EFFECT OF ELECTRIC DISCHARGE MACHINING PROCESS PARAMETER ON SURFACE TOPOGRAPHY

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Nowadays, the application of advanced machining processes in manufacturing industry is become more important for company to produce the better or good product the better or good products that happened such as in machining high hardness and the strength of the material, creating complex shape, obtains the better surface finish and dimensional tolerances. Electric discharge machining (EDM) is one of the most popular non-traditional material removal processes and has became a basic machining method for the manufacturing industries of aerospace, automotive, nuclear, medical and die-mold production. The theory of the process was established by a Soviet scientist, Lazarenko, in the middle of 1940s. They invented the relaxation circuit and a simple servo controller tool that helped to maintain the gap width between the tool and the work piece. This reduced arcing and made EDM machining more profitable and produced first EDM machine in 1950s. Major development of EDM was observed when computer numerical control systems were applied for the machine tool industry. Thus, the EDM process became automatic and unattended machining method . (Kiyak and Kakir, 2007)

The process uses thermal energy to generate heat that melts and vaporizes the work piece by ionization within the dielectric medium. The electrical discharges generate impulsive pressure by dielectric explosion to remove the melted material. Thus, the amount of removed material can be effectively controlled to produce complex and precise machine components. However, the melted material is flushed away incompletely and the remaining material resolidifies to form discharge craters. As a result, machined surface has micro cracks and pores caused by high temperature gradient which reduces surface finish quality. There have been many published studies considering surface finish of machined materials by EDM. It was noticed that various machining parameters influenced surface roughness and setting possible combination of these parameters was difficult to produce optimum surface quality. The influences of some machining parameters such as pulsed current, pulse time, pulse pause time, voltage, dielectric liquid pressure, electrode material. (Kiyak and Kakir, 2007).

Titanium has been recognized as an element (Symbol Ti; atomic number 22; and atomic weight 47.9) for at least 200 years. However, commercial production of titanium did not begin until the 1950's. At that time, titanium was importance because it has very high strength and light weight, extraordinary to corrosion resistance. These characteristics made it as efficient as metal for critical, high-performance aircraft, such as jet engine and airframe components. The worldwide production of this originally exotic, "Space Age" metal and its alloys has since grown to more than 50 million pounds annually. Increased metal sponge and mill product production capacity and efficiency, improved manufacturing technologies, a vastly expanded market base and demand have dramatically lowered the price of titanium products. Today, titanium alloys are common, readily available engineered metals that compete directly with stainless and specialty steels, copper alloys, nickel based alloys and composites. As the ninth most abundant element in the Earth's Crust and fourth most abundant structural metal, the current worldwide supply of feedstock ore for producing titanium metal is virtually unlimited. Significant unused worldwide sponge, melting and processing capacity for titanium can accommodate continued growth into new, high-volume applications. In addition to its attractive high strength-to-density characteristics for aerospace use, titanium's exceptional corrosion resistance derived from its protective oxide film has motivated extensive application in seawater, marine, brine and aggressive industrial chemical service over the past fifty years. Today, titanium and its alloys are extensively used for military applications, aircraft, spacecraft, medical devices, connection rods on expensive sports cars and some premium sports equipment and consumer electronics. Auto manufacturers Porsche and Ferrari also use titanium alloys in engine components due to its durable properties in these high stress engine environments.

In statistics, response surface methodology (RSM) explores the relationships between several explanatory variables and one or more response variables. The method was introduced by Box and Wilson in 1951. (Bhattacharyya et al. 2007). A sequence of designed experiments generated by RSM use to obtain an optimize response. Box and Wilson suggest using a second-degree polynomial model to do this. They acknowledge that this model is only an approximation, but use it because such a model is easy to estimate and apply, even when little is known about the process.

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1.2 PROBLEM STATEMENT

Traditionally electric discharge machining process carried out by relying heavily on the operator’s experience or conservative technological data provided by the EDM equipment manufacturers, which produced inconsistent machining performance. The parameter settings given by the manufacturers are only applicable for the common steel grades. The settings for new materials such as titanium alloys, aluminum alloys, special steels, advanced ceramics and metal matrix composites (MMCs) have to be further optimized experimentally. Optimization of the EDM process often proves to be difficult task owing to the many regulating machining variables. A single parameter change will influence the process in a complex way. Thus the various factors affecting the process have to be understood in order to determine the trends of the process variation. The selection of best combination of the process parameters for an optimal surface roughness involves analytical and statistical methods. Once the optimum parameter is obtain, it reduces the machining cost and improved product’s quality.

1.3 OBJECTIVES

The objectives of this project are as following:

1. To develop mathematical models for predicting the material removal rate, electrode wear rate and surface roughness.
2. To optimize the machining parameters using RSM method.
3. In addition, this study was generated more knowledge and experience during operating EDM.

1.4 SCOPES

This study mainly focuses on machining of titanium alloys, which will be carried out in die-sinking EDM. MINITAB software is using to design the experiment by response surface design. Response surface design was used because its suspect has curvature relationships between input and output parameter. The machining (input) parameters selected in this project were peak current, servo voltage, pulse on time, pulse off time; output parameter were material removal rate, electrode wear rate and surface roughness. Three mathematical models were develops by using response surface method. Adequate test is necessary to make sure the model is fit. Next, the surface topography was observed by using metallurgical microscope and integrated software.

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1.5 ORGANIZATION OF REPORT

Chapter 1 focused on the introduction of EDM die-sinker machine, titanium alloy grade 5 and Response Surface Method. Chapter 2 was about literature review from the previous study. Chapter 3 presents the methodology on the progress. Chapter 4 presents the result and discussion and chapter 5 summarize the finding for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter contents the properties and composition of Ti_6Al_4V. Besides, it reviews the history and machining concern of die-sinking EDM. Response surface method used to develop the mathematical models so can predict the output. In addition, the previous study of relationship between input and output parameters.

2.2 TITANIUM ALLOYS

Titanium alloys are replacing traditional aluminum alloys in many aerospace applications because of their unique high strength to weight ratio that is maintained at elevated temperatures and their exceptional corrosion resistance. The demand of titanium alloy was predicted increase gradually at the following years. Titanium alloy is more difficult to cut than common steel alloys and hence titanium is considered a difficult-to-machine material. The main concern of titanium alloys is the difficult to cut. Their low thermal conductivity leads to high cutting temperatures, and their high chemical reactivity with many tool materials leads to strong adhesion between the tool and work material. These two factors lead to rapid tool wear during machining of titanium alloys, which in turn increases the manufacturing cost. Therefore, unconventional machining, Electrical Discharge Machine is recommended.

Titanium Alloys, Ti_6Al_4V, sometimes called titanium grade 5 or VT6, is classified as alpha-beta alloy. Alpha and Beta Alloys, which are metastable and usually contains some combination of both alpha and beta stabilizers, and which can be heat treated. Generally, beta-phase titanium is stronger yet less ductile and alpha-phase titanium is more ductile. Alpha-beta-phase titanium has a mechanical property which is in between both. It is the most commonly used alloy because over 70% of all alloy grades melted are a sub-grade of Ti_6Al_4V. Table 2.1 and Table 2.2 show the composition and characteristic of Titanium Ti_6Al_4V.

Table 2.1: The chemical composition by weight for Ti_6Al_4V

Chemical composition	**C**	**Fe**	**N_2**	**O_2**	**Al**	**V**	**H_2**	**Ti**
Wt(%)	< 0.08	< 0.25	< 0.05	< 0.2	5.5-6.76	3.5-4.5	< 0.0125	rest

Table 2.2: Typical physical properties for Ti6Al4V

Property	**Typical Value**
Density g/cm^3	4.42
Melting Range ^{0}c	1649
Specific Heat J/kg.^{o}C	560
Volume Electric Resistivity ohm.cm	170
Thermal Conductivity W/m.k	7.2
Tensile Strength MPa	897-1000
0.2% Proof Stress Mpa	828-910
Elastic Modulus GPa	114
Hardness Rockwell C	36

2.3 Die-Sinking EDM

Non-conventional machining processes such as the electrode discharge machining (EDM) are being widely used to machine hard tool and die materials used in the industries. Materials of any hardness can be cut as long as the material can conduct electricity. Many complex shapes can be reproduced in the workpiece. A small amount of material, up to 15% is expelled violently from the surface melt and the remaining liquid resolidifies. The recast structure is typically very fine grained and hard, and may be alloyed with carbon from the cracked dielectric or with material transferred from the tool. Many mould makers use two electrodes, one for roughing operations and another one for the finishing operation. This process finishes the surface and produces a thin plastically deformed layer at the surface. Unfortunately even though EDM technology has proved to be very efficient in machining out complex shapes and also to machine very hard materials, there are several problems that are associated with this machining method. The main problem is the formation of a 'recast' white layer, which is very hard and contains many imperfections such as cracks, micro cracks and high tensile residual stresses. These features are undesirable in most cases since early failure of the component might result. The severity of the damage in the recast layer depends on the machining conditions. A roughing condition will entail fast machining (high productivity) operation but severe damage and high surface roughness. Thus a suitable process parameter is important so as to improve the productivity of this process and at the same time getting an optimum surface integrity.

2.4 MACHINING PARAMETER

Basically, there have two types of parameters which were input parameters and output parameters. Input parameters are help to distribute the output parameters, in order words, they are interrelated. Various input result various output. One of the objectives of this study is study the relationship between input and output. After analysis, then get a set of optimum parameters. In this study, the input parameters were peak current, pulse-on-time, pulse-off-time and servo voltage. These input parameters were various for the experiments. Others parameters were remains constant at these experiments .Constant parameters were included polarity, servo speed, flushing pressure, main power supply, jump-up time, jump-down machining time, jump speed and so on. Usually, constant parameter takes a least effect on the output parameter so there was no investigation needed. The output parameters were material removal rates, electrode wear rate and surface roughness. Material removal rate is the rate of the Ti_6Al_4V removed per second. Electrode wear rate is the rate of copper electrode removed per second. Surface roughness is the measure if the finer surface irregularities in the surface texture. These are the result of the manufacturing process employed to create the surface. Surface roughness Ra is rated as the arithmetic average deviation of the surface valleys and peaks expressed in micro inches or micro meters Table 2.3 shows all the machining parameters.

Table 2.3: Machining parameter

Parameter	Function
PL	Polarity
ON	Electric discharge time
OFF	Electric discharge off time
IP	Electric discharge peak current
SV	Servo voltage
S	Servo speed
UP	Jump-up time
DN	Jump-down machining time
JS	Jump speed
LNS	Loran shape
STEP	Loran orbiting motion distance on one side
V	Main supply voltage
HP	Auxiliary power supply current control, pulse control, capacitor, selection
PP	PIKADEN pulse, shutoff circuit control
C	Capacitor
ALV	Arc detection level
OC	ON pulse control
LF	OFF pulse control, HS servo
JM	Jump mode
LS	Loren speed and direction
LNM	Loran mode

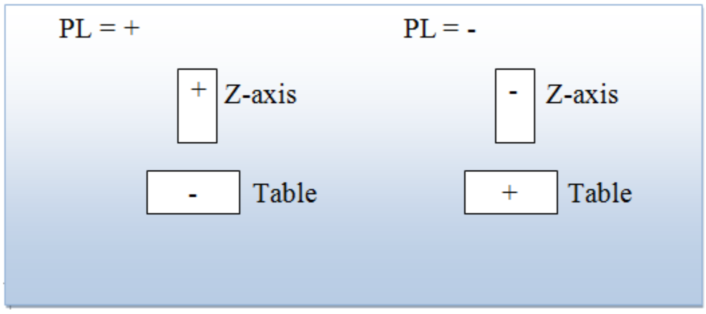


Figure 2.1: Polarity

Polarity, PL, determines electric polarity of the electrode and work piece. Choose ‘positive’ and ‘negative’ for the z-axis. Usually z-axis was referred to electrode. Polarity selection depending on the machining conditions and the material combination of the work piece and the electrode, it may be necessary to change the polarity. If wrong polarity is set, good machining performance may not be obtained. Figure 2.1 show the polarity.

Pulse on-time specifies the duration of an electric discharge and determines the electric discharge pulse control system. In others words, it was the duration of time the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on time. This energy is controlled by the peak current and the length of the on-time.

Pulse off-time specifies the duration of a stop between electric discharge pulses off. It is the duration of time between the sparks. This time allows the molten material to solidify and to be wash out of the arc gap. This parameter is to affect the speed and the stability of the cut. Therefore, the performance will more stable for the long off-time.

Peak current specifies the peak current for EDM. Peak current is the sum of the main electric discharge current and the SVC electric discharge current. This is an important parameter that determines the machining performance such as machining speed, surface roughness, electrode wear, or discharge gap, in combination of the time.

Servo voltage specifies a reference voltage for servo motions to keep gap constant. This servo motion control is performed in accordance with gap voltage .Fluctuation relative to servo voltage when gap voltage is higher than servo voltage, the electrode advances for machining; when it is lower, the electrode retracts to open the gap.

2.5 RESPONSE SURFACE METHODOLOGY

Response surface methodology is a collection of mathematical and statistical techniques that are useful for the modelling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response. When higher order polynomial model is used, the accuracy will be increase but generally it up to second order only. To provide some context, there is good commercial software available to help with designing and analyzing response surface experiments. The most popular include Design-Expert, Minitab and many others.

Response-surface method involve some unique experimental-design issues, due to the emphasis on iterative experimentation and the need for relatively sparse designs that can be built-up piece-by-piece according to the evolving needs of the experimenter. Besides, response-surface analysis is not simply regression problem, there are several intricacies in this analysis and how it is commonly used that are enough different from routine regression problems that some special help is warranted. These intricacies include the common use of coded predictor variables; the assessment of the fit; the different follow-up analyses that are used depending on that type of model is fitted, as well as the outcome of the analysis; and the importance of visualizing the response surface. Below is a general overview of response-surface method.

1. Provides functions and data types that provide for the coding and decoding of factor levels, since appropriate coding is an important element of response-surface analysis
2. Provides functions for generating standard designs.
3. Extends R’s lm function to simplify the specification of standard response-surface models, and provide appropriate summaries.
4. Provides means of visualizing a fitted response surface.
5. Provides guidance for further experimentation.

Generally, DOE is used to design a set of experiment by control the variation. In the design of experiments, the experimenter is often interested in the effect of some process or intervention on some objects which may be people, parts of people, groups of people, plants, animals, etc. Response surface designs are types of Experimental Design that suspect that has the curvature response between input and output. The design matrix originally used included the limits of the factor settings available to run the process. In other words, response surface designs achieve this by using a quadratic regression equation rather than the linear form of the regression equation used in factorial designs. (Anderson and Whitcomb. 2005.)

Central composite designs consist of factorial points, axial points and central point. Central composite designs are often recommended when the design plan calls for sequential experimentation because these designs can incorporate information from a properly planned factorial experiment. The factorial and centre points may serve as a preliminary stage where you can fit a first-order (linear) model, but still provide evidence regarding the importance of a second-order contribution or curvature (Anderson and Whitcomb. 2005). Orthogonally blocked designs allow for model terms and block effects to be estimated independently and minimize the variation in the regression coefficients. Rotatable designs provide the desirable property of constant prediction variance at all points that are equidistant from the design centre, thus improving the quality of prediction.

2.6 ANALYSIS OF VARIANCE

Analysis of variance (ANOVA) is a powerful statistical tool. It has the function that quantifying interactions between independent variables and at the same time to determine their impact on the predicted variables. Besides that, the treatment data must be normally distributed. ANOVA table lists the sources of variation, their degrees of freedom, the total sum of squares, and the mean squares. The analysis of variance table also includes the *F*-statistics and *P*-values. Use these to determine whether the predictors or factors are significantly related to the response (Healey and Prus 2009). *P*-value ranges from zero to one. *P*-value has the function that determines the probability to rejecting the null hypothesis in hypothesis test. When the *P*-values is higher that the α-values, its mean significant. The smaller *P*-value has higher accuracy. Because of their indispensable role in hypothesis testing, *P*-values are used in many areas of statistics including basic statistics, linear models, reliability, and multivariate analysis among many others. The key is to understand what the null and alternate hypotheses represent in each test and then use the *P*-value to aid in your decision to reject the null. (Healey and Prus 2009)

Lack-of-fit used in regression and DOE, lack-of-fit tests assess the fit of your model. If the *P*-value is less than your selected α-level, evidence exists that your model does not accurately fit the data. You may need to add terms or transform your data to more accurately model the data. Minitab calculates two types of lack-of-fit tests (Ott and Longnecker 2008).

R-square is percentage of response variable variation that is explained by its relationship with one or more predictor variables. In general, the higher the R^2, the better the model fits your data. R^2 is always between 0 and 100%. It is also known as the coefficient of determination or multiple determinations in multiple regressions (Ott and Longnecker 2008). Used in regression analysis to indicate how well the model predicts responses for new observations, whereas R^2 indicates how well the model fits your data. Predicted R^2 can prevent over fitting the model and can be more useful than adjusted R^2 for comparing models because it is calculated using observations not included in model estimation. Over fitting refers to models that appear to explain the relationship between the predictor and response variables for the data set used for model calculation but fail to provide valid predictions for new observations. Percentage of response variable variation that is explained by its relationship with one or more predictor variables, adjusted for the number of predictors in the model. This adjustment is important because the R^2 for any model will always increase when a new term is added. A model with more terms may appear to have a better fit simply because it has more terms. However, some increases in R^2 may be due to chance alone.

The adjusted R^2 is a useful tool for comparing the explanatory power of models with different numbers of predictors. The adjusted R^2 will increase only if the new term improves the model more than would be expected by chance. It will decrease when a predictor improves the model less than expected by chance. (Ott and Longnecker. 2008)

2.7 RELATIONSHIP BETWEEN PARAMETERS

For sure, there were relationships between input and output parameters. If second order of RSM was used, it can generate up to linear, interaction, or square relations between parameters. This study was indicated the relationship between peak current, servo voltage, pulse on-time, pulse off-time with material removal rate, electrode removal rate and surface roughness.

2.71 Material Removal Rate

Yang et al. (2000), Salman and Kayacan (2007), Hascalık. and Caydas (2007), Rao et al. (2010) were found that material removal rate have positive relationship with peak current. Material removal rate is increased when peak current increased. Yang et al. (2000), and Hascalık and Caydas (2007) were observed that material removal rate has maximum performance on pulse on-time, 200µs. Rao et al. (2010) were found that servo voltage is inversely proportional to material removal rate.

2.72 Electrode Wear Rate

Rao et al. (2010) were found that peak current has curvature relationships with electrode wear rate. There has minimum EWR at peak current 12A. Besides that, they discovered that servo voltage is inversely proportional to EWR. Yang et al. (2000) were found that EWR is inversely proportional to pulse on-time and peak current. EWR decreases When pulse on time and peak current increases.

2.73 Surface Roughness

Ramasawmy and Blunt (2004) found that the pulse current is the most dominant factor in affecting the surface texture compare to pulse on-time. Moreover, the interaction effect between pulse current and its duration on the 3D surface roughness parameters is relatively small. Salman and Kayacan (2007) found that the peak current, pulse on-time and arc voltage is has directly proportional to the surface roughness. Hascalık and Caydas (2007) were reveals that the value of material removal rate, surface roughness, electrode wear and average white layer thickness are tendency of increase with increasing current density and pulse duration. However, extremely long-pulse durations such as 200 µs led to decrease surface roughness. Rao et al. (2009) found that titanium alloy is that it has good surface finish at voltage 40V and at constant current of 16 A. Aluminium alloy has good erosion properties than titanium alloy due to the high electrical and thermal conductivities, low hardness and low melting and vaporization temperatures. Rao et al. (2010) found that peak current has curvature relation with surface roughness. At around 13 A, there has maximum surface roughness. Besides, they found that’s servo voltage increase will decrease the surface roughness.

2.8 CONCLUSION

In conclusion, the input of parameter to use in machining was pulse current, pulse in time, duty factor, and voltage. Besides that, the investigated output parameter was material removal rate, electrode wear rate and surface roughness which is directly reflect the machining quality. Chapter 3 will discuss experimental work step by step from DOE until analysis part.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter concentrates the methodology from experimental details and design of experiment to analysis using response surface method. Design of experiment (DOE) is apply to design 31 experiments. 31 sets of experimental work carried out with by setting the difference EDM die-sinking input parameters. Difference input parameter give various output parameter. Response surface is used to develop mathematical model.

3.2 FLOW CHART AND FLOW DIAGRAM

Figure 3.3 shows the flowchart for this project. A Flowchart is a diagram that uses graphic symbols to depict the nature and flow of the steps in a process. The advantage of the flowchart is identifying problem areas and opportunities for process improvement. Once you break down the process steps and diagram them, problem areas become more visible. It is easy to spot opportunities for simplifying and refining your process by analyzing decision points, redundant steps, and rework loops. Besides that, it Promote understanding of a process by explaining the steps pictorially. People may have differing ideas about how a process works. A Flowchart can help you gain agreement about the sequence of steps. Flowcharts promote understanding in a way that written procedures cannot do. One good Flowchart can replace pages of words.

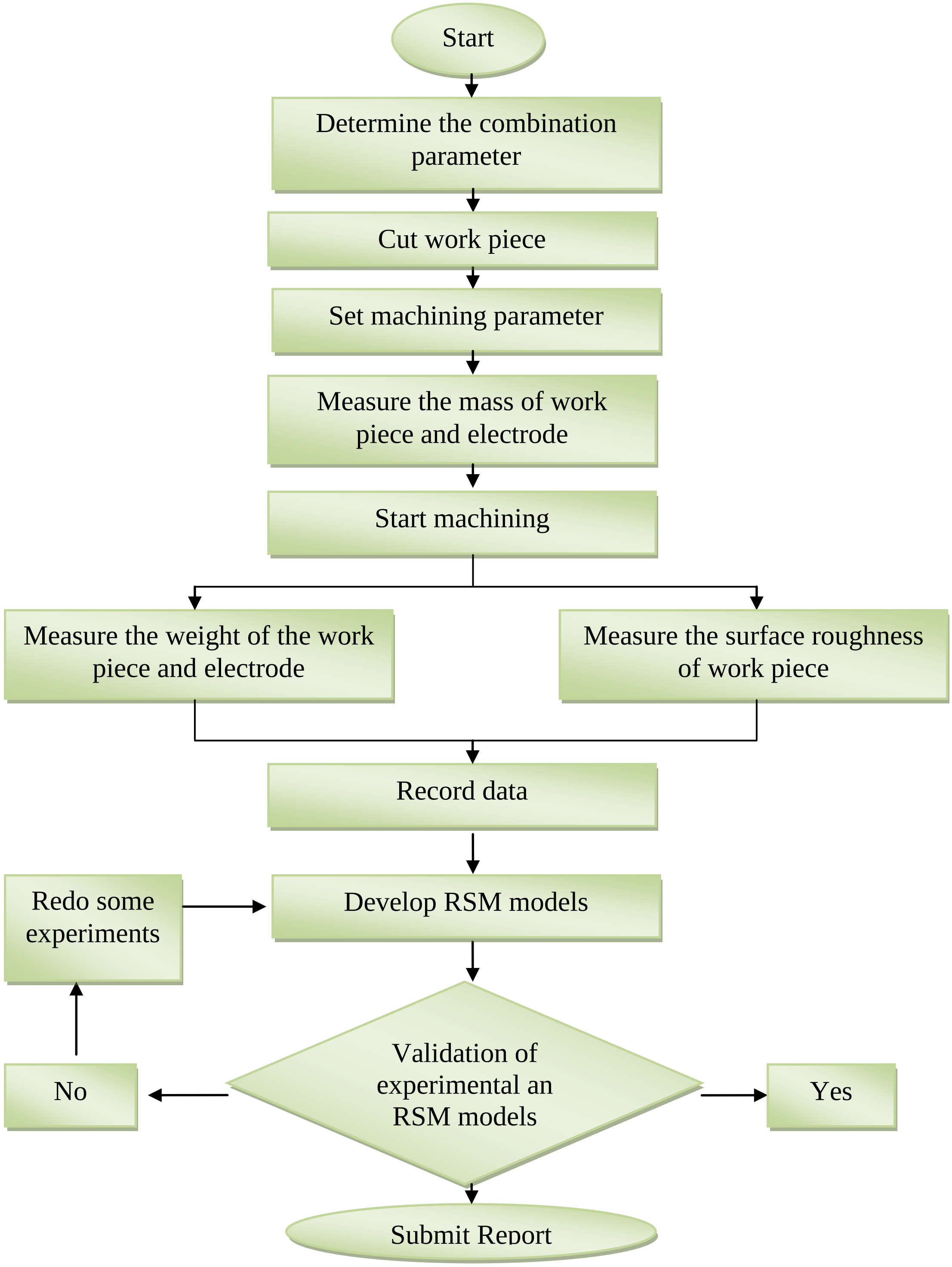


Figure 3.1: Flow chart of the project

3.3 DESIGN OF EXPERIMENT

The inputs parameter are current, voltage, duty of factor and pulse on time, and the output parameter are surface roughness, electrode wear ratio and material removal rate. The input and output parameters are shown in Table 3.1.

Table 3.1: Input and output parameters

Input Parameter	**Output parameter**
Peak Current	Material Removal Rate
Servo voltage	Electrode Wear Rate
Pulse on-time	Surface Roughness
Pulse off-time	

Design of experiment is important because it helps to select design parameters so that the product will work well under a wide variety of field condition. Response surface design is carried out by using software MINITAB. Since the number of input parameters chosen is peak current, servo voltage pulse-on-time and pulse-off-time, hence, there were four factors. The centre composite is selected and the level define was axial point. Table 3.3 showed the design block and set of experiments. From the previous studies, experimental investigation and analysis were carried out in different parametric combinations, for deriving effective parametric combination like pulse-on time, current, servo voltage. Response surface design is used to design the experiment scheme in such a way that the objectives of the study can be fulfilled satisfactorily. Full central composite designs include factorial points from a full factorial (2k), axial points and centre points. Central composite design requires five coded levels of each factor: plus or minus one (factorial points, ±1), plus or minus alpha (axial points, ±2), and the all zero level (centre point,0).). For a four-factor problem, the axial points are(±α, 0, 0, 0), (0, ±α, 0, 0), (0, 0, ±α, 0), and (0, 0, 0, ±α) which need 8 runs.(Myers and Montgomery, 2002) When α = 2, this design is both orthogonal and rotatable.(Lenth,R,V. 2009). For full factorial, 2^4 need 16 runs. 7 run for centre point. Total experiment runs were 31. Table 3.2 show the range for every parameters and code number.

Table 3.2: Level of independence variables

Levels coding	**Lowest, -2**	**Lower, 1**	**Medium, 0**	**High, 1**	**Highest, 2**
Peak current, IP (A)	1	8	15	22	29
Servo voltage, SV (V)	75	85	95	105	115
Pulse on-time, τ_{on} (μs)	10	95	180	265	350
Pulse off-time, τ_{off} (μs)	60	120	180	240	300

Table 3.3: Design of block and design of the experiment

Peak Current	**Servo Voltage**	**Pulse on-time**	**Pulse off-time**	**Peak Current**	**Servo Voltage**	**Pulse on-time**	**Pulse off-time**
-1	1	-1	1	8	105	95	240
-1	-1	-1	-1	8	85	95	120
-2	0	0	0	1	95	180	180
1	1	1	-1	22	105	265	120
0	0	-2	0	15	95	10	180
0	0	0	0	15	95	180	180
0	0	0	0	15	95	180	180
0	0	0	0	15	95	180	180
0	0	0	-2	15	95	180	60
2	0	0	0	29	95	180	180
-1	1	1	1	8	105	265	240
-1	-1	-1	1	8	85	95	240
-1	1	1	-1	8	105	265	120
0	-2	0	0	15	75	180	180
1	-1	-1	-1	22	85	95	120
0	0	0	0	15	95	180	180
0	0	0	0	15	95	180	180
1	1	-1	-1	22	105	95	120
1	-1	-1	1	22	85	95	240
1	-1	1	1	22	85	265	240
0	0	0	0	15	95	180	180
-1	-1	1	1	8	85	265	240
0	2	0	0	15	115	180	180
1	1	1	1	22	105	265	240
0	0	0	0	15	95	180	180
1	-1	1	-1	22	85	265	120
0	0	2	0	15	95	350	180
-1	1	-1	-1	8	105	95	120
0	0	0	2	15	95	180	300
-1	-1	1	-1	8	85	265	120
1	1	-1	1	22	105	95	240

3.4 MACHINING OF WORKPIECE

For this study, the material used to run the experiment is the Titanium alloys, Ti_6Al_4V. The composition of titanium alloys Ti_6Al_4V is shown in table 3.4.

Table 3.4: Composition for Ti_6Al_4V

Chemical composition	**C**	**Fe**	**N_2**	**O_2**	**Al**	**V**	**H_2**	**Ti**
Wt(%)	< 0.08	< 0.25	< 0.05	< 0.2	5.5-6.76	3.5-4.5	< 0.0125	rest

At the beginning, the work piece was cut into the desire dimension of 21.50 mm × 21.00 mm × 13.16 mm by using EDM wire cut. First, the titanium plate is clamped parallel. For the wire-cut EDM, the dielectric fluid used was distilled water. Wire-cut EDM machine AQ535L has copper wire with diameter 0.2mm. Setup the machine as Table 3.5 after drew the cutting diagram in CAD format. Figure 3.2 illustrate a piece of work piece cut from titanium plate.

Table 3.5: Wire-cut setup

	ON	**OFF**	**IP**	**HRP**	**MAO**	**SV**	**V**	**SF**	**C**	**PIK**	**CTRL**	**WK**	**WT**	**WS**	**WP**
C000	006	014	2210	000	240	040	8	0010	0	000	0000	020	080	090	045
C001	008	014	2210	000	242	015	8	0010	0	000	0000	020	080	090	055

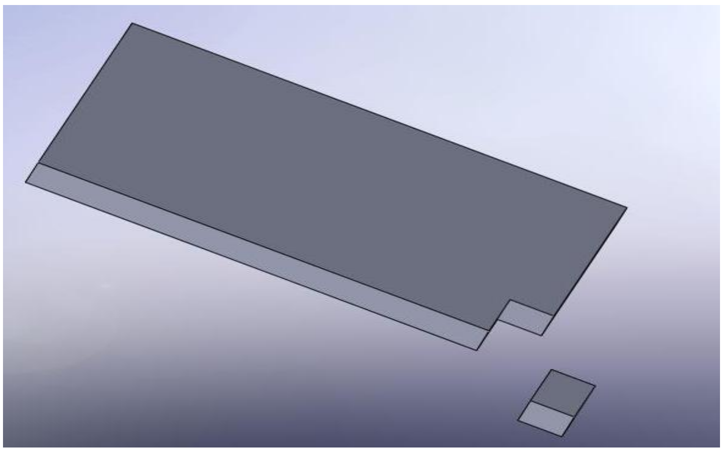


Figure 3.2: Wire-cut EDM process

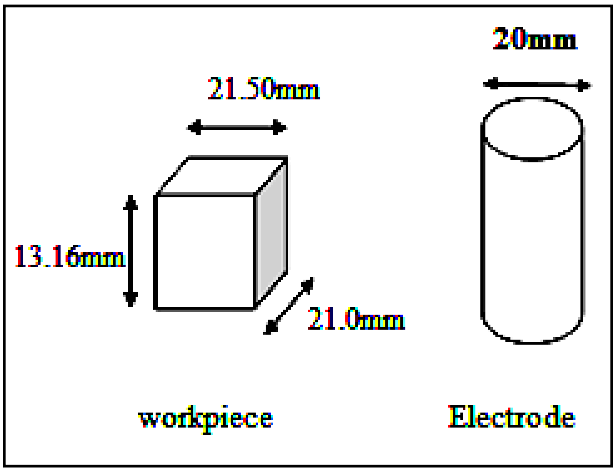


Figure 3.3: Work piece and electrode dimension

The size of each work sample is 21.50 mm × 21.00 mm × 13.16 mm at ambient temperature as Figure 3.3. To study the influences of various EDM process parameters on surface roughness, machining removal rate and electrode wear rate. The copper diameter of 19 mm was selected as electrode for experiment. Dielectric fluid was a fluid that does not conduct an electric current under normal circumstances. For EDM, the dielectric fluid insulates and cools the electrode and work piece, conveys the spark, and flushes away the removed metal. Dielectric fluid Kerosene was selected as dielectric because of its high flash point, good dielectric strength, transparent characteristics and low viscosity and specific gravity. Then, input variables current, servo voltage, pulse-on time and pulse-off time were used for experimentation. A number of experiments were carried out according to the design of experiment (DOE) to investigate the influence of various machining factors on EDM process. Four variables such as peak current, pulse on time, pulse off time and servo voltage were considered to ascertain their effect on material removal rate, TWR and SR. Peak current (I_p) is the maximum current during spark. Pulse on time (T_{on}) is the duration of time the current is allowed to flow per cycle while the pulse off-time (T_{off}) is the duration of time between two consecutive sparks (Puertas et al., 2005). Servo voltage (S_v) specifies a reference voltage for servo motions to keep gap voltage constant. When gap voltage is higher than servo voltage, the electrode advances for machining; when it is lower, the electrode retracts to open the gap. The titanium alloy material Ti-6Al-4Sn was machined with copper tool electrode. The electrode polarity was retained as positive polarity. Kerosene was used as dielectric fluid. The experiments were performed on a numerical control programming EDM

AQ55L. The weights of the work piece before and after machining were measured by a digital balance (AND GR-200) with readability of 0.1mg. Figure 3.4 shows the work piece and electrode dimension. The machining was usually carried out for a fixed time interval. The experimental settings is shown in Table 3.6.

Table 3.6: Experimental setting

Parameters	**Description**
Work piece material	Ti_6Al_4V
Work piece size	21.50 mm × 21.00 mm × 13.16MM
Electrode material	Copper
Electrode size (diameter × length)	20 mm × 44 mm
Electrode polarity	Positive
Dielectric fluid	Commercial Kerosene
Applied voltage	120 V
Flushing pressure	1.75 MPa
Machining time	40 Minutes

3.5 OUTPUT PARAMETERS EVALUATION

The weight of both the work piece and electrode are weighted by using precision analytical balance before and after the machining process. Each machining was operated for 40 minutes. The sets of combination parameter that was set earlier serve as the input data. The experiments are performs at constant voltage (*V*) which is 120V. A total of thirty-one machining is being done according to the generated parameter. The material removal rate is calculated as Eq. (3.2).

$$WRW = W_{w1} - W_{w2} \tag{3.1}$$

$$MRR = \frac{WRW}{T} \tag{3.2}$$

where, W_{w1} is the weight of work piece before machining and W_{w2} the weight of work piece after machining, *WRW* is the weight loss of the work piece and *T* time taken for the machining.

The tool wear rate is the amounts of electrode being used in the machining process are represented by Eq. (3.3) and Eq. (3.4):

$$\mathrm{EWR} = \frac{100 \times W_e}{\rho_e \times T} \tag{3.3}$$

$$W_e = W_1 - W_2 \tag{3.4}$$

where, W_e is the weight loss of the electrode in gm, ρ_e is the density of the electrode material (Density of Cu is 8.93 g/cm^3), W_1 is initial weight of electrode, W_2 is final weight of electrode, T is the machining time in minutes.

The surface roughness of the work-piece can be expressed in different ways including arithmetic average (R_a), average peak to valley height (R_z), or peak roughness (R_P), etc. Generally, the SR is measured in terms of arithmetic mean (S_a) which according to the ISO 4987: 1999 is defined as the arithmetic average roughness of the deviations of the roughness profile from the central line along the measurement (Wu et al., 2005). Arithmetic mean or average surface roughness, S_a is considered in this study for assessment of roughness. Figure 3.4 shows the Analytical Balance and Pethormeter.

Figure 3.4: Analytical Balance and Perthometer

3.6 RESPONSE SURFACE ANALYSIS

After knowing the values of the observed response, the values of the different regression coefficients of second order polynomial mathematical equation have been evaluated and the mathematical models based on the response surface methodology have been developed by utilizing test results of different responses obtained through the entire set of experiments by using computer software, MINITAB. The response surface methodology based analysis has been done to establish the mathematical model through the development of mathematical relationships between Surface Roughness and the important process parameters, between MRR and the important process parameters, between EWR and the important process parameters. The next step was Analysis on parametric influences based on developed models and test results. The influences of the predominant process parameters, for example peak current and pulse-on duration on surface roughness, in EDM process have been analyzed based on the non-linear mathematical model developed through the response surface methodology. After that, a graph was plotted to summarize and ease the analysis.

3.7 CONCLUSION

In conclusion, the methodology was discussed step by step as above. Some output parameter can be calculated. Surface roughness, Ra, was taken directly from Pethormeter. After that, all these output parameters were key in MINITAB. The next chapter will be presents about the result and related discussion.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter contains result and discussion. Besides, it has show adequate test that fit the model. Moreover, three dimensional surface plot use to explain the relationships of the parameters. Validation is carried out to compare the predicted and experimental result. Surface topography analysis is also presented.

4.2 EXPERIMENTAL RESULTS

Table 4.1 show all the calculated output parameter which were material removal rate, electrode wear rate and surface roughness. It is important to check the adequacy of the fitted model, because an incorrect or under-specified model can lead to misleading conclusions. Adequacy of the models developed is validated by checking the statistical properties to augment the ANOVA table. Properties such as lack-of-fit, *R*-squared, adjusted *R*-squared, predicted *R*-squared and adequate precision are examined. The values of the different regression coefficients of second order polynomial mathematical equation have been evaluated. The mathematical models based on the response surface methodology have been developed by utilizing test results of different responses obtained through the entire set of experiments. The response surface methodology based analysis has been done to establish the mathematical model through the development of mathematical relationship between material removal rate and the important process parameters, such as servo voltage peak, peak current, pulse on time, and pulse off time.

Table 4.1: Experimental data

peak current	servo voltage	on time	off time	MRR(μms^{-1})	EWR(μms^{-1})	Sa(μm)
22	85	265	120	5.9975	0.4	5.617
22	105	95	120	3.4	0.6525	4.358
15	115	180	180	1.375	0.0775	5.704
15	95	180	180	2.0775	0.0475	4.319
15	95	180	180	2.035	0.19	4.326
1	95	180	180	0.145	3.8	1.999
15	95	180	180	0.96	0.1575	5.334
8	85	95	240	1.4125	1.075	2.316
8	105	265	240	0.5	2.0275	3.108
15	95	10	180	1.2375	0.52	4.322
15	95	180	180	2.3125	0.06	4.268
22	85	265	240	4.3975	0.4475	5.983
15	95	180	180	2.49	0.0175	4.799
22	105	265	240	3.47	0.4775	5.402
8	105	95	240	0.8825	0.765	2.851
22	85	95	120	4.445	1.1825	6.041
8	85	265	240	1.115	1.705	1.747
15	95	180	60	2.6875	0.75	3.461
22	85	95	240	3.505	0.4925	5.544
8	105	265	120	0.87	2	3.989
29	95	180	180	6.715	1.5	6.11
15	75	180	180	2.9875	0.3275	4.66
15	95	180	180	2.1675	0.2575	4.684
22	105	265	120	3.8975	0.305	6.535
8	85	265	120	1.345	1.6	2.638
22	105	95	240	3.2425	0.2	4.043
15	95	180	180	2.1025	0.095	3.709
15	95	180	300	1.7525	0.185	5.413
15	95	350	180	2.77	0.45	3.751
8	85	95	120	1.7675	2.3325	2.612
8	105	95	120	0.555	1.5075	2.976

At the beginning, a quadratic model is analyzed. Table 4.2 shows the *P*-value is <0.05 for the developed model of S_a. This indicates that the linear model is significant but not for the square and interaction. Therefore, a linear model is carried out to analysis, because the quadratic model does not adequately fit the response surface. Thus, it needs to fit the linear (first order) model, and the result is shown at Table 4.3. It is observed that the lack of fit value is 0.130 which is more than 0.05, this indicates not significant. This shows that the linear model developed for the S_a adequately fit the data for the response. In addition, the experiments data in the plot as Figure 4.1, it able to generated straight line, this mean the residuals are normally distributed. It can be shown from Table 4.4 that the *R*-squared is >0.8 and adjusted *R*-squared (Adj *R*-Squared) is >0.7 as parts of the conditions for model adequacy. From above foregoing explanation, it has been shown that it have enough accuracy to predict for experiment (Iqbal and Khan, 2010). Let us consider, $X_1 = IP$; $X_2 = SV$; X_3 = pulse on time; X_4 = pulse off time. A developed linear equation for S_a is expressed as Eq. (3.1).

Table 4.2: Analysis of Variance for S_a (quadratic)

SOURCE	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	14	44.258	44.258	3.1613	6.91	0.000
Linear	4	37.029	37.029	9.2574	20.23	0.000*significant
Square	4	2.134	2.134	0.5335	1.17	0.363
Interaction	6	5.094	5.094	0.8490	1.86	0.151
Residual Error	16	7.321	7.321	0.4576		
Lack-of-fit quadratic	10	5.760	5.760	0.5760	2.21	0.171*not significant
Pure Error	6	1.561	1.561	0.2601		
Total	30	51.579				

Table 4.3: Analysis of Variance for S_a (linear)

SOURCE	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	4	44.258	44.258	3.1613	6.91	0.000
Linear	4	44.258	44.258	3.1613	6.91	0.000*significant
Residual Error	26	14.549	14.549	0.5596		
Lack-of-fit quadratic	20	12.988	12.988	0.64940	2.250	0.130*not significant
Pure Error	6	1.561	1.561	0.2601		
Total	30	51.579				

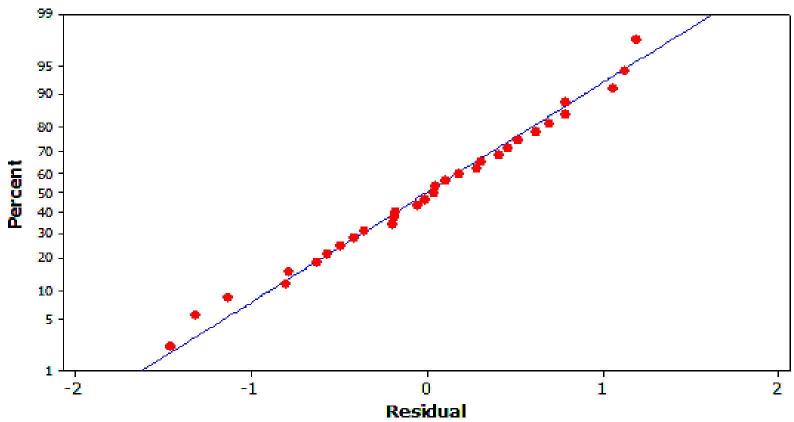


Figure 4.1: Normal Probability Plot for S_a

$S_a = 0.221267 + 0.175643\ X_1 – 0.0118833\ X_2 – 0.00153725\ X_3 + 9.16667E\text{-}05\ X_4$ (4.1)

Table 4.4: Fit Summary for S_a

Statistical analysis	Values
R-square	85.85%
R-square (adjust)	73.39%
R-square(predict)	31.55%

Table 4.5 shows the *P*-value is <0.05 for the developed model of *MRR*. This indicates that the square model is significant but not for the interaction. Therefore, a square model is carried out to analysis, because the full quadratic model does not adequately fit the response surface. Thus, it needs to fit the linear and square model, and the result is shown at Table 4.6. It is observed that the lack of fit value is 0.659 which is more than 0.05, this indicates not significant. This shows that the quadratic model developed for the *MRR* adequately fit the data for the response. In addition, the experiments data plot as Figure 4.2, it able to generated straight line, this mean the residuals are normally distributed. A developed linear and quadratic equation for *MRR* is expressed as Eq. (3.2).

$$MRR = 10.368 - 0.00451\ X_1 - 0.149\ X_2 + 0.00212\ X_3 - 0.0104\ X_4 + 0.00750\ X_1^2 + 0.000554\ X_2^2 + 1.522\times10^{-6}X_3^2 + 1.807\times10^{-5}X_4^2 \quad (4.2)$$

Table 4.5: Analysis of Variance for *MRR* (full quadratic)

SOURCE	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	14	70.272	70.272	5.0194	31.39	0.000
Linear	4	64.242	64.242	16.0605	102.16	0.000 *significant
Square	4	3.918	3.918	0.9795	6.23	0.003 *suggest
Interaction	6	2.112	2.112	0.3520	2.24	0.093
Residual Error	16	2.515	2.515	0.1572		
Lack-of-fit	10	1.053	1.053	0.1053	0.43	0.884 *not significant
Pure Error	6	1.462	1.462	0.2467		
Total	30	72.787				

Table 4.6: Analysis of Variance for *MRR* (linear and square)

SOURCE	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	8	68.160	68.160	8.52	40.51	0.000
Linear	4	64.242	64.242	16.0605	76.36	0.000
Square	4	3.918	3.918	0.9795	4.66	0.007 *suggest
Residual Error	22	4.627	4.627	0.2103		
Lack-of-fit	16	3.165	3.165	0.1978	0.81	0.659 *not significant
Pure Error	6	1.462	1.462	0.2467		
Total	30	72.787				

Table 4.7: Fit Summary for *MRR*

Statistical analysis	Values
R-square	93.64%
R-square (adjust)	91.33%
R-square(predict)	88.55%

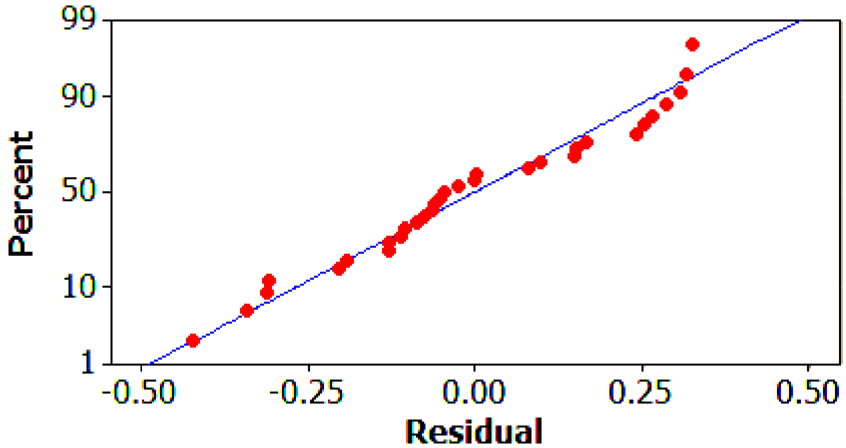


Figure 4.2: Normal Probability Plot for *MRR*

The analysis of variance Table 4.8 shows the p-value (probe>f) is <0.05 for the developed model of *EWR*. This indicates that the model is significant. Table 4.9 shown that the lack of fit indicates not significant. This shows that the full quadratic model developed for the *EWR* adequately fit the data for the response. The interaction is chosen for the develop the mathematical model because a equation with combination linear, square and interaction is appear to be more accurate. In addition, the experiments data is plot as Figure 4.3 able to generated straight line, this mean the residuals are normally distributed. A developed full quadratic equation for *EWR* is expressed as Eq. (4.3).

$$\begin{aligned} EWR = {} & 15.8355 - 0.4169X_1 - 0.1295X_2 - 0.02724X_3 - 0.03123X_4 + 0.01333X_1^2 \\ & + 0.0004147X_2^2 + 1.5515\times10^{-5}X_3^2 + 2.9923\times10^{-5}X_4^2 - 4.2411\times10^{-4}X_1X_2 \\ & - 2.6786\times10^{-4}X_1X_3 + 1.4062\times10^{-4}X_1X_4 + 1.9228\times10^{-4}X_2X_3 \\ & + 8.3333\times10^{-5}X_2X_4 + 4.2831\times10^{-5}X_3X_4 \end{aligned} \tag{4.3}$$

Table 4.8: Analysis of Variance for *EWR*

SOURCE	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	14	22.3706	22.3706	1.5979	81.06	0.000
Linear	4	8.3342	8.3342	2.08356	105.69	0.000
Square	4	12.3292	12.3292	3.08231	156.36	0.000
Interaction	6	1.7071	1.7071	0.28452	14.43	0.000*significant
Residual Error	16	0.3154	0.3154	0.01971		
Lack-of-fit (Linear)	20	14.3066	14.3066	0.71533	95.02	0.00
Lack-of-fit (Linear + regression)	10	0.2702	0.2702	0.02702	3.59	0.066 *not significant
Pure Error	6	0.0452	0.0452	0.00753		
Total	30	22.6860				

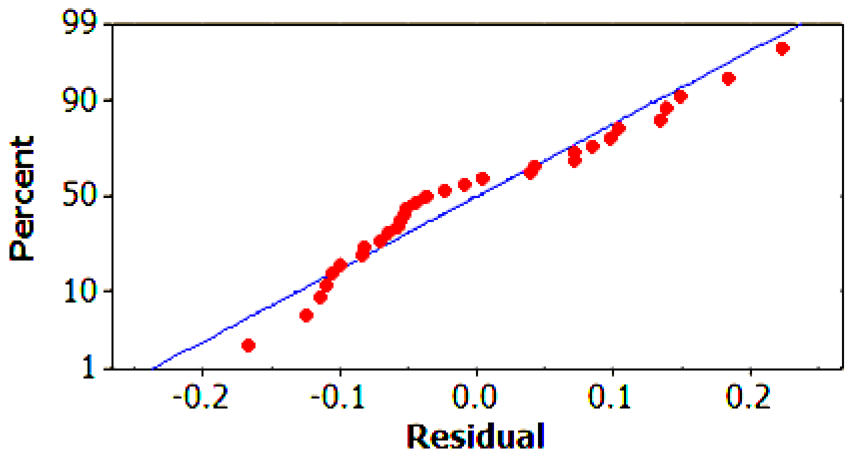


Figure 4.3: Normal Probability Plot for *EWR*

Table 4.9: Fit Summary for *EWR*

Statistical analysis	Values
R-square	98.61%
R-square (adjust)	92.87%
R-square(predict)	97.39%

It can be shown from Table 4.9 that the adjusted *R*-squared (Adj *R*-Squared) is >0.7 as part of the conditions for model adequacy. Further checking on the model adequacy is that the difference between adjusted *R*-squared and predicted *R*-squared is<0.20 indicates that the model is adequate. From above foregoing explanation, it has been shown that it have enough accuracy to predict for experiment.

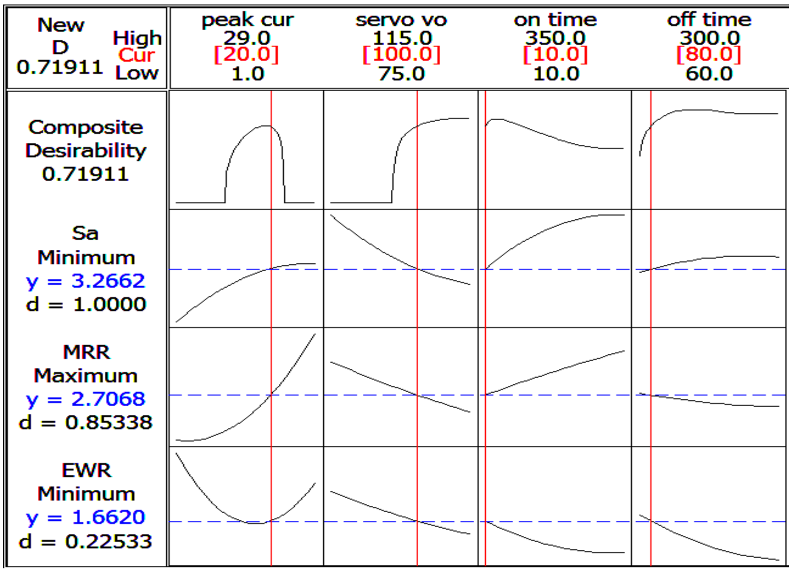


Figure 4.4: Sa, MRR, EWR versus IP, SV, On time, Off time

Figure 4.4 shows the relation between input and output. The hold values were 20A (peak current), 100V (servo voltage), 10µs (pulse on time), 80µs (pulse off time). At this hold values, I found that the relationship between input and output exactly same as the journals that I studied. As you can see, the peak current was directly proportional to surface roughness and material removal rate and even electrode wear rate after reach certain values. The trend of the electrode wear rate graph behaves straight after current is exceeding around 20A. This means when peak current increases, at the same time, surface roughness and material removal rate and electrode wear rate were increases.

High peak current results in larger energy discharge release from electrode thereby increases the energy of a single discharge to facilitate the action of melting and vaporization of the electrode and work piece, this results in higher amount of material being removed from electrode and hence leads to high MRR. However, large discharging energy causes violent sparks and impulsive forces and results in a deeper and larger erosion crater on the surface. The peak current was inversely proportional to surface roughness and material removal rate and electrode wear. This is because when the discharge gap is closer; the discharge energy spark is concentrate at centre point. It means that the cutting areas will be deepest at centre and hence cause rough surface. Besides, short circuit may occur frequently due to the unstable performance of the discharge. MRR is inversely proportional to servo voltage. Low servo voltage, the discharge gap is narrow and clogging likely to occur. The discharge frequency is high and hence the machining speed is fast.

The pulse duration is affecting the surface roughness negatively as expected. But at the extended pulse durations at 270 µs, the surface roughness is being remained unchanged. At this pulse duration, the spark intensity is decreasing in the discharge spots because of the expansion of the plasma channel. The material removal rate is also increasing with pulse on duration. During the machining period, in addition to the expansion of plasma channel, at high pulse on duration levels the localized temperature is increased. Moreover, pulse on time inversely proportional to electrode wear rate. They both decreases simultaneously. Figure 2 shows almost straight line for pulse off time versus surface roughness and machining removal speed; when the pulse off time exceeding 100µs. This indicated pulse off time has no significant influence in surface roughness. However, pulse off time has decreases the electrode wear rate. This is because the electric discharge stop time is increase.

4.2.1 Contour and Surface plot

A contour plot is like a topographical map in which x-, y-, and z-values are plotted instead of longitude, latitude, and elevation. Contour plot used to explore the potential relationship between variables. Contour plots display the three-dimensional relationship in two dimensions, with x- and y-factors (predictors) which is servo voltage and pulse on time plotted on the x- and y-scales and response values (surface roughness or material removal rate or electrode wear rate) represented by contours. Contour and surface plots are useful for establishing desirable response values and operating conditions. A contour plot provides a two-dimensional view where all points that have the same response are connected to produce contour lines of constant responses; a surface plot provides a three-dimensional view that may provide a clearer picture of the response surface.

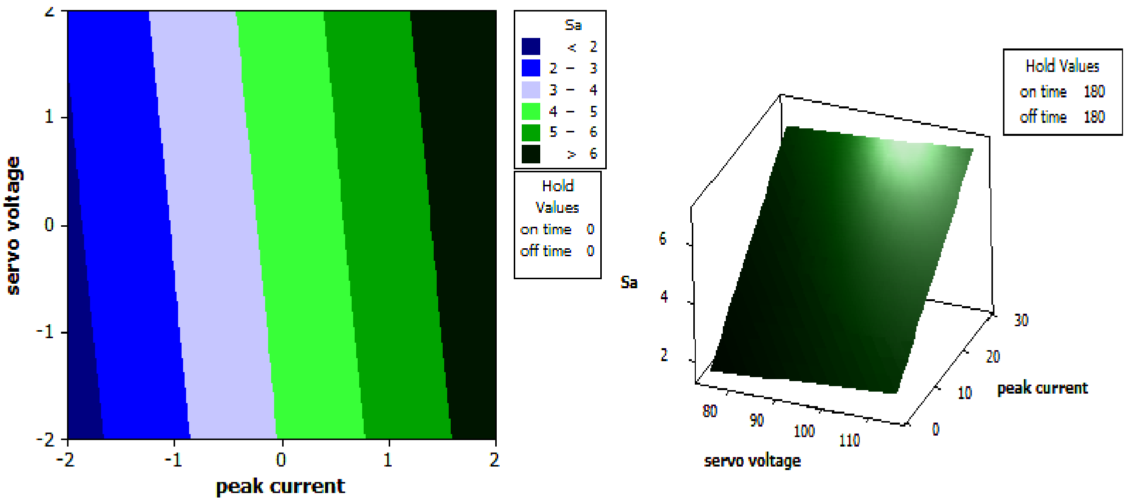


Figure 4.5: Surface roughness vs servo voltage, peak current

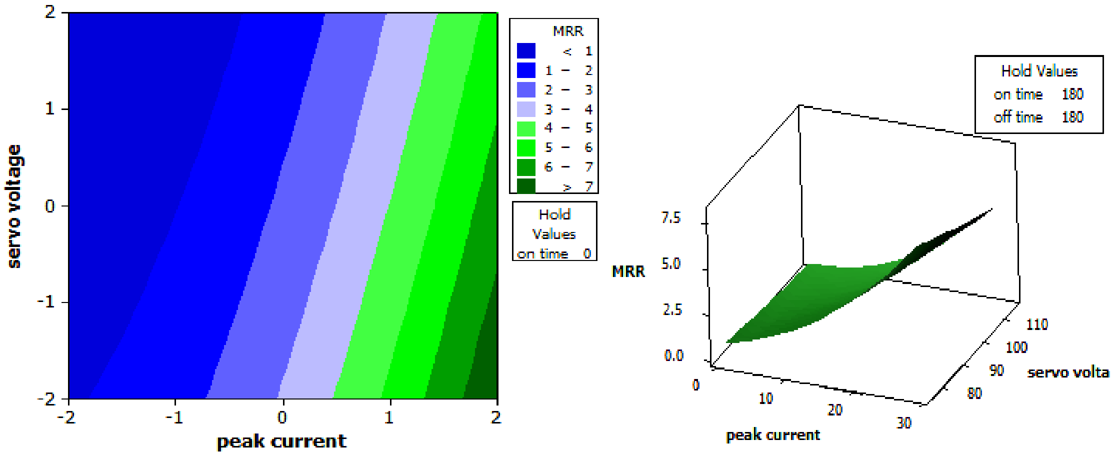


Figure 4.6: Material removal rate vs peak current, servo voltage

Figure 4.5 shown that the peak current greatly significant in affect the surface roughness while the servo voltage is has minor role in influence the surface roughness.

It can be seen that, the surface roughness just increase slightly when the servo voltage increase. But for the peak current, the surface roughness increase dramatically when it increase. This indicated that peak current is the most significant input parameter compare to others (*SV*, *MRR*, and *EWR*).

Figure 4.6 shows the relation between material removal rates with peak current, servo voltage. Although both input parameters have directly proportional relations, peak current is the more significant input. This is because when current is increase from 1-29 A, the material removal rate increase from 1-7.5 μms^{-1} when the servo voltage is hold at 75 V. The difference is around 6± μms^{-1}. However, for the servo voltage, the difference just 2± μms^{-1}. Therefore, peak current is very important in the material removal rate.

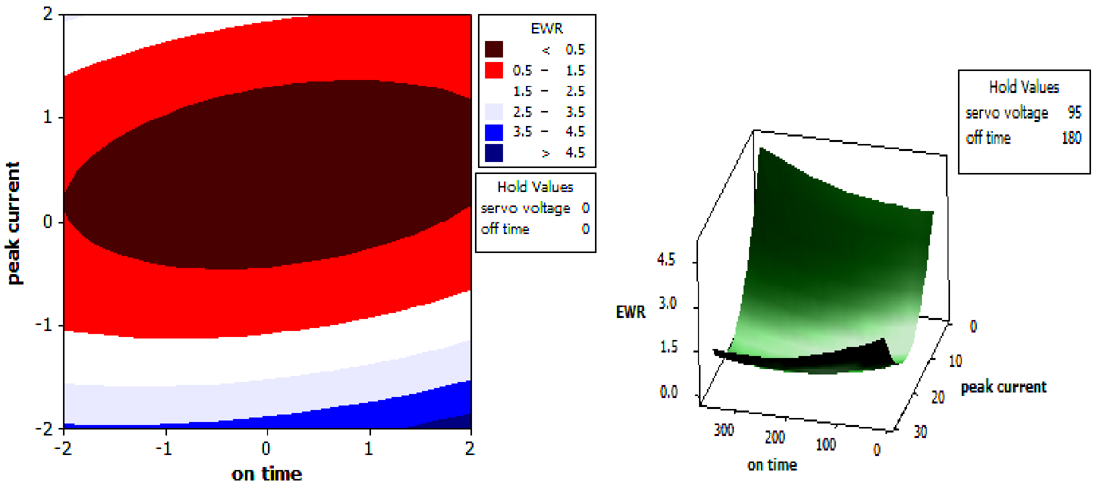


Figure 4.7: Electrode wear rate vs peak current, pulse on time

Figure 4.7 shows the relation between material removal rates versus peak current, servo voltage. The peak current has negative polynomial function with respect to electrode wear rate. The electrode wear rates reach minimum when the current at around 20 A. MINITAB predict that the electrode will reach highest, 4.5± μms^{-1} when pulse on time is equal to 350 µs and the current equal to 1 A. Besides, the peak current again was the most significant input parameter because it changed a lot with respect to electrode wear rate.

4.2.2 Response Optimization and Confirmation Test

One of the response-surface-methodology is to optimize the machining parametric combinations. This is carried out to determine with the optimal combination of the machining parameters and their combinational effects on the desired response criteria. Use response optimization to help identify the combination of input variable settings that jointly optimize a set of responses. Joint optimization must satisfy the requirements for all the responses in the set, which is measured by the composite desirability. The optimal solution serves as the starting point for the plot. This optimization plot allows you to interactively change the input variable settings to perform sensitivity analyses and possibly improve the initial solution. The optimized values are tabulated in Table 4.10.

Table 4.10: Optimum prediction results

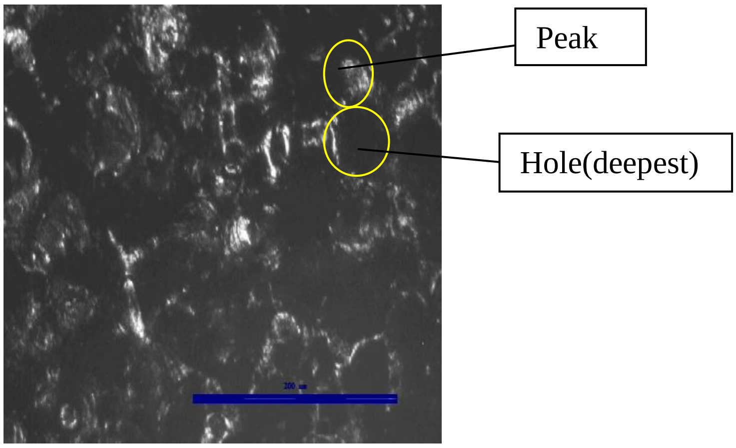
Parameters	Predicted results
Peak current	24.7576
Servo voltage	115
On time	10
Off time	300
S_a	2.62278
MRR	3.04928
EWR	0.32185

A confirmation test experiment is carried out to check the accuracy of prediction. Validation experiments were carried out to validate the models developed for all the responses. An experiment were conducted with the parameter setting of peak current 24.76 ≈ 25 A, servo voltage 115, pulse-on-time 10 μs and pulse-off-time 300 μs. The predicted values and the confirmation experimental results are compared and the percentages of error are calculated. The results of the confirmation runs for MRR, EWR and S_a are presented in Table 4.11 Confirmation runs for response models reveal that the percentage of error for the conditions is very less, within 5%. This affirms that the models developed are precisely adequate for predicting the responses.

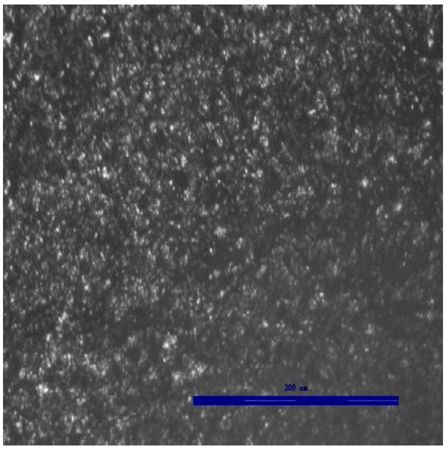
Table 4.11: Analysis of the confirmation experiments for MRR

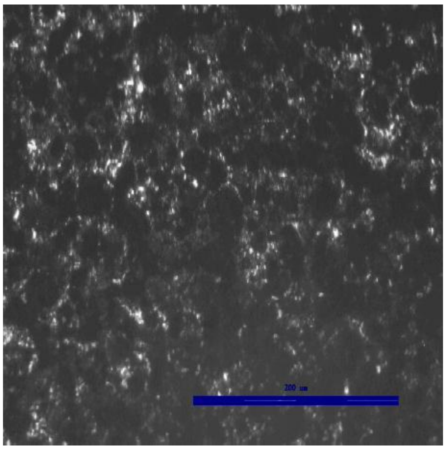
S_a			MRR			EWR		
Predict	Actual	Error	Predict	Actual	Error	Predict	Actual	Error
2.6228	2.7775	4.17%	3.04928	2.9521	3.18%	0.3219	0.3150	2.14%

4.3 SURFACE TOPOGRAPHY



(a): S_a = 6.535µm





(b) S_a = 1.747 µm **(c)** S_a = 3.709 µm

Figure 4.8: Surface Topography

Figure 4.8 (a) shows a work piece has a rough surface with surface roughness 6.535 µm. It is observed that the diagram has many deep and large big holes. This is because the higher input power associated with increase in peak current causes more frequent cracking of dielectric, leading to more frequent melt expulsion. This in turn gives rise to higher density of globules accumulated at the close vicinity of machining zone and poorer surface finish.(Bhattacharyya,B. et al ; 2007)

Figure 4.8 (b) shows a work piece has a rough surface with surface roughness 3.709 µm. As compare to Figure 8, it found that the size of the hole is reduced. This is because reducing in peak current lead to minimize the power of energy discharge. These energy cannot produce deepest hole as compare to Figure 4.8 (a).

Figure 4.8 (c) shows a work piece has a fine surface with surface roughness 1.747 µm. In this figure, the size of hole is very small. The microscope cannot product good visualization for this surface roughness. However, it still can observe that the distance peak to peak is very close.

4.4 CONCLUSION

In conclusion, adequate test show that the model was fit. Three mathematical models were form for MRR, EWR, and Sa respectively. The relationships of the input and output parameters were shown in surface plot, 3D and 2D graph. The next chapter will be summarizing the important finding.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INDRODUCTION

This chapter contents the summarizing of the relation between input and output parameters.

5.2 CONCLUSION

A mathematical model was developed by using response surface method. These mathematical models are used to predict the material removal rate, electrode wear rate and surface roughness. An adequate test was carried out and it was proved that the model is fit for this study. In conclusion, the test results evident that peak current, servo voltage, pulse on time and pulse off time significantly influence various criteria of surface roughness, electrode wear rate and machining removal rate. A linear model was developed for surface roughness and quadratic models were developed for material removal rate and electrode wear rate. The developed mathematical models for surface roughness and machining removal rate, with peak current, 20 A, servo voltage ,100 V, pulse on time, 10 µs, and pulse off time , 80 µs, it can concluded that:

1) It is observed that the peak current is directly proportional to *MRR*, S_a and *EWR*.
2) Servo voltage is inversely proportional to *MRR*, *Sa* and *EWR*.
3) Pulse on time is directly proportional to *MRR* and S_a, but inversely to *EWR*. But at the extended pulse durations at 270 µs, the surface roughness is being remained unchanged.

4) Pulse off time has almost no effect on surface roughness and machining removal rate. By the way, pulse off time has decreases the electrode wear rate.

5) Peak current and servo voltage has the greater impact on surface roughness, material removal rate and electrode wear rate.

6) Optimum of a set parameter was with peak current 27.5 A, servo voltage 115V, pulse on time 10µs, pulse of time 300µs. The actual outputs obtained were S_a, 2.7775 µm, and *MRR*, 2.9521 ms^{-1}, *EWR*, 0.3150 ms^{-1}.

5.3 RECOMMENDATION FOR FUTURE WORK

The objectives of this project were successfully achieved as discussed in the conclusion before. However there is still room for improvement in obtaining better and accurate result. If the highly accurate results are desirable, there are some recommendations for it.

First at all, there are still have others parameter that influence the MRR, or EWR, or surface roughness such as polarity, main supply voltage, flushing pressure and so on. Besides, the machining time can be increase to improve the accuracy of the result. In addition, the residual carbon during machining may affect the machining performance too.

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APPENDIX A1

Electric discharge duration for EDM AO55L machining manual

ON ****	Pulse ON (μ sec)	interval
*000	0.5	
*001…*100	1…100	Every 1 μ sec
*101…*104	100	Every 5 μ sec
*105…*109	105	
*985…*989	985	
*990	990	
*991	1000	Notch input
*992	1250	
*993	1500	
*994	1750	
*995	2000	
*996	2250	
*997	2500	
*998	3000	
*999	4000	

APPENDIX A2

Electric Discharge Pulse Control System

ON ****	Control system	Major application	Standard/optional
0***	Pulse control B	Cu-St, Gr-St machining	Standard
1***	Pulse control A		
2***	Pulse control B	Tungsten carbide machining	Optional
3***	Pulse control A		

Pulse control B: For normal machining

Pulse control A; For better surface finish or machining with ON pulse duration less than 4 μs

APPENDIX A3

Electric discharge OFF pulse for EDM AQ55L machining manual.

ON ****	Pulse ON (µ sec)	interval
0000	0.5	Every 1 µ sec
0001…0250	1…250	
0251	250	Every 2 µ sec
0252, 0253	252	
0254, 0255	254	
0498, 0499	498	
0500	500	
0501…0504	500	Every 5 µ sec
0505…0509	505	
0995…0999	995	
1000	1000	
1001…1009	1000	Every 10 µ sec
1010…1019	1010	
2490…2499	2490	
2500	2500	

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing

Signature : ……………………………
Name of Supervisor : DR MD MUSTAFIZUR RAHMAN
Position : Associate Professor
Date : 6th DECEMBER 2010

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature : ……………………………

Name : LEE WAI LOON

ID Number : ME07047

Date : 6 DECEMBER 2010

Dedicated to my beloved parents

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ABSTRACT

This paper was developed the mathematical modelling of EDM process parameters to predict the surface roughness of Ti-6Al-4V. The process is used in situations where intricate complex shapes need to be machined in very hard materials such as titanium alloy. However, the process generates surfaces that have poor properties such as high surface roughness, slow machining removal rate and moderate electrode wear rate. These properties vary with different levels of the main process parameters such as peak current, servo voltage, pulse on-time and pulse off-time. The aim of this paper is to perform experimental work that has been done in order to explore the relationships between input and output parameters. Response surface design is used because the input and output parameter were suspect have curvature relationships. A mathematical model develops base on response surface method. The significant coefficients were obtained by performing Analysis of Variance (ANOVA) at 95% level of significance. Adequacy test was carried out to check the fitting of the models. It found that the peak current, servo voltage and pulse on time are significant in material removal rate and surface roughness. Peak current has the greater impact on surface roughness and material removal rate. Finally, a metallurgical microscope is carried to observe the surface topography.

‘

ABSTRACT

Tujuan untuk project ini adalah mengembangkan model metamatik bagi EDM proses parameter untuk memprediksi kekasaran permukaan. EDM proses biasanya digunakan dalam situasi di mana bentuk kompleks rumit perlu memotong bahan yang sangat keras seperti gabungan titanium. Namun, proses tersebut menghasilkan permukaan yang memiliki sifat buruk seperti kekasaran permukaan tinggi, tahap enjin removal yang lambat dan laju kehausan elektrod. Property ini berbeza dengan tahap yang berbeza dari parameter proses utama seperti tegangan arus puncak, servo, pulsa pada waktu dan pulsa off-bila masa. Tujuan makalah ini adalah untuk melakukan kerja eksperimen yang telah dilakukan untuk mengeksplorasi hubungan antara parameter input dan output. Respon design surface digunakan kerana parameter input dan output disyaki mempunyai hubungan kelengkungan. Tiga model matematik mengembangkan pangkalan pada kaedah response surface method. Pekali signifikan diperolehi dengan melakukan Analisis Varian (ANOVA) pada peringkat 95% signifikansi. Adequate test dilakukan untuk memeriksa pemasangan model. Didapati bahawa puncak saat ini, voltan servo dan pulsa pada waktu yang signifikan pada angka removal material dan kekasaran permukaan. Puncak saat ini mempunyai kesan yang lebih besar pada kekasaran permukaan dan tahap bahan penghapusan. Akhirnya, mikroskop metalurgi dilakukan untuk mengamati topografi permukaan.

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LIST OF SYMBOLS

A	Ampere
V	Voltage
ms^{-1}	Meter per second
μ	Micro
W_{w1}	Weight of work piece after machining
W_{w2}	Weight of work piece before machining
W_e	Weight difference of electrode
W_1	Weight of electrode after machining
W_2	Weight of electrode before machining
T	Time
ρ_e	Density of copper

LIST OF ABBREVIATIONS

EDM	Electric Discharge Machine
S_a	Surface roughness
EWR	Electrode Wear Rate
MRR	Material Removal Rate
RSM	Response Surface Methodology
CCD	Central Composite Design
MMCs	Metal Matrix Composites
Ti_6Al_4V	Titanium alloy Grade 5
IP	Peak Current
SV	Servo voltage
ON	Pulse on time
OFF	Pulse off time
DOE	Design of Experiment
UMP	University Malaysia Pahang