmation experiments that verify reasonably good concurrence with prediction of response surface method. The confirmation results revealed that the average error between the predicted and experimental value is 5.68 %. Accordingly, the obtained error is acceptable and agreeable. Therefore it can be concluded that the evolved model given by Eq. 4 are adequately explained the variation in the machining parameters on MRR as well.

Table 5: Optimal Values of MRR

Process parameters	Optimum values
Peak current (A)	30
Pulse on time (μs)	400
Pulse off time (μs)	55

Table 6: Confirmation Test and Their Composition with Results for MRR

Trial No.	Optimum conditions	Experimental MRR (mm^3/min)	Predicted MRR (mm^3/min)	Error (%)	Average (%)
1	I_p = 30 A, t_i=400 μs and t_o=55 μs	2.756	2.605	5.48	
2	I_p = 30 A, t_i=400 μs and t_o=55 μs	2.768	2.605	5.89	5.68

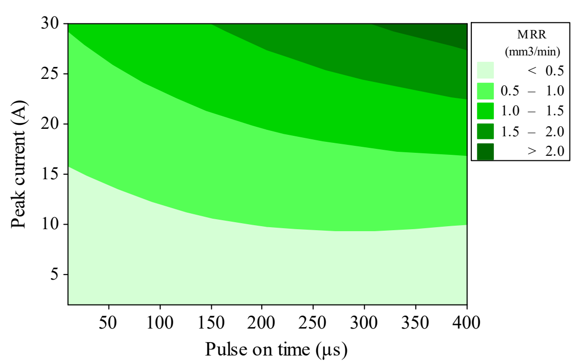


Figure 3: Contour plot of the effect of I_p and t_i on MRR.

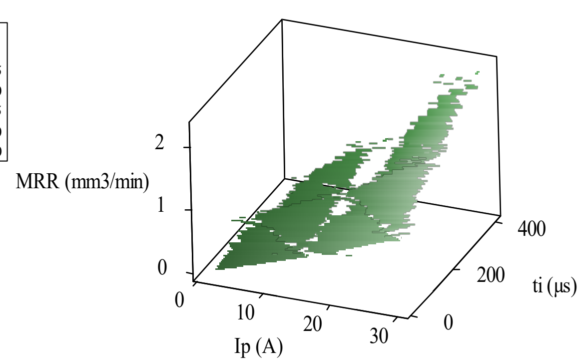
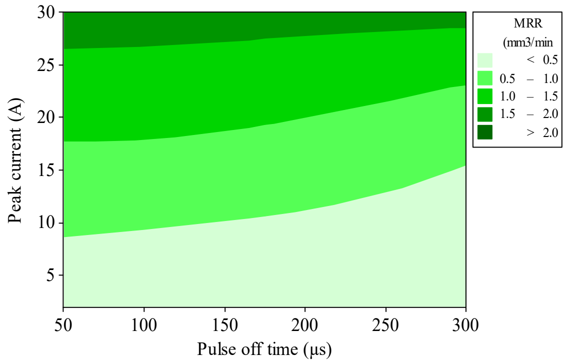


Figure 4: Surface plot of the effect of I_p and t_i on MRR.

4.2 Performance Characteristics

The influences of peak current and pulse on time are displayed in Fig. 3 and Fig. 4. It is revealed from the experimental results that the material removal rate increases with increase of peak current and pulse on time. The MRR is associated with energy intensity that depends merely on current and pulse duration. Thus, increase of current and pulse on time increase energy intensity and that generates higher MRR. Lee and Li (2001), Pradhan and Biswas (2008) and Tomadi *et al.* (2009) are also stated this circumstance. The maximum MRR can be achieved at high peak current and at high pulse on time.

Fig. 5 and Fig. 6 illustrate the impact of peak current and pulse off time on MRR. It is obvious that increasing peak current increases MRR conversely increasing pulse off time decreases MRR. Its two motivations can be explained, one is as to the pulse off time no voltage and current are detected in the gap (Kao and Tarng, 1997). Then the EDM machine is at temporary rest during the time of off pulses. Another ground is increase pulse off time exhibit an undesirable heat loss which does not contribute to MRR (Pradhan and Biswas, 2008; Tomadi *et al.,* 2009).



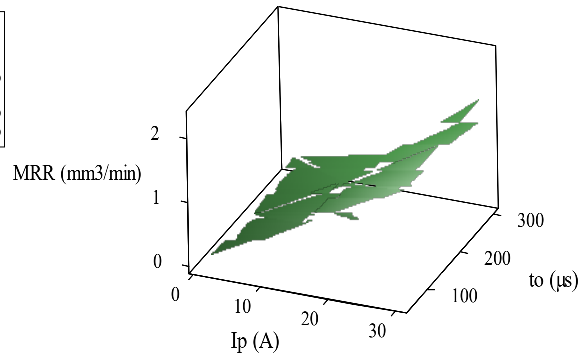


Figure 5: Contour plot of the effect of I_p and t_o on MRR Figure 6: Surface plot of the effect of I_p and t_o on MRR.

5. CONCLUSIONS

It was attempted to build mathematical model and to investigate the influence of the peak current, pulse on time and pulse off time on the EDM performance characteristics. The following conclusions can be highlighted from the analysis of the experimental observations.

i. The model is developed which can represent the material removal rate in electrical discharge machining process with an agreeable accuracy (5.48–5.89%).
ii. The MRR is influenced considerably by peak ampere and pulse on time. A significant impact of pulse off time on the material removal rate is investigated. The material removal rate increases with current. High pulse on time produce MRR more conversely less material removal is obvious at high pulse off time.
iii. The empirical values of the EDM parameters for optimum machining efficiency are 30 A peak current, 400 µs pulse on time and 55 µs pulse off time in the case of MRR.

Henceforth, the analysis will be carried out through fuzzy logic method. A comparison between fuzzy logic and RSM method will also be accomplished in other study.

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