OPTIMIZATION OF ELECTRICAL DISCHARGE MACHINE PARAMETER ON MILD STEEL BY USING RESPONSE SURFACE METHODOLOGY

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for the award of the degree of
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2010

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 Engineering.

Signature :
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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.

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Dedicated to my family

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In the name of Allah, the Most Gracious and Most Compassionate

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Deepest gratitude to my family, who give me a real love, pray, support, and all they have. Finally, I am grateful to Universiti Malaysia Pahang for all of support during the period of this research work.

ABSTRACT

This thesis deals with machining steel workpiece using Electrical Discharge Machining (EDM). The objective of this thesis is to determine the relationship between the machining parameters which is pulse-on time, pulse-off time, flushing pressure, peak current and servo voltage with material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR). This thesis uses the response surface methodology techniques to turn out the equation the equation that use to optimize the MRR, EWR and SR and the fractional factorial design of experiment was used in the project. The machining of mild steel workpiece was performed by using an EDM machine ROBOFORM 200 and the analysis was done by using the MINITAB software. Based from the result, it is observed that the second order modal give more accurate prediction data for both MRR and EWR. The significant parameters that effect the EWR was the discharge current and discharge voltage. The EWR increased when this two parameter increase. The significant parameters are discharge voltage and pulse-on time for MRR. By previous researchers found that machining parameters had a large effect on geometric tool wear characteristics and machining performance outputs. Considering all of these parameters, a good machining condition can be obtained. This result also can significantly reduce the cost of operation and cost of product.

ABSTRAK

Tesis ini membincangkan proses pemesinan keluli kerja menggunakan proses pemesinan nyahcas elektrik (EDM). Objektif tesis ini adalah untuk menentukan hubungan antara parameter memesin yang digunakan iaitu, denyutan masa terbuka, denyutan masa tertutup, pembilasan tekanan, puncak arus dan servo voltan dengan kadar penyingkiran (MRR), nisbah kehausan elektrod (EWR) dan kekasaran permukaan (SR). Tesis ini menggunakan kaedah permukaan gerak balas untuk mengeluarkan persamaan persamaan yang digunakan bagi meramalkan MRR, EWR dan SR serta faktoran pecahan reka bentuk eksperimen telah digunakan dalam projek ini. Kerja pemesinan keluli ringan dilakukan dengan menggunakan mesin EDM ROBOFORM 200 dan analisis dibuat menggunakan perisian MINITAB. Daripada hasil, diperhatikan bahawa peringkat kedua modus memberi ramalan data yang lebih tepat untuk kedua-dua MRR dan EWR. Daripada keputusan, parameter penting yang member kesan kepada EWR adalah arus pelepasan dan voltan pelepasan. EWR meningkat apabila kedua-dua parameter ini meningkat. Untuk MRR, parameter yang penting adalah voltan pelepasan dan denyut pada masa. Daripada kajian yang telah dijalankan oleh penyelidik sebelum ini mendapati parameter pemesinan mempunyai kesan yang besar terhadap kerosakan alat dan prestasi pemesinan. Dengan mempertimbangkan kesemua parameter ini, kaedah pemesinan yang baik boleh dipersembahkan. Hasil ini juga boleh mengurangkan kos operasi dan kos produk.

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LIST OF SYMBOLS

t_i	Pulse On-time
t_o	Pulse Off-time
μs	The duration of time machining
$\mu\Omega$	Electrical resistivity
s	second
W_b	Weight of workpiece material before machining (g)
W_a	Weight of workpiece material after machining (g)
A	Ampere
μm	Micrometer
$x_1, x_2, x_3, \ldots, x_k$	Input variables
α	Alpha phase
β	Beta phase
y	Response
ε	Error
η	Expected response
V	Voltage
I	Current

LIST OF ABBREVIATIONS

EDM	Electrical Discharge Machining
MRR	Material Removal Rate
EWR	Electrode Wear Ratio
SR	Surface Roughness
RSM	Response Surface Methodology
DOE	Design of Experiment
EWW	Weight of Electrode Use
WRW	Weight of Workpiece Used
ANOVA	Analysis of Variance
MS	Mean Square
D.O.F	Degree of Freedom
SS	Sum of Square
F	Fisher Test
P	Probability

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Since electrical discharge machining (EDM) was developed, much theoretical and experimental work has been done to identify the basic processes involved. It is now one of the main methods used in die production and has good accuracy and precision with no direct physical contact between the electrodes so that no mechanical stress is exerted on the work piece.

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The important output parameters of the process are the material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR). Optimization of the EDM process is concerned with maximizing MRR while minimizing EWR, and also producing the optimum SR usually, the finish should be as smooth as possible. This paper describes an investigation of EDM process optimization using response surface methodology (RSM) on mild steel material.

In 1979, Kruth et al. has developed an adaptive control system that optimizes settings on line, for example, servo reference voltage, pulse duration, pulse interval and dielectric flow rate. However, developed a new model reference adaptive control for EDM, which improved the machine stability and gave up to 40% higher machining productivity (Rajurkar et al. 1989)

1.2 IMPORTANT OF RESEARCH

The important of this research are:

1. Enhance the production rate.
2. Improve efficiency of production process.
3. Analyzing the effect and behaviors of mild steel in application die-sinking machine under various parameter machining.
4. Enhance the quality surface finish of the cut metal.

1.3 OBJECTIVE

There are some objectives of this research:

1. To optimize the cutting condition for maximum MRR, minimum EWR and better surface roughness using response surface methodology.
2. To establish mathematical models for some of the dependent variables by using RSM in a specific range of parameter.

1.4 PROBLEM STATEMENT

Wear will occur on the electrode during machining process. The efficiency of production process will be disturbed because of that. Otherwise, the characteristic condition of workpiece will be cracked during the process. Mild steel AISI 1020 is a soft material, thus a proper machining is required to avoid the crack.

1.5 PROJECT SCOPES

A research focus on machining parameter and methodology that effect to the result. There are several main scopes in this project are:

1. Make analysis by using Response Surface Methodology (RSM) in optimizing Electrical Discharge Machine (EDM) on mild steel workpiece.
2. The type of machine is Die-sinking Electrical Discharge Machine (EDM)
3. Design Of Experiment (DOE) methodology is applied to define the main parameters and relationship between parameters.
4. Copper is used as an electrode.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Electric discharge machining (EDM) is a widely used non-traditional machining process in the manufacture of complex shaped dies, molds and critical parts used in automobile, aerospace, surgical and other industrial applications. The process uses thermal energy of the spark to machine electrically conductive parts regardless of the hardness of the work material. This unique feature of EDM has a distinct advantage in the manufacture of complex shaped die and molds made up of hard materials which are difficult to machine by conventional machining processes (K.H. Ho and S.T. Newman, 2003). The EDM process has limitations such as longer lead times and lower productivity which restricts its application. Researchers worldwide are thus, focusing their attention on improving the productivity and finishing capability of the EDM process.

2.2 ELECTRICAL DISCHARGE MACHINE (EDM)

EDM has been an important manufacturing process for the tooling, mould and die industries for several decades. The process is finding an increasing industrial use due to the ability of producing geometrically complex shapes as well as its ability to machine hard materials that are extremely difficult to machine when using conventional process. According to Sommer (2000) EDM can be categorized into two: die sink EDM and wire EDM. However, Pandey and Shah (1980) classified EDM processes into three main categories as shown in Figure 2.1.

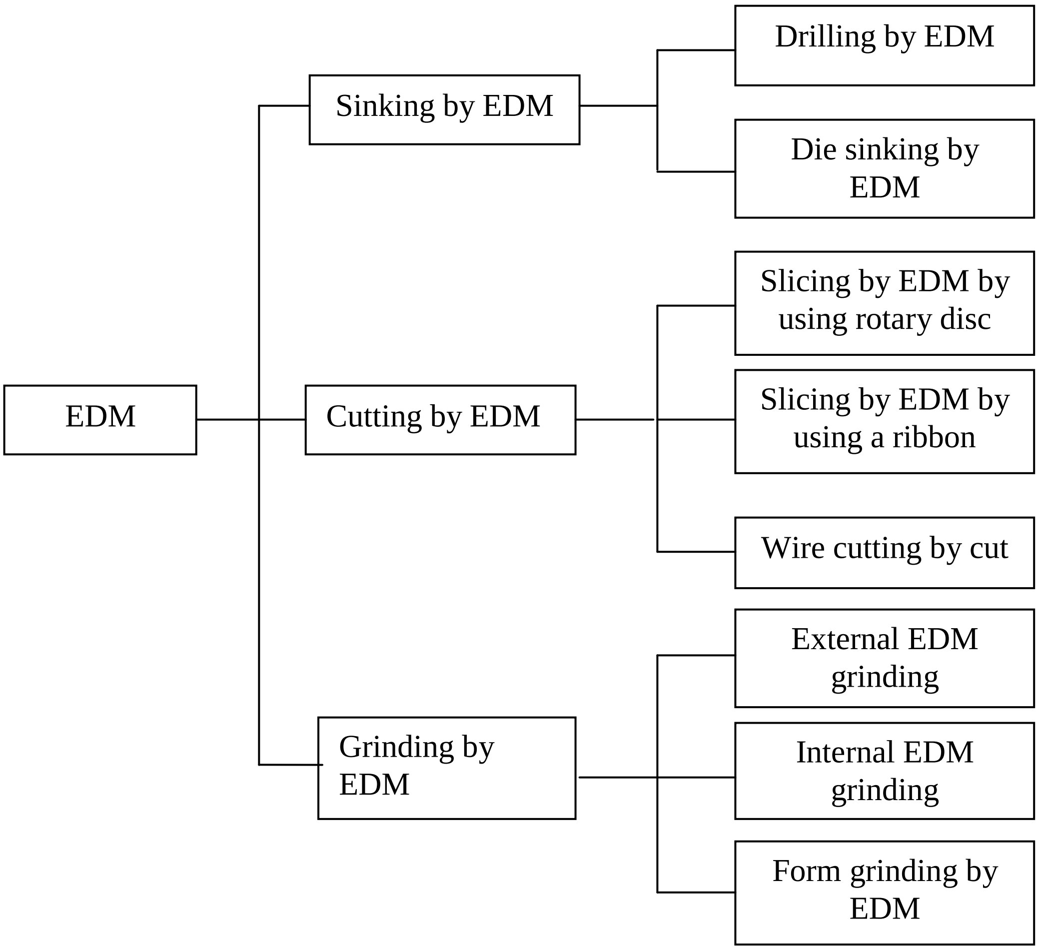


Figure 2.1: Classification of EDM processes

Conventional EDM, also known as sinker EDM, die sinker, vertical EDM, or plunge EDM is generally used to produce blind cavities (Sommer, 2000). When blind cavities are required, a formed electrode is machined to the desired shape. Then, by means of electrical current the preformed electrode surrounded by dielectric fluid, reproduced its shape in the workpiece. A powerful spark causes pitting or erosion of the metal on both the anode (+) and cathode (-). This process is also called spark machining or spark erosion machining. The EDM process involves a controlled erosion of electrically conductive materials by the initiation of rapid and repetitive spark discharges between the electrode and workpiece which is separated by a small gap.

EDM is known to have capability in producing small holes. It can be used for making nozzles, irregular holes and complicated shape and profiles, for embossing and engraving operations on hardened materials (Mahajan, 1981). The sinker EDM is best suited for machining deep and thin cavities in hard materials (Altan *et al*., 1993), the process, however, relatively slow when compared to milling operation. Much work in recent years has been devoted to orbital EDM, EDM milling, unattended and high speed EDM, use of non flammable dielectrics fluids, increasing machining accuracy, and the reduction and control of electrode wear (Abu Zeid, 1996, 1997; Yan and Wang, 1999; Lin *et.al*, 2000; Wang and Yan, 2000; Yan *et al*., 2000; Rozenek *et al*., 2001; and, Kaminski and Capuano, 2003). Ho and Newman (2003) have classified research areas in EDM machining process as shown in the Figure 2.2.

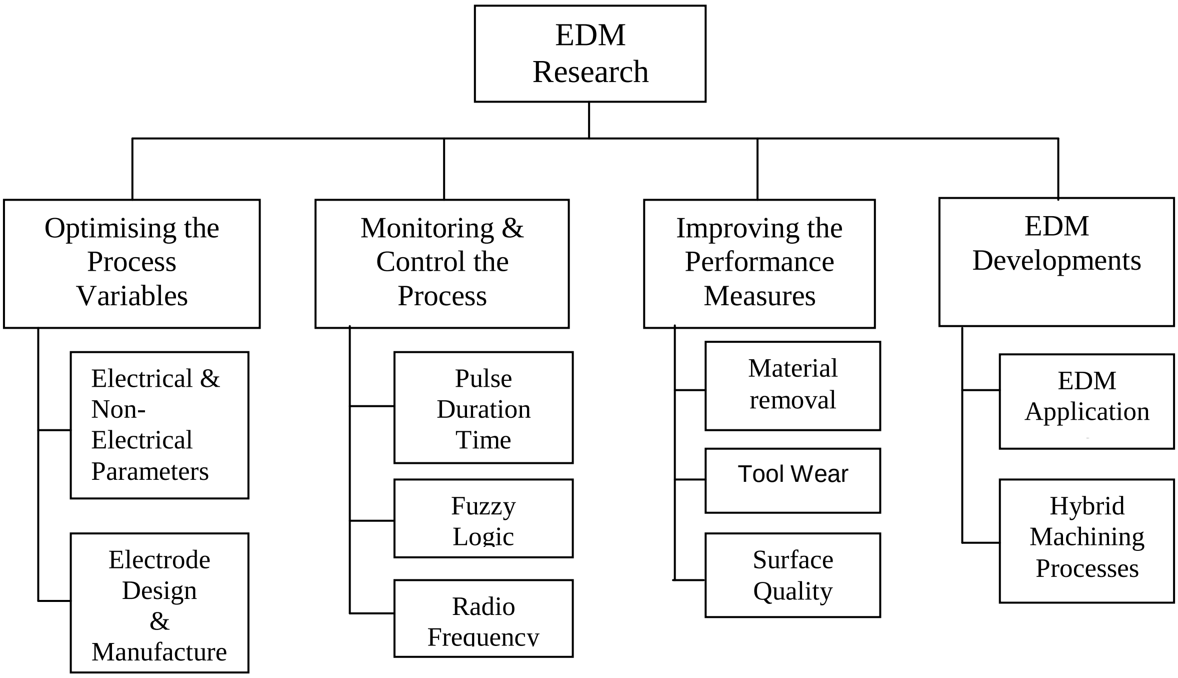


Figure 2.2: Classification of major EDM research areas

Source: Ho and Newman, 2003

2.3 DIE-SINKING EDM MACHINE

Die-sinking EDM machines are also known as ram or vertical EDMs. The equipment used to perform the experiments was a die-sinking EDM machine of type ONA DATIC D-2030-S. Also, a jet flushing system in order to assure the adequate flushing of the EDM process debris from the gap zone was employed. The dielectric fluid used for the EDM machine was a mineral oil (Oel-Held Dielektrikum IME 82) with a flash point of 82 ◦C. The electrodes used were made of electrolytic copper (with a cross-section of 12mm×8 mm) and the polarity was negative.

Die-sinking EDM has four sub-systems, that are:

1. DC power supply to provide the electrical discharges, with controls for voltage, current, duration, duty cycle, frequency, and polarity.
2. Dielectric system to introduce fluid into the voltage area/discharge zone and flush away work and electrode debris, this fluid is usually a hydrocarbon or silicone based oil.
3. Consumable electrode, usually of copper or graphite.
4. Servo system to control in feed of the electrode and provide gap maintenance.

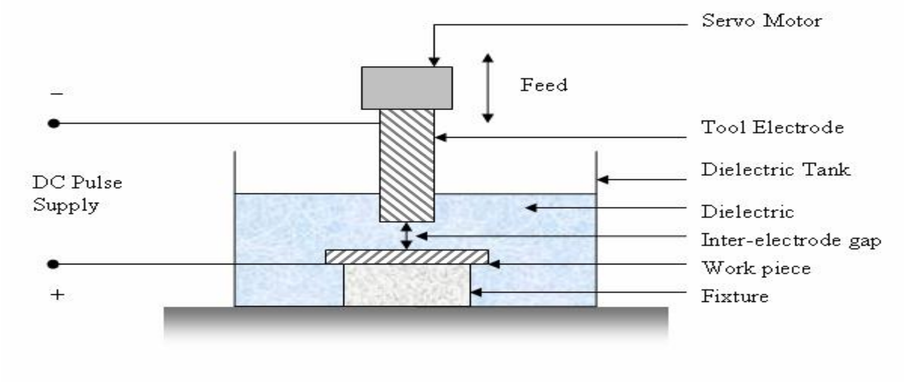


Figure 2.3: Schematic of an Electric Discharge Machining (EDM) machine tool

The schematic of an EDM machine tool is shown in Figure 2.3. The tool and the workpiece form the two conductive electrodes in the electric circuit. Pulsed power is supplied to the electrodes from a separate power supply unit. The appropriate feed motion of the tool towards the workpiece is generally provided for maintaining a constant gap distance between the tool and the workpiece during machining. This is performed by either a servo motor control or stepper motor control of the tool holder. As material gets removed from the workpiece, the tool is moved downward towards the workpiece to maintain a constant inter-electrode gap. The tool and the workpiece are plunged in a dielectric tank and flushing arrangements are made for the proper flow of dielectric in the inter-electrode gap, (Sourabh Kumar Saha, 2008).

Typically in oil die-sinking EDM, pulsed DC power supply is used where the tool is connected to the negative terminal and the workpiece is connected to the positive terminal. The pulse frequency may vary from a few kHz to several MHz. The inter electrode gap is in the range of a few tens of micro meter to a few hundred micro meter. Material removal rates of up to 300 mm3/min can be achieved during EDM. The surface finish (Ra value) can be as high as 50 μm during rough machining and even less than 1 μm during finish machining, (Sourabh Kumar Saha, 2008).

2.4 MACHINING PARAMETERS

The machining performances depend on various EDM parameters (variables). Wang and Yan (1999, 2000) categorized the parameters into two groups;

1. Electrical Parameters:
    a. Polarity
    b. Peak current
    c. Pulse duration
    d. Power supply voltage

2. Non electrical parameters:
    a. Rotational of speed electrode
    b. Injection flushing pressure

In the other hand, Van Tri (2002) categorized the parameters into five groups:

1. Dielectric fluid; type of dielectric, temperature, pressure, flushing system
2. Machine characteristics; servo system and stability stiffness, thermal stability and accuracy.
3. Tool; material, shape, accuracy.
4. Workpiece
5. Adjustable parameters; discharge current, gap voltage, pulse duration, polarity, charge frequency, capacitance and tool materials.

However, previous researchers (Osycka *et al*., 1982; Singh *et al*., 1985; Madan and Sagar, 1994; Yan and Wang, 1999; Lin *et al*., 2000; Tsai and Wong, 2001; Liu, 2003; and, Tzeng and Chen, 2003) described that adjustable parameters are always considered as critical parameters. From the description above, the electrical parameters are more significant than non-electrical parameters on the machining characteristics (Singh *et al*., 1985; Abu zeid, 1997; Wang and Yan, 2000; Marafona and Wykes, 2000 ; Van Tri, 2002; and, George *et al*., 2003).

Although the non-electrical parameters are less significant as compared to electrical parameters, many researchers had focused on this area. Erden (1982) reported that dielectric flushing affected the EDM performance due to the changing of erosion rate, mirror like finishing achieved by multi divided electrode method (Mohri and Saito, 1985). Yan and Wang (1999) investigated the effect of rotary tube electrode on machining characteristics of Al2O3/6061Al composite. Improved jet flushing for EDM was investigated by Masuzawa *et al*. (1992). They found that the distribution phenomenon of debris had a good correlation with the geometry of the workpiece surface produced.

2.5 EDM PROCESS PARAMETERS

2.5.1 Discharge voltage

Discharge voltage in EDM is related to the spark gap and breakdown strength of the dielectric (Kansal et al., 2005). Before current can flow, the open gap voltage increases until it has created an ionization path through the dielectric. Once the current starts to flow, voltage drops and stabilizes at the working gap level. The preset voltage determines the width of the spark gap between the leading edge of the electrode and workpiece. Higher voltage settings increase the gap, which improves the flushing conditions and helps to stabilize the cut. MRR, tool wear rate (TWR) and surface roughness increases, by increasing open circuit voltage, because electric field strength increases. However, the impact of changing open circuit voltage on surface hardness after machining has been found to be only marginal.

2.5.2 Peak Current

This is the amount of power used in discharge machining, measured in units of amperage, and is the most important machining parameter in EDM. During each on-time pulse, the current increases until it reaches a preset level, which is expressed as the peak current. In both die-sinking and wire-EDM applications, the maximum amount of amperage is governed by the surface area of the cut. Higher amperage is used in roughing operations and in cavities or details with large surface areas. Higher currents will improve MRR, but at the cost of surface finish and tool wear. This is all more important in EDM because the machined cavity is a replica of tool electrode and excessive wear will hamper the accuracy of machining. New improved electrode materials, especially graphite, can work on high currents without much damage (Ho and Newman, 2003).

2.5.3 Pulse duration and pulse interval

Each cycle has an on-time and off-time that is expressed in units of microseconds. Since all the work is done during on-time, the duration of these pulses and the number of cycles per second (frequency) are important. Metal removal is directly proportional to the amount of energy applied during the on-time (Singh et al, 2005). This energy is controlled by the peak amperage and the length of the on-time. Pulse on-time is commonly referred to as pulse duration and pulse off-time is called pulse interval. With longer pulse duration, more workpiece material will be melted away. The resulting crater will be broader and deeper than a crater produced by a shorter pulse duration. These large craters will create a rougher surface finish. Extended pulse duration also allow more heat to sink into the workpiece and spread, which means the recast layer will be larger and the heat affected zone will be deeper.

However, excessive pulse duration can be counter-productive. When the optimum pulse duration for each electrode-work material combination is exceeded, material removal rate starts to decrease. A long duration can also put the electrode into a no-wear situation. Once that point is reached, increasing the duration further causes the electrode to grow from plating build-up. The cycle is completed when sufficient pulse interval is allowed before the start of the next cycle. Pulse interval will affect the speed and stability of the cut. In theory, the shorter the interval, the faster will be the machining operation. But if the interval is too short, the ejected workpiece material will not be swept away by the flow of the dielectric and the fluid will not be deionized. This will cause the next spark to be unstable. Unstable conditions cause erratic cycling and retraction of the advancing servo. This slows down cutting more than long, stable off-times. At the same time, pulse interval must be greater than the deionization time to prevent continued sparking at one point (Fuller, 1996). Modern power supplies allow independent setting of pulse on-times and off-times. Typical ranges are from 2 to 1000µs. In ideal conditions, each pulse creates a spark. However, it has been observed practically that many pulses fail if duration and interval are not properly set, causing a loss of the machining efficiency. Such pulses are known as “open pulses”.

2.5.4 Polarity

The polarity of the electrode can be either positive or negative. The current passing through the gap creates high temperatures causing material evaporation at both electrode spots. The plasma channel is composed of ion and electron flows. As the electron processes (mass smaller than anions) show quicker reaction, the anode material is worn out predominantly. This effect causes minimum wear to the tool electrodes and becomes of importance under finishing operations with shorter on-times. However, while running longer discharges, the early electron process predominance changes to positron process (proportion of ion flow increases with pulse duration), resulting in high tool wear. In general, polarity is determined by experiments and is a matter of tool material, work material, current density and pulse length combinations. Modern power supplies insert an opposite polarity “swing pulse” at fixed intervals to prevent arcing. A typical ratio is 1 swing pulse for every 15 standard pulses (Ho and Newman, 2003).

2.5.5 Electrode gap

The tool servo-mechanism is of considerable importance in the efficientworking of EDM, and its function is to control responsively the working gap to the set value. Mostly electro-mechanical (DC or stepper motors) and electro-hydraulic systems are used, and are normally designed to respond to average gap voltage. The most important requirements for good performance are gap stability and the reaction speed of the system; the presence of backlash is particularly undesirable. The reaction speed must be high in order to respond to short circuits or open gap conditions. Gap width is not measurable directly, but can be inferred from the average gap voltage (Crookall and Heuvelman, 1971).

2.6 ELECTRODE

All EDM electrode materials must possess certain properties in order to perform economically in a given application (Mahajan, 1981). The mandatory property is electrical conductivity; however, other properties may vary depending upon the material. The function of an electrode is to transmit the electrical charges and to erode the workpiece to the desired shape. Different electrode materials have different effects on the machining characteristics. Some remove metal efficiently with greater electrode wear; while others may experience minimal wear but remove metal very slowly.

The following materials are often used as electrode: tungsten, copper tungsten, silver tungsten, yellow brass, chrome plated materials, zinc alloys, tungsten carbide, copper, graphite, etc (Mahajan, 1981). Copper electrodes have been used primarily in resistance capacitance circuits where higher voltages are employed. Graphite electrodes are commonly used in application requiring little tool wear and high material removal rate. Brass electrodes are mainly used in pulse type circuits because of their good machinability. Lately some researchers used composite electrode material. Shu and Tu (2003) studied the metal matrix (Cu/SiCp) electrode applied in electrical discharge grinding and Tsai *et al*. (2003) reported that Cr/Cu based composite electrodes produced a higher MRR and thinner recast layer than Cu metal electrodes.

2.7 FLUSHING

Flushing is important because it removes eroded particles from the gap for efficient cutting. Flushing also enables fresh dielectric oil flow into the gap and cools both the electrode and the workpiece. Improper flushing causes erratic cutting, thus prevents the electrode from cutting efficiently. It is then necessary to remove the attached particles by cleaning the workpiece. Dielectric fluid is used as flushing to assist in the removal process of particles from the work area hence giving better surface finish (Wong *et al*., 1995).

There are five types of flushing fluid system in EDM (Sommer, 2000):

1. Pressure flushing
    a. Through electrode
    b. Through workpiece
2. Suction flushing
3. Combined pressure and suction flushing
4. Jet flushing
5. Pulse flushing:
    a. Vertical flushing
    b. Rotary flushing
    c. Orbiting Flushing

Kuneida and Furuoya (1991) studied the improvement of EDM efficiency by supplying gas into the gap and they found that the stock removal rate is increased, similar effect was also found by Erden (1982). Masuzawa *et al.*(1992) reported that improvement of jet flushing was found to increase the effectiveness of EDM.

2.8 DIELECTRIC FLUID

Basic characteristics required for dielectric used in EDM are high dielectric strength and quick recovery after breakdown (Wong *et al.*, 1995). Dielectric fluid performs three important functions (Sommer, 2000);

1. The fluid forms a dielectric barrier for the spark between the workpiece and the electrode
2. The fluid cools the eroded particles between the workpiece and the electrode
3. The pressurized fluid flushes out the eroded gap particles and remove the particles from the fluid by causing the fluid to pass through a filter system

Most dielectric media are hydrocarbon compounds and water. The hydrocarbon compounds are in the form of refined oil; better known as kerosene. While the fluid properties are essential, the correct fluid circulating methodology is also important. The selection of suitable dielectric is based on the type of materials and the processes that are used. The performance of the dielectric may vary from one workpiece to another. During the investigation of EDM of Ti 6Al 4V, Chen *et.al* (1999) found that the MRR was greater and the relative EWR is lower, when using distilled water as dielectric solution. Kuneida and Yoshida (1996) used gas as dielectric media, and they found that tool EWR was almost zero for any pulse duration.

2.9 MACHINING CHARACTERISTICS

EDM performance, regardless of the type of the electrode material and dielectric fluid, is measured usually by the following criteria:

2.9.1 Material Removal Rate (MRR)

$$\mathrm{MRR}=\frac{W_B\text{-}W_A}{T} \tag{2.1}$$

Where, T is the period of machining time in minute,W_B is the weight workpiece before and W_A is weight workpiece after machined.

This method is also adopted by Puertas and Perez (2003) and Puertas *et al.*(2004), and many other researchers. Maximum of MRR is an important indicator of the efficiency and cost effectiveness of the EDM process, however increasing MRR is not always desirable for all applications since this may scarify the surface integrity of the workpiece. A rough surface finish is the outcome of fast removal rates.

2.9.2 Electrode Wear Ratio (EWR)

In EDM, the tool wear problem is very critical since the tool shape degeneration directly affects the final shape of the die cavity. The EDM operations, performed using tools designed and produced by considering the geometric tool wear characteristics, reduce the machining errors to minimum level and result in parts of higher quality and lower cost (Ali Ozgedik,2005). The following equation is used to determine the EW value:

$$\mathrm{EWR}=\frac{\mathrm{EWW}}{\mathrm{WRW}}\times 100\% \tag{2.2}$$

Where;

EWW = weight of electrode used (g)
WRW = weight of workpiece used (g)

Mohri et al. (1995) refers that the EW is very small in the beginning of the machining and tends to a certain value, depending on the machining conditions. According to Marafona and Wykes (2000), the decrease of the tool wear is obtained with the increase of carbon on the tool surface in the beginning of machining.

Shanker Singh *et al.* (2004) investigated the EDM characteristics of hardened tool steel using copper, copper tungsten, brass and aluminium electrode materials. Their investigations indicate that the output parameters (material removal rate, diameteral overcut, electrode wear and surface roughness) of EDM increase with increase in pulsed current and the best machining rate are achieved with copper and aluminium electrodes. They reported that copper have minimal wear and aluminium have considerable high wear with increase in the current.

2.9.3 Surface Roughness (SR)

The surface produced by EDM process consists of a large number of craters that are formed from the discharge energy. The quality of surface mainly depends upon the energy per spark (S.H.Tomadi et al, 2009).The SR of the machined workpiece is measure using Perthometer surface roughness measuring machine. Due to the variability of surface finish data, multiple measurements were taken of each surface evaluated so that averages could be calculated.

2.10 DESIGN OF EXPERIMENT (DOE)

Design of experiment (DOE) is a test or series of tests in which purposeful changes are made to the input variables of a process or system so that the reasons for change in the output responses can be observed and identified (Lochner and Matar, 1990). This method has found broad application in many disciplines. Experimental design methods also play a major role in engineering design activities (Diamond, 2001), where new products are developed and existing ones needed improvement. Some applications of experimental design in engineering design include (Montgomery, 2001):

(i) Evaluation and comparison of basic design configuration.

(ii) Evaluation of material alternatives.

(iii) Selection of design parameters so that the product will work well under a wide variety of field conditions.

(iv) Determination of key product design parameters that impact product performance.

Applying DOE to monitor the process characteristics in EDM is very much appropriate, since it provides the best setting of EDM parameters to fulfill the multi objectives. Lin *et al*. (2000), Wang and Yan (2000), Marafona and Wykes (2000), and, Tsai and Wang (2001) employed Taguchi method to obtain the characteristics of EDM process. Most of EDM experiments were done by using this method because of the number of experiments can be reduced since EDM process involves many parameters. Response surface methodology (RSM) was applied by George *et al*. (2004) for modeling of the machinability parameters in EDM of carbon-carbon composite.

2.10.1 Two-level Fractional Factorial Design

The fractional factorial designs are among the most widely DOE tools used for product, process design and process improvement. A major application of fractional factorials is in screening the experiments. These are experiments in which many factors are considered and the objective is to identify those factors that significantly effect the responses. Screening experiments are usually performed in the early stages of a project when it is likely that many of the factors initially considered have little or no effect on the responses (Montgomery, 2001). The important factors that are identified are then investigated more thoroughly in the subsequent stages of the experiment. The fraction can be one-half, one-quarter or less of the 2k factorial which depends on the design estimates and the interactions of interest.

The resolution will be found in each fractional factorial on the two-level factorial design (State ease, Inc, 2000). Designs resolutions III, IV, and V are particularly important (Myers and Montgomery, 2002) and the definitions of these design are given below.

1. Resolution III designs. These are designs in which no main effects are aliased with any other main effect, but main effect aliased with two factor interactions and two factor interaction may be aliased with each other.

2. Resolution IV designs. These are designs in which no main effect isaliased with any other main effect or with any two factor interaction, but two factor interactions are aliased with each other.
3. Resolution V designs. These are designs in which no main effect or two factor interactions are aliased with any other main effect or two factor interaction, but two factors interactions are aliased with three factor interactions.

It is prefered to employ fractional designs that have the highest possible resolution. The higher the resolution, the less restrictive the assumptions that are required regarding which interactions are negligible in order to obtain a unique interpretation of data. In this study, one-half fractional factorial design was chosen for the screening experiment during the EDM process. Details of this theory are explained in Montgomery (2001) and Myers and Montgomery (2002).

2.10.2 Response Surface Methodology (RSM)

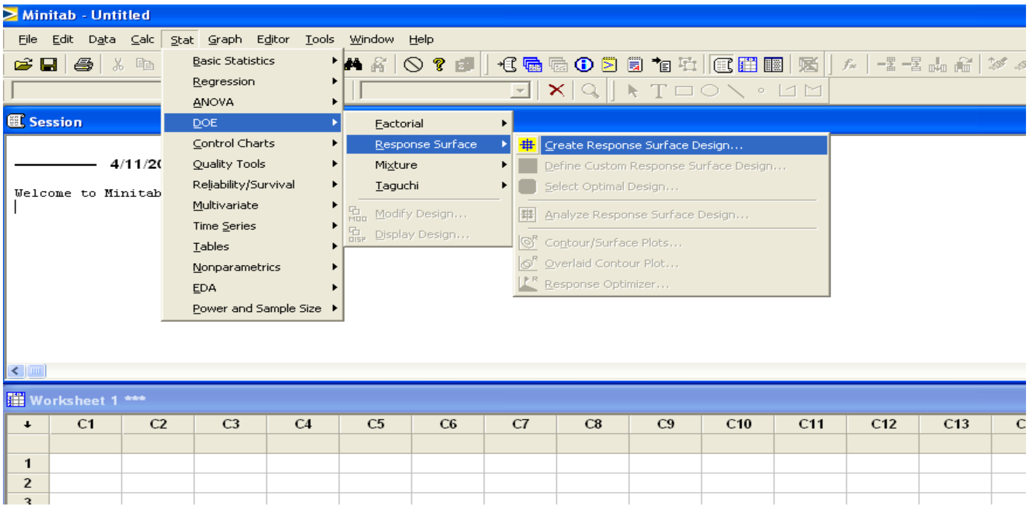
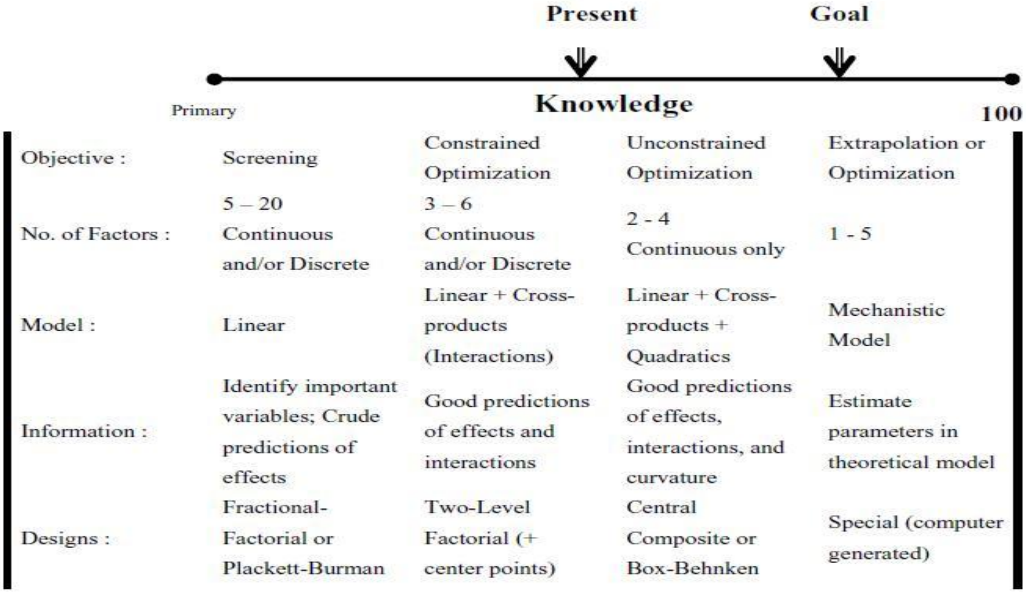


Figure 2.4: Minitab software

Response surface methodology (RSM) is a collection of statistical and mathematical techniques which is useful for developing, improving and optimizing processes (Montgomery, 2000). It also has important applications in the design, development and formulation of new products, as well as in the improvement of existing product designs. The field of RSM consists of the experimental strategy for exploring the space of the process or independent variables, empirical statistic modeling to develop an appropriate approximating relationship between the yield and process variables, and optimization methods for finding the levels or values of the process variables that produce desirable values of the responses. Figure 2.5 shows the objectives of RSM.



Objective :	Screening	Constrained Optimization	Unconstrained Optimization	Extrapolation or Optimization
No. of Factors :	5 – 20 Continuous and/or Discrete	3 – 6 Continuous and/or Discrete	2 - 4 Continuous only	1 - 5
Model :	Linear	Linear + Cross-products (Interactions)	Linear + Cross-products + Quadratics	Mechanistic Model
Information :	Identify important variables; Crude predictions of effects	Good predictions of effects and interactions	Good predictions of effects, interactions, and curvature	Estimate parameters in theoretical model
Designs :	Fractional-Factorial or Plackett-Burman	Two-Level Factorial (+ center points)	Central Composite or Box-Behnken	Special (computer generated)

Figure 2.5 Objectives of response surface methods

Source: Lawson and Erjavec, 2001

As described above, RSM is a combination of experimental and regression analysis and statistical inferences. The concept of a response surface involves a dependent variable y called the response variable and several independent variables x1 , x2 ,….., xk. This has been widely used in modeling several kinds of machining processes.

If all the variables are assumed to be measurable, the response surface can be expressed as:

$$y = f(x1 , x2 ,…., xk)$$

The goal is to optimize the response variable y. It is assumed that the independent variables are continuous and controllable with negligible error. In term of EDM process, it is necessary to find suitable combination of current (x1), voltage (x2), pulse on time (x3), interval time (x4) and content of the powder (x5). The observed response y as function of MRR, EWR, and surface roughness can be written as

$$y = f(x1 , x2 , x3 , x4 , x5) + \varepsilon$$

where ε is a random error. If the expected response is denoted by $E(y)=\eta$, then the surface represented by $\eta = f(x1 , x2 , x3 , x4 , x5)$ is called a response surface. It is required to find a suitable approximation for the true functional relationship between y and the set of independent variables.

In order to determine if there exist a relationship between the factors and response variables investigated, the data collected is analyzed statistical using regression. The regression is performed in order to describe the data collected whereby an observed response is approximated based on a functional relationship between the estimated variable.

2.10.3 Central Composite Design

In this study, face central cube design (FCD) or face centered central composite design was chosen as a tool for optimization and generating of the design plan, this design is derived from the standard central composite design (CCD). In the FCD, the axial points occur at the centers of the faces, rather than outside the faces as in the case of CCD. The FCD was chosen because of the practical situations where specific ranges on EDM parameters are not flexible. The details of the solution by this approach are explained by Myers and Montgomery (2002).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Before the experiment was done, the bill of material had to be determined since that the material need is in a huge amount and are not available in our factory. Some discussion has been made with the lab coordinator and lecturer on the selection of material for the work piece and cutting tool. In the end, the material use is AISI 1020 mild steel for the work piece.

3.2 RESEARCH DESIGN VARIABLES

The design variables are described into two main groups, which are response parameters and machining parameters.

3.2.1 Response Parameter

The response parameter include ;

(i) Material removal rate (MRR)
(ii) Electrode wear rate (EWR)
(iii) Surface Roughness (SR)

3.2.2 Metal Removal Rate (MRR) Measurement

The MRR of the workpiece was measured by dividing the weight of workpiece before and after machining (found by weighing method using balance) againts the machining time that was achieved. After completion of each machining process, the workpiece was blown by compressed air using air gun to ensure no debris and dielectric were present. A precise balance (Precisa 92SM – 202A DR) was used to measure the weight of the workpiece required. The following equation is used to determine the MRR value ;

$$MRR=\frac{W_B\text{-}W_A}{T}$$

3.2.3 Electrode Wear Rate (EWR) Measurement

The concept of EWR can be defined in many ways, the present study define the EWR according to ratio in weight of the electrode and the workpiece where expressed as percentage. This definition is the most commonly used among the researchers as mentioned in section 2.2.6. Similar procedure for measuring the weight of workpiece was used to determine the weight of the electrode before and after machining. The following equation was used for determine the EWR value:

$$EWR=\frac{EWW}{WRW}\times 100\%$$

3.2.4 Surface Roughness Measurement

There are various methods available for measuring the surface roughness of the workpiece. The arithmetic surface roughness value (Ra) was adopted and measurements were carried out at the bottom of the holes using a Perthometer. Before conducting the measurement, all the samples were cleaned with acetone. The Ra values of the EDMed surface were obtained by averaging the surface roughness values of 5.6 mm measurement length. A cut off length of 0.8 mm was used for the surface roughness measurement.

3.3 EXPERIMENTAL SETUP

3.3.1 Workpiece material

The workpiece used in this project is mild steel AISI 3020 which is a conductive material. This material also is a cheaper material compare to others while the properties make it suitable for this project. The estimated size of the workpiece is 15x15x15 mm. Table 1 show the properties:

Table 3.1: Chemical composition of the work materials

Work Materials
Chemical composition
Mild steel C: 0.14%–0.2%, Fe: 98.81–99.26%, Mn: 0.6%–0.9%, P: 0.04%, S: 0.05%

Source:

3.3.2 Electrode material

The electrode material used in this experiment is copper. The estimated size of the electrode used is 10mm in diameter and 15 mm in length.The properties of the copper are listed in table 3.2:

Table 3.2: Copper Properties

Electrode material properties	
Material	Graphics
Composition	
Density (g/cm^3)	1.811
Melting point (^{0}C)	3350
Electrical resistivity (μΩ cm)	1400
Hardness	HB 100

Source: S.H.Lee et al,1999

3.3.3 Design factors selected

There are a large number of factors to consider within the EDM process, but in this work the level of the pulse on duration, pulse off time, dielectric flushing pressure, peak current and servo voltage have only been taken into account as design factors. The reason why these five factors have been selected as design factors is that they are the most widespread and used amongst EDM researchers. Other that, the level of experimentation in this project is to two.

Table 3.3: Machining parameters and their respective levels

Factors	Description	Level 1	Level 2	Level 3	Units
A	On time	100	200	300	(s)
B	Off time	300	400	500	(s)
C	Flushing	0.05	0.10	0.15	Bar
D	Peak current	12	24	36	(*A*)
E	Servo voltage	20	30	40	(V)

3.4 EXPERIMENTAL DESIGN

Table 3 shows the machining parameters and their respective levels based on literature reviews conducted. All the parameters were selected for the control factors because they affected MRR, EWR and SR analysis.

Table 3.4: Results DOE in Minitab

Run Order	Blocks	On time	Off time	Flushing Pressure	Peak current	Servo Voltage
1	1	100	300	0.15	36	20
2	1	100	300	0.15	12	20
3	1	200	300	0.1	24	30
4	1	300	300	0.1	36	30
5	1	300	300	0.1	12	20
6	1	100	300	0.1	12	30

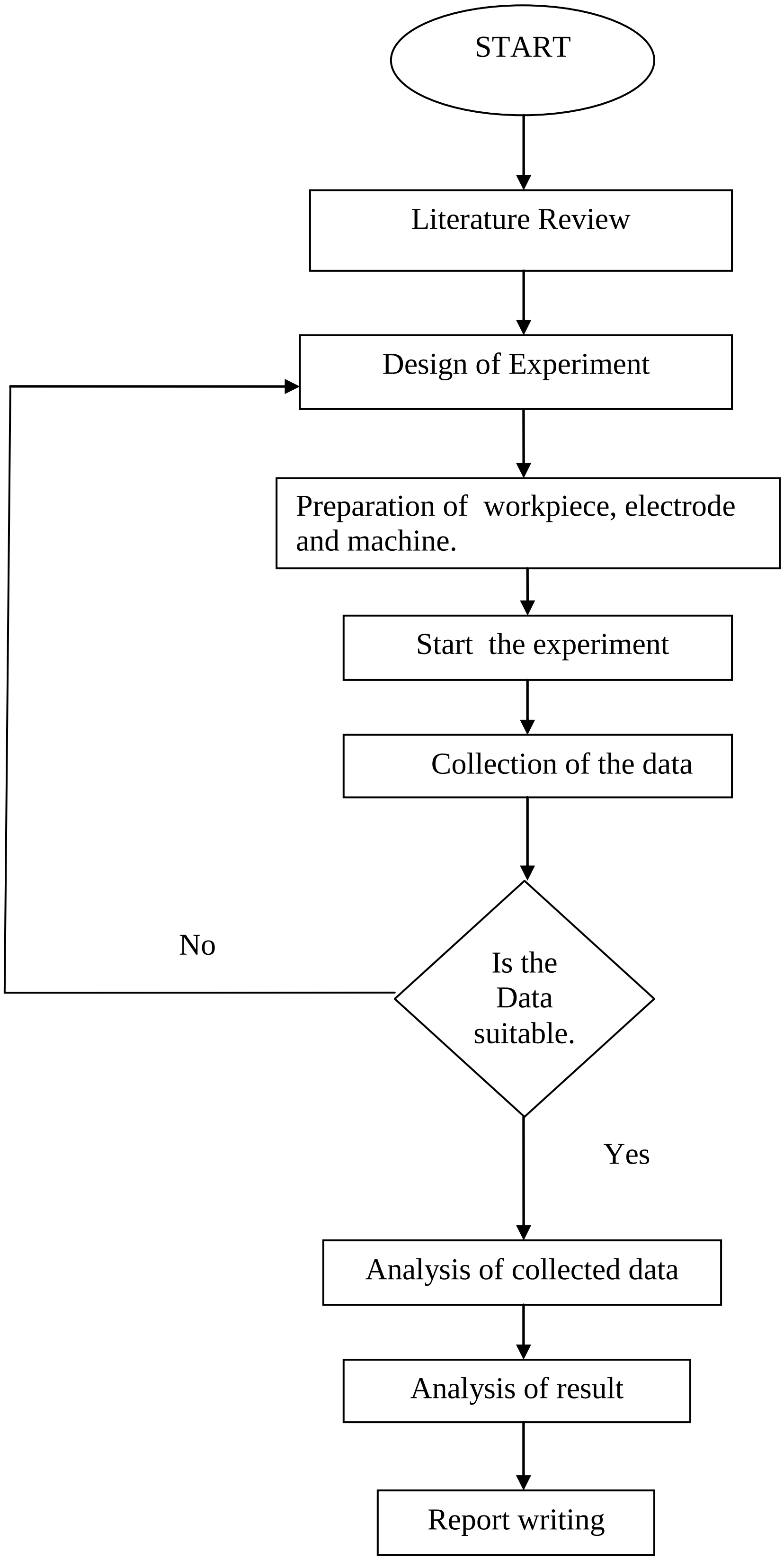
7	1	300	500	0.15	12	20
8	1	300	300	0.15	36	20
9	1	100	300	0.15	12	20
10	1	300	300	0.05	36	40
11	1	200	400	0.15	24	40
12	1	100	400	0.05	36	30
13	1	300	400	0.1	12	20
14	1	100	500	0.15	12	30
15	1	300	500	0.1	36	40
16	1	200	500	0.05	24	20
17	1	300	300	0.15	12	30
18	1	100	500	0.1	36	30
19	1	300	500	0.1	12	30
20	1	200	300	0.05	24	40
21	1	200	400	0.1	36	30
22	1	100	400	0.05	24	40
23	1	300	400	0.15	12	20
24	1	100	500	0.15	36	20
25	1	100	500	0.05	24	40
26	1	100	300	0.1	36	20
27	1	200	500	0.1	36	30
28	1	100	500	0.15	36	30
29	1	300	500	0.15	36	30
30	1	100	300	0.1	12	20
31	1	100	500	0.1	12	20
32	1	300	500	0.1	36	20

3.5 MACHINE TOOL

The machine used in this study is a AQ55L (ATC) Die-sinking EDM. The picture of the Die-sinking EDM is shown in figure

Figure 3.1: AQ55L (ATC) Die-sinking EDM.

3.6 FLOW CHART



CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter presents the experimental results of EDM Die-sinking on mild steel experiments. Analysis and discussion are made on the MRR, EWR and surface roughness (SR). The results are extracted from a series of experiment trials, based on the variation of machining parameters given in Table 4.1. The experimental plans for EDM process were based on the fractional factorial design. For EDM Die-sinking process, it was based on the face-centered central composite design. The significant parameters that affected the machining workpiece during the EDM were used for the machining process. The performance of EDM Die-sinking on mild steel was described using RSM.

4.2 EXPERIMENTAL RESULT

The experimental plans and results for the series of machining test are presented in this section. The experimental involved five factors which were varied at three levels; high, medium and low levels. The five factors were On Time, Off Time, Flushing Pressure, Peak Current and Servo Voltage. The machining responses that were investigated were MRR, EWR and SR.

Table 4.1: Experimental results for EDM Die-sinking

StdOrder	**Output Response**		
	MRR g/min	**EWR g/min**	**SR µm**
1	0.0411	25.53	9.389
2	0.0043	7.76	4.4265
3	0.076219	6.78	4.7819
4	0.3079	0.9569	11.55
5	0.1913	1.0915	5.625
6	0.0186	8.921	4.463
7	0.0037	1.8705	5.339
8	0.3301	4.2707	9.693
9	0.0216	8.7632	4.598
10	0.015019	5.23	6.5713
11	0.214444	1.1	9.846
12	0.134119	3.041	9.5718
13	0.2360	2.31	8.7652
14	0.0079	17.09	4.173
15	0.108419	1.79	13.215
16	0.185844	1.112	4.9874
17	0.0312	1.2111	4.377
18	0.0527	23.3262	7.268
19	0.0235	1.2454	5.522
20	0.061119	7.01	4.8546
21	0.0385	1.3	10.0256
22	0.230775	4.96	6.9225
23	0.0106	3.03	5.3462
24	0.0095	47.1517	6.352
25	0.137869	3.45	5.8791
26	0.0396	27.3234	9.64
27	0.095894	6.16	6.085
28	0.083844	22.88069	9.3821
29	0.2500	2.1944	12.2
30	0.0323	11.15866	6.6613
31	0.0093	15.2577	3.709
32	0.2795	8.821	11.35

4.3 REGRESSION ANALYSIS AND MODEL FITTING

Analysis of the experimental results has been done using the Minitab 15 software. The software was first used for model fitting. The CCD design is capable of quadratic model fitting. Hence, first a quadratic fitting of MRR EWR and SR was done. Analysis of Variance (ANOVA) based statistical tests was performed to determine the suitability of the fitted model. Several models such as linear, linear with first-order interaction terms and quadratic models could be fitted using the software. Each one of them was tested to obtain the highest F-value for model significance F-test. Values of various regression statistics have been compared to select the most suitable model. Additionally, not all terms in the fitted model may have significant effects. In such a case, the fitting can be improved by removing some of the terms (Myers, R. H. and D. C. Montgomery, 2002) This was done by a step wise model fitting. Here, a backward step-wise model fitting has been used.

Adequancy of the models developed is validated by checking the statistical prorperties to augment the ANOVA table. Properties such as lack-of-fit, R-squared, adjusted R-squared, predicted R-squared and adequate are examined. At a level of confidence of 95%, the model is checked for its adequacy, *P* value is not significant with the lack-of fit (<0.05). This implies that the model could fit and it is adequate (Kadirgama and Abou-El-Hossein, 2005, Noor and Kadirgama, 2009).

4.3.1 FIRST ORDER ANALYSIS

Analysis of variance

Table 4.2: analysis of variance for MRR(first order)

source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	0.098056	0.098056	0.019611	2.3	0.074
Linear	5	0.098056	0.098056	0.019611	2.3	0.074
Residual Error	26	0.221667	0.221667	0.008526		
Lack-of-Fit	25	0.221517	0.221517	0.008861	59.21	0.102
Pure Error	1	0.00015	0.00015	0.00015		
Total	31	0.319723				

MRR = 0.0256458 + (0.000464631)A – (1.93208E-05)B – (0.468861)C + (0.00314814)D – (0.00116321)E

Table 4.3: analysis of variance for EWR(first order)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	2094.89	2094.89	418.977	8.54	0.000
Linear	5	2094.89	2094.89	418.977	8.54	0.000
Residual Error	26	1275.64	1275.64	49.063		
Lack-of-Fit	25	1275.14	1275.14	51.006	101.36	0.078
Pure Error	1	0.50	0.50	0.503		
Total	31	0.319723				

EWR = 11.3994 – (0.0690026)A + (0.0101527)B + (72.7312)C+ (0.359855)D – (0.366348)E

Table 4.4: analysis of variance for SR(first order)

source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	138.280	138.280	27.6560	8.18	0.000
Linear	5	138.280	138.280	27.6560	8.18	0.000
Residual Error	26	87.868	87.868	3.3795		
Lack-of-Fit	25	87.853	87.853	3.5141	238.96	0.051
Pure Error	1	0.50	0.015	0.0147		
Total	31	0.319723				

SR = 11.3994 – (0.0690026)A + (0.0101527)B + (72.7312)C+ (0.359855)D – (0.366348)E

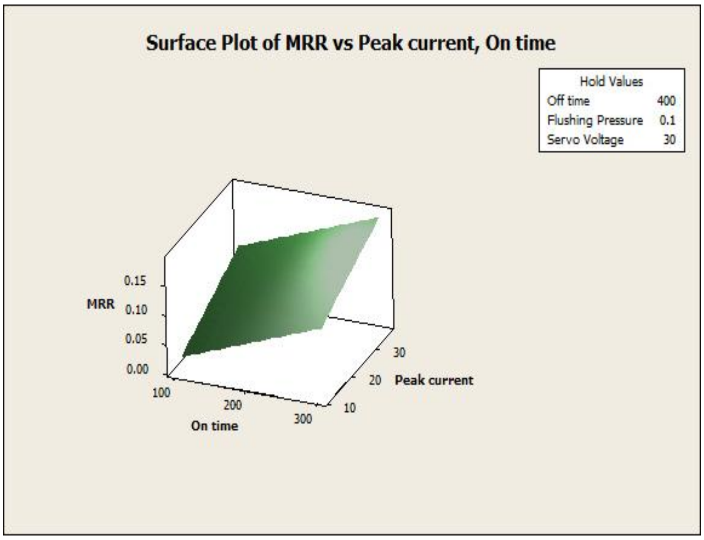


Figure 4.1 : Surface Plot MRR vs Peak Current, On Time

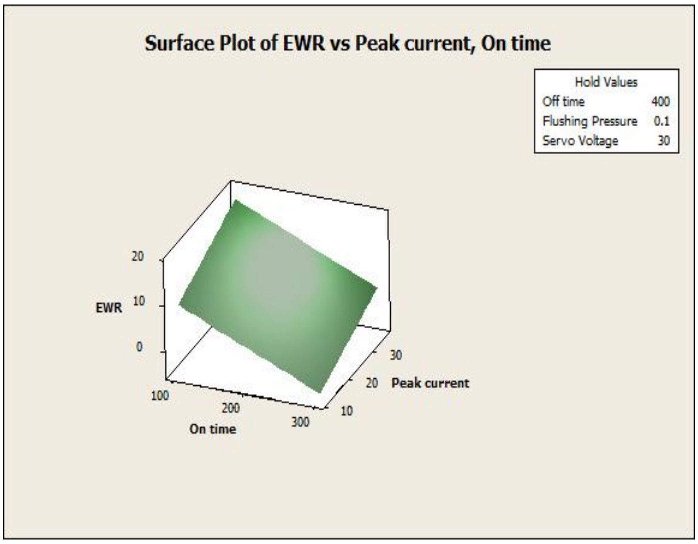


Figure 4.2 : Surface Plot EWR vs Peak Current, On Time

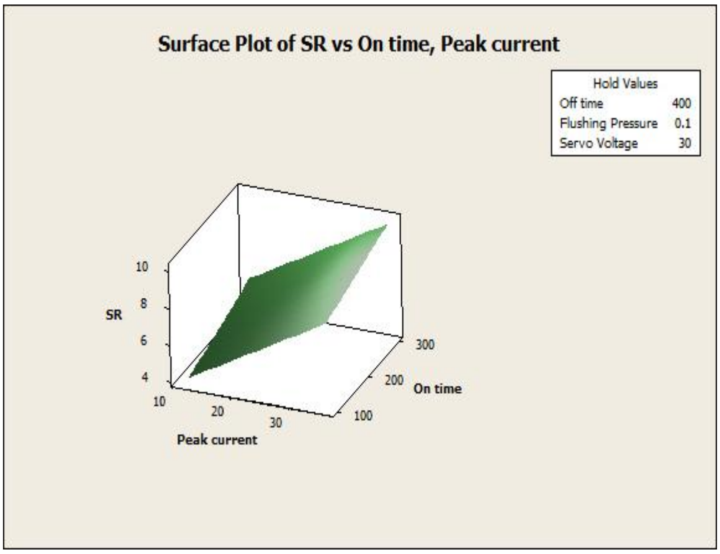


Figure 4.3 : Surface Plot SR vs Peak Current, On Time

4.3.2 Second Order Analysis

Table 4.5 : Analysis of Variance for MRR(second order)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	20	0.283873	0.283873	0.014194	4.36	0.008
Linear	5	0.098056	0.052450	0.010490	3.22	0.049
Square	5	0.090457	0.033884	0.006777	2.08	0.145
Interaction	10	0.095359	0.095359	0.009536	2.93	0.046
Residual Error	11	0.035850	0.035850	0.003259		
Lack-of-Fit	10	0.035700	0.035700	0.003570	23.86	0.158
Pure Error	1	0.000150	0.000150	0.000150		
Total	31	0.319723				
R-square = 88.79%		Adj R-square = 68.40%		Pred R-square = 12.40%		

Table 4.2 reveals that the model was significant as proven by the Prob>F which is less than 0.05. A, B, E, CC, EE, AB, AD, AE, CE, and DE were significant model terms at a 95 percent confident level (Appendix A). On the other hand the value of R-square was high which was close to 1 hence indicating that it was desirable.

The following equations are the final empirical models for MRR in coded factors. The procedure for converting the equations from coded factors Appendix A1. Final equation in terms of coded factors:

MMR = -0.162648 - (0.00207028)A + (0.00366128)B - (6.49591)C + (0.0216596)D - (0.00941203)E + (9.93089E-06)AA - (5.01867E-06)BB + (9.59281)CC - (7.09167E-04)DD - (7.84139E-06)EE - (5.42365E-07)AB - (0.00229356)AC + (3.67849E-05)AD - (6.58411E-05)AE - (0.00187770)BC + (3.58653E-06)BD + (1.37788E-05)BE + (0.0659323)CD + (0.132082)CE + (3.66085E-05)DE

Table 4.6: Analysis of Variance for EWR(second order)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	20	3307.85	3307.854	165.3927	29.03	0.00
Linear	5	2094.89	475.895	95.1790	16.71	0.000
Square	5	238.20	181.526	36.3051	6.37	0.005
Interaction	10	974.77	974.769	97.4769	17.11	0.000
Residual Error	11	62.67	62.674	5.6976		
Lack-of-Fit	10	62.17	62.170	6.2170	12.35	0.218
Pure Error	1	0.50	0.503	0.5032		
Total	31	3370.53				
R-square = 98.14%		Adj R-square = 94.76%		Pred R-square = 74.74%		

In term of EWR, the statistically significant quadratic model is as shown in Appendix B. It was observed that the terms D, AD, and CE were significant. From table 4.3,the lack of fit was not significant which satisfy the model to be fitted (0.218). The value of R-square was high (0.9814) and closed to 1 which is desirable.

The following equations are the final empirical models for EWR in coded factors. The procedure for converting the equations from coded factors Appendix B1. Final equation in terms of coded factors:

EWR = -3.14550 - (0.223946)A - (0.0484522)B + (427.849)C + (3.35891)D - (1.12899)E + (0.000563432)AA + (2.05250E-05)BB - (2188.96)CC - (0.0355544)DD + (0.0356768)EE - (2.88683E-04)AB - (0.341708)AC -

(0.00216333)AD + (0.00539168)AE + (0.925142)BC + (0.00140542)BD - (8.36802E-04)BE - (0.704505)CD - (7.06473)CE - (0.0556716)DE

Table 4.7 : Analysis of Variance for SR(second order)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	20	213.294	213.2935	10.6647	9.13	0.000
Linear	5	138.28	80.7283	16.1457	13.82	0.000
Square	5	41.382	26.8153	5.3631	4.59	0.017
Interaction	10	33.631	33.6314	3.3631	2.88	0.049
Residual Error	11	12.854	12.8541	1.1686		
Lack-of-Fit	10	12.839	12.8394	1.2839	87.31	0.083
Pure Error	1	0.015	0.0147	0.0147		
Total	31	226.148				
R-square = 94.32%		Adj R-square = 83.98%		Pred R-square = 45.33%		

Table 4.4 shows the ANOVA table for SR with quadratic model and. The model was significant based on the Prob>F value. The model terms A, B, C, E and BC were significant whilst the lack of fit is not significant (0.083). The R2 value was 0.9432 which is closed to 1.

The following equations are the final empirical models for SR in coded factors. The procedure for converting the equations from coded factors Appendix C(Table C1). Final equation in terms of coded factors:

SR = 9.79529 - (0.116657)A + (0.112948)B - (104.751)C + (0.110998)D - (0.913006)E + (0.000242427)AA - (1.85300E-04)BB - (91.5792)CC -(0.00235453)DD + (0.00640237)EE + (7.83532E-05)AB - (0.0128582)AC + (0.000294702)AD - (3.78096E-04)AE + (0.0455704)BC -(1.45069E-04)BD + (0.000574902)BE + (0.993529)CD + (3.23068)CE + (0.00354343)DE

After the ANOVA procedure, further analysis was performed in graphicplots. The normal probability plot of residuals, plot were performed and these plots are shown in Figures 4.4, 4.5 and 4.6 respectively. Figure 4.4 and 4.5 revealed that the residuals spread on a straight line implying that the errors are distributed normally.

Correspondently the plots in Figures 4.6 show no obvious pattern and unusual structure and all the results fall in theacceptable range. Only run number one go far from other runs number, however it still fall within the range. Therefore it can be concluded that the model proposed was adequate and could proceed for further analysis.

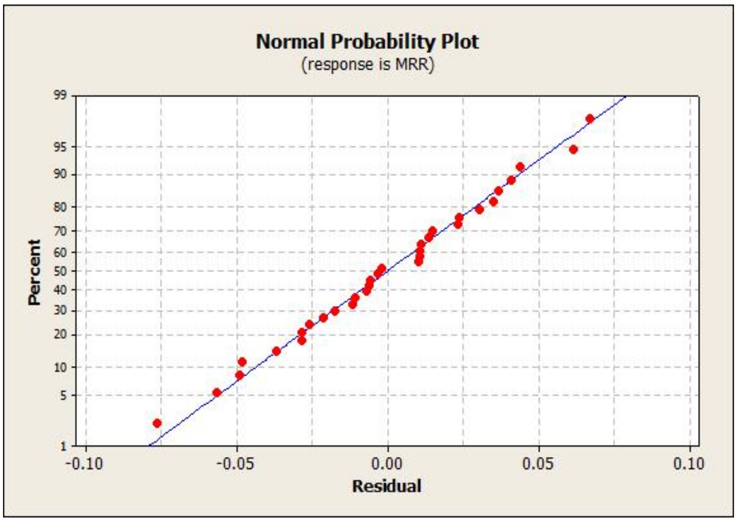


Figure 4.4: Normal probability plots of residuals for MRR in EDM process

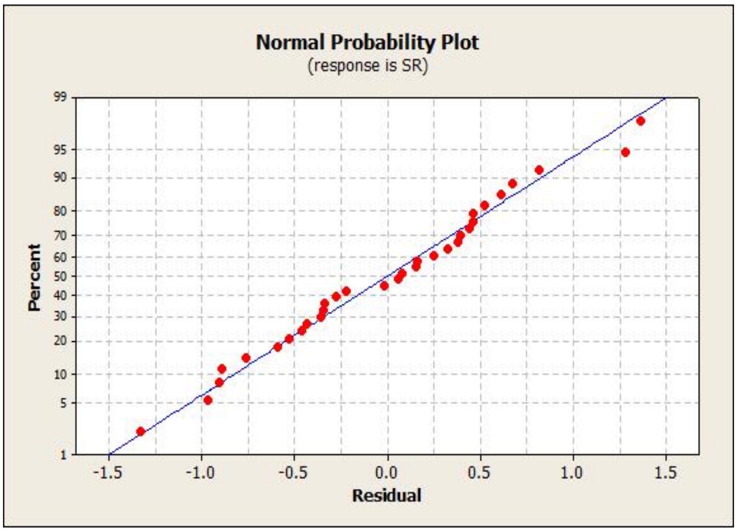


Figure 4.5: Normal probability plots of residuals for EWR in EDM process

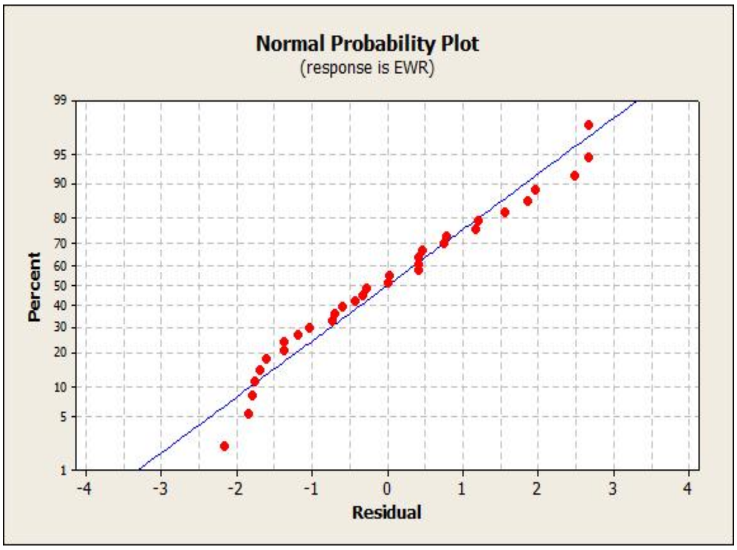


Figure 4.6: Normal probability plots of residuals for SR in EDM process

Figure 4.7, 4.8 and 4.9 shows the surface plot which enables the comparison of the effects of the various factors in the design space. Result show that the factor A (pulse on time) has a significant effect on the MRR, while the factor A(pulse on time) and D(peak current) had a significant effect on the EWR and SR For another factors B (pulse off time), C(flushing pressure) and E(servo voltage) was less significant in influencing the MRR, EWR and SR values.

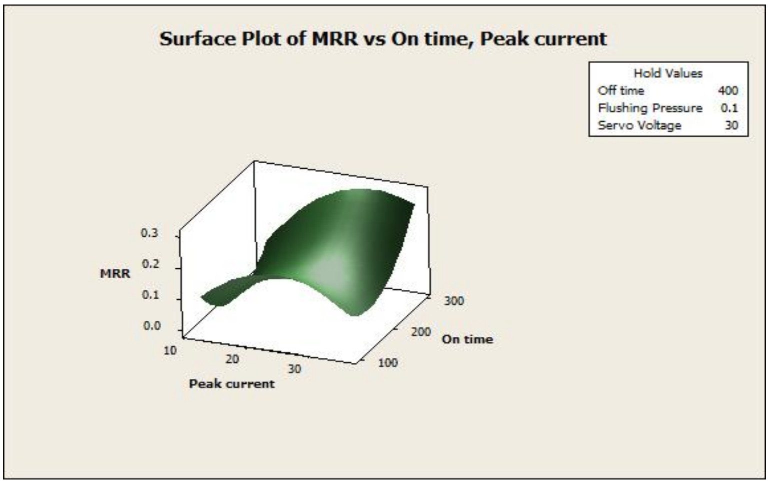


Figure 4.7: Surface Plot MRR vs Peak Current, On Time

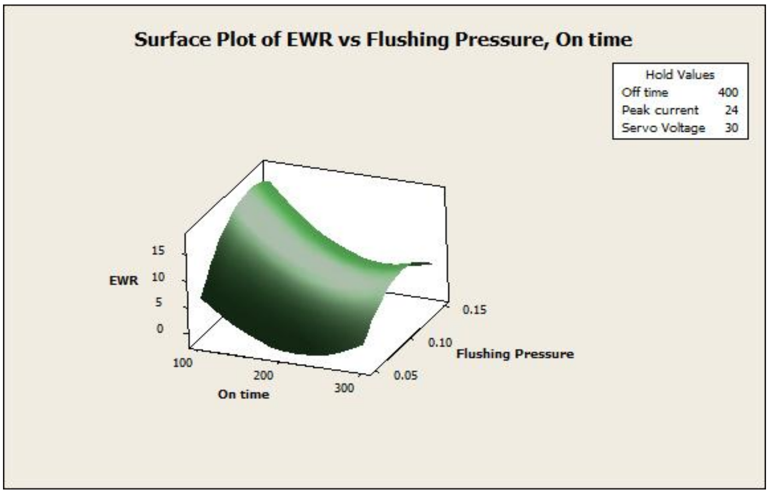


Figure 4.8: Surface Plot EWR vs On time, Flushing Pressure

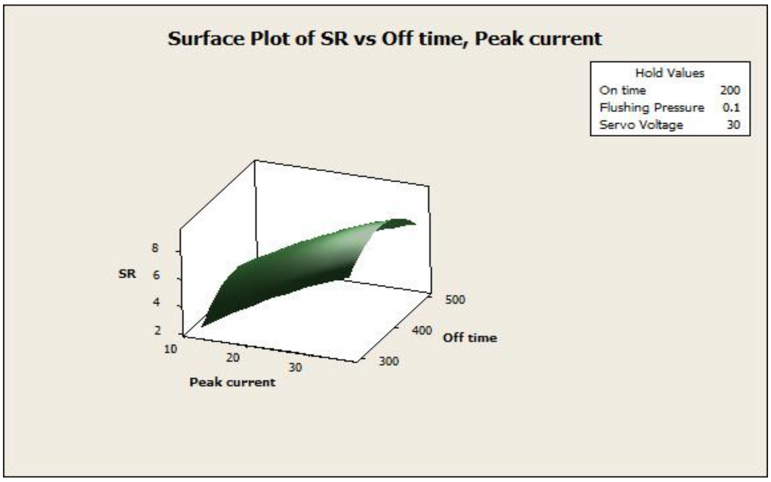


Figure 4.9: Surface Plot SR vs Peak Current, Off Time

4.4 OPTIMIZATION IN EDM DIE-SINKING

Optimization could be performed numerically or graphically. In the numerical optimization test, the desired goals for the factors and responses were set by using the feature provided by MINITAB software. Several goals are combined into the overall desirability function and the search of optimal solutions involves the maximization of the said function.

Higher material removal rate is preferable in any machining process as this condition could reduce machining time and thus increase productivity. The preliminary results from EDM indicated that current significantly effect the MRR. Increasing the current increases the MRR values. Based on the previous findings, current was set to a maximum value and other factors were set at within their range values. With regards to the overall objective, MRR was expected to be maximum and the other two responses (EWR and SR) were expected to be minimum. With of minimum EWR the advantage is that the electrode can maintain its dimension within the tolerance which will lead to a better accuracy of machined profile. Similarly smaller SR of the machined surface is preferred. (Madan and Sagar, 1994; and, Tzeng and Lee, 2000)

4.5 COMFIRMATION TEST

In order to verify the adequacy of the models that were developed, one confirmation runs were performed. Using the point prediction tool of the software, the MRR, EWR and SR of selected experiments were predicted within 95% confidence interval (CI) and prediction interval (PI).

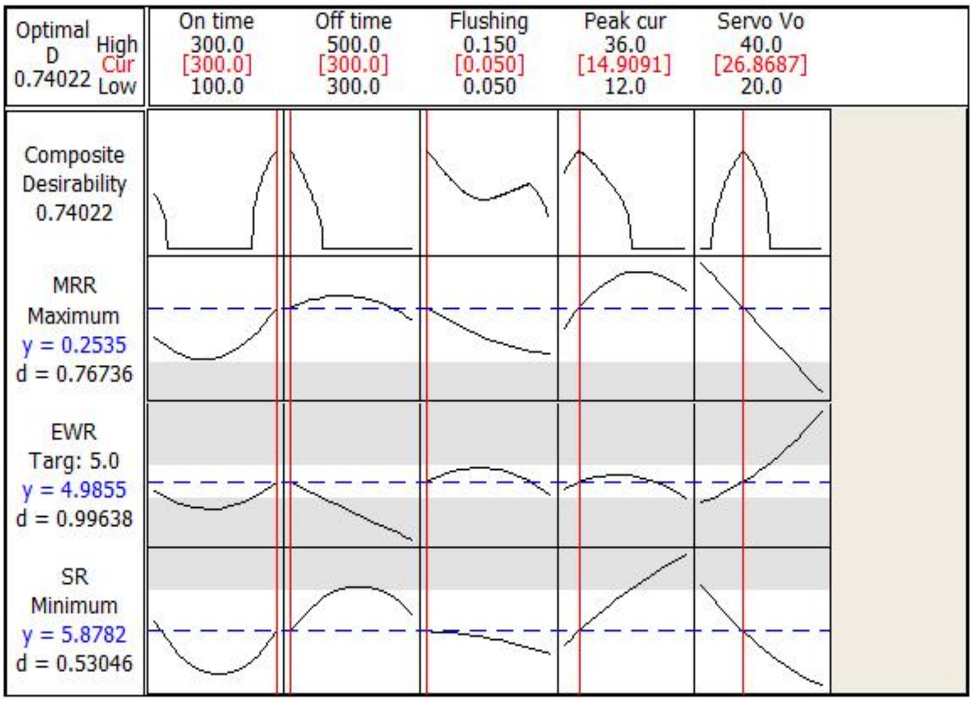


Figure 4.10: Optimazation Plot of MRR, EWR, SR

A confirmation test experiment is carried out to check the accuracy of prediction. Validation experiment were carried out to validate the models develop for all the responses. An experiment were conducted with the parameter setting of on time 300**µ**s, off time 300**µ**s, flushing pressure 0.05, peak current 14.9091 and servo voltage 26.8687.

4.6 DISCUSSION

Results from EDM experiments based on half fractional factorial design indicated that the primary factors influencing the MRR are peak current. Similar results were also found by many researchers (Lin *et.al*., 2000, and, Asokan *et.al.*, 2000) when EDM Ti-64. Results also show that the effect of pulse on time and interval time on MRR was not in agreement with study conducted by Asokan *et.al.* (2000) when EDM. Higher current resulted in higher MRR value but increased the surface roughness of the machined surface. As such higher MRR will not always be the objective when EDM. However it will be useful for rough machining.

The interaction of peak current and servo had a significant effect on EWR, since all these parameters tended to produce heat. This finding was accordance with study conducted by George *et. al*. (2004). Basically electrode erosion was affected by the heat that was conducted from the discharge gap between workpiece and electrode during the EDM process. The volume of erosion was seriously affected by the material properties of the electrode and workpiece. The results of perturbation (Figure 4.2) shows that increasing the current increases the electrode wear. This is probably due to high energy that impacted the workpiece material and the electrode, thus reducing the electrode volume. With respect to the pulse on time, the EWR value tended to increase for a considered work interval. This had been expected, as increased in the pulse on time was equivalent to a decrease in the frequency of the pulse, which is usually associated with a decrease in electrode wear (Puertas and Perez, 2003). In general the lower the electrode wear ratio in EDM process, the better the machining performance.

It had been proved that the peak current was the most significant factor that influenced the surface roughness. At higher current, the impact of the discharge on the surface of the workpiece became more intense and the resulting erosion led to the increase in the deterioration of the surface roughness (Lee and Tai, 2003). Heating and cooling effect during machining process resulted in a thermal affected layer to form on the surface of the workpiece hence affected the surface roughness value.

4.7 SUMMARY

The significant factors on the EDM using one-half fractional factorial design, were presented. Performance of the EDM die sinking using RSM was also discussed.

Table 4.8: Summary of Significant Factors in Linear Experiments

Response	Significant factor
MRR	A
EWR	A-D
SR	D-A

Table 4.9: Summary of Significant Factors in Quadratic Experiments

Response	Significant factor
MRR	D-AD-CE
EWR	A-B-E-CC-EE-AB-AD-AE-CE-DE
SR	D-AA-BB-AB-AD-CD

Note : A=Pulse On Time, B=Pulse Off Time, C=Flushing Pressure, D=Peak Current, E=Servo Voltage

The confirmation run experiments verified that empirical models that was developed are reasonably accurate and could be used for the prediction within the limits of the factors investigated.

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

An application of the response surface methodology analysis to optimize the multiple performance characteristics of the MRR, EWR, and SR in the EDM die sinking.

5.2 CONCLUSION

In the present work, parametric analysis of the dry EDM process has been done based on experimental results. Experiments based on the Central Composite Design (CCD) were conducted to develop empirical models of the process. Process optimization was then performed using response surface methodology (RSM). Following conclusions can be drawn from the analysis of the results:

1. Feasibility of EDM process for mild steel by using cooper electrode has been proven.

2. Of all the machining parameters investigated, peak current was found to be the most significant factor. Higher current produced higher MRR and SR. In term of EWR in EDM, increasing current increased the EWR. In EDM, increasing current increased the EWR when applied in higher pulse on time but EWR decreased on low pulse on time.

3. Pulse on time significantly affects the EWR, SR and overcut in EDM process. But in EDM process this factor also influence the MRR, in addition to EWR and SR values. Decreasing the pulse on time increased the MRR and EWR but decreased the SR.

4. In EDM process interaction of interval time (D) with other factors affected the EWR and SR. However, this factor was less significant to the machining characteristics in the EDM process.

5. Mathematical models developed to predict the various machining characteristics are statistically valid and sound within the range of the factors investigated. Verification and confirmation run experiments were carried out and therefore could be used for prediction within the limits of the factors investigated. The optimized machining parameters were established to achieve the desired responses.

5.2 RECOMMENDATION FOR FUTURE WORK

1. Compare the error prediction of MRR, EWR and SR by neutral network (NN), taguchi method and RSM and which one has great potential to be employed in predicting optimum MRR, EWR and SR without needing extensive iterative machining trials.
2. Use different material in machining with can be informative about the behavior of MRR, EWR, and SR will give different in ideal in machining parameter across different material. Different material will give different machining parameter.

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APPENDIX A

Response Surface Regression: MRR versus PARAMETER

The analysis was done using coded units.

Table A: Estimated Regression Coefficients for MRR

Term	Coef	SE Coef	T	P
Constant	0.148095	0.06800	2.178	0.052
On time	0.036338	0.02114	1.719	0.114
Off time	-0.015045	0.01630	-0.923	0.376
Flushing Pressure	-0.012116	0.02481	-0.488	0.635
Peak current	0.049232	0.02215	2.223	0.048
Servo Voltage	-0.034524	0.02783	-1.241	0.241
On time*On time	0.099309	0.04575	2.170	0.053
Off time*Off time	-0.050187	0.03747	-1.339	0.208
Flushing Pressure*Flushing Pressure	0.023982	0.03177	0.755	0.466
Peak current*Peak current	-0.102120	0.07050	-1.449	0.175
Servo Voltage*Servo Voltage	-0.000784	0.03459	-0.023	0.982
On time*Off time	-0.005424	0.01530	-0.354	0.730
On time*Flushing Pressure	-0.011468	0.02173	-0.528	0.608
On time*Peak current	0.044142	0.01375	3.211	0.008
On time*Servo Voltage	-0.065841	0.02862	-2.300	0.042
Off time*Flushing Pressure	-0.009389	0.02473	-0.380	0.711
Off time*Peak current	0.004304	0.01435	0.300	0.770
Off time*Servo Voltage	0.013779	0.02711	0.508	0.621
Flushing Pressure*Peak current	0.039559	0.02499	1.583	0.142
Flushing Pressure*Servo Voltage	0.066041	0.02689	2.456	0.032
Peak current*Servo Voltage	0.004393	0.03033	0.145	0.887

Table A1: Estimated Regression Coefficients for MRR using data in uncoded units

Term	Coef
Constant	-0.162648
On time	-0.00207028
Off time	0.00366128
Flushing Pressure	-6.49591
Peak current	0.0216596
Servo Voltage	-0.00941203
On time*On time	9.93089E-06
Off time*Off time	-5.01867E-06
Flushing Pressure*Flushing Pressure	9.59281
Peak current*Peak current	-7.09167E-04
Servo Voltage*Servo Voltage	-7.84139E-06
On time*Off time	-5.42365E-07
On time*Flushing Pressure	-0.00229356
On time*Peak current	3.67849E-05
On time*Servo Voltage	-6.58411E-05
Off time*Flushing Pressure	-0.00187770
Off time*Peak current	3.58653E-06
Off time*Servo Voltage	1.37788E-05
Flushing Pressure*Peak current	0.0659323
Flushing Pressure*Servo Voltage	0.132082
Peak current*Servo Voltage	3.66085E 05

APPENDIX B

Response Surface Regression: EWR versus PARAMETER

The analysis was done using coded units.

Table B: Estimated Regression Coefficients for EWR

Term	Coef	SE Coef	T	P
Constant	7.2997	2.8431	2.567	0.026
On time	-3.8387	0.8839	-4.343	0.001
Off time	1.1371	0.6816	1.668	0.123
Flushing Pressure	3.1462	1.0374	3.033	0.011
Peak current	0.4944	0.9262	0.534	0.604
Servo Voltage	-2.8736	1.1634	-2.470	0.031
On time*On time	5.6343	1.9131	2.945	0.013
Off time*Off time	0.2052	1.5669	0.131	0.898
Flushing Pressure*Flushing Pressure	-5.4724	1.3282	-4.120	0.002
Peak current*Peak current	-5.1198	2.9476	-1.737	0.110
Servo Voltage*Servo Voltage	3.5677	1.4464	2.467	0.031
On time*Off time	-2.8868	0.6399	-4.511	0.001
On time*Flushing Pressure	-1.7085	0.9087	-1.880	0.087
On time*Peak current	-2.5960	0.5748	-4.517	0.001
On time*Servo Voltage	5.3917	1.1969	4.505	0.001
Off time*Flushing Pressure	4.6257	1.0341	4.473	0.001
Off time*Peak current	1.6865	0.6000	2.811	0.017
Off time*Servo Voltage	-0.8368	1.1337	-0.738	0.476
Flushing Pressure*Peak current	-0.4227	1.0451	-0.404	0.694
Flushing Pressure*Servo Voltage	-3.5324	1.1244	-3.142	0.009
Peak current*Servo Voltage	-6.6806	1.2681	-5.268	0.000

Table B1: Estimated Regression Coefficients for EWR using data in uncoded units

Term	Coef
Constant	-3.14550
On time	-0.223946
Off time	-0.0484522
Flushing Pressure	427.849
Peak current	3.35891
Servo Voltage	-1.12899
On time*On time	0.000563432
Off time*Off time	2.05250E-05
Flushing Pressure*Flushing Pressure	-2188.96
Peak current*Peak current	-0.0355544
Servo Voltage*Servo Voltage	0.0356768
On time*Off time	-2.88683E-04
On time*Flushing Pressure	-0.341708
On time*Peak current	-0.00216333
On time*Servo Voltage	0.00539168
Off time*Flushing Pressure	0.925142
Off time*Peak current	0.00140542
Off time*Servo Voltage	-8.36802E-04
Flushing Pressure*Peak current	-0.704505
Flushing Pressure*Servo Voltage	-7.06473
Peak current*Servo Voltage	-0.0556716

APPENDIX C

Response Surface Regression: SR versus PARAMETER

The analysis was done using coded units.

Table C: Estimated Regression Coefficients for SR

Term	Coef	SE Coef	T	P
Constant	7.09466	1.2876	5.510	0.000
On time	0.60995	0.4003	1.524	0.156
Off time	-0.12995	0.3087	-0.421	0.682
Flushing Pressure	0.66772	0.4698	1.421	0.183
Peak current	2.45459	0.4194	5.852	0.000
Servo Voltage	0.33588	0.5269	0.637	0.537
On time*On time	2.42427	0.8664	2.798	0.017
Off time*Off time	-1.85300	0.7096	-2.611	0.024
Flushing Pressure*Flushing Pressure	-0.22895	0.6015	-0.381	0.711
Peak current*Peak current	-0.33905	1.3349	-0.254	0.804
Servo Voltage*Servo Voltage	0.64024	0.6550	0.977	0.349
On time*Off time	0.78353	0.2898	2.704	0.021
On time*Flushing Pressure	-0.06429	0.4115	-0.156	0.879
On time*Peak current	0.35364	0.2603	1.359	0.201
On time*Servo Voltage	-0.37810	0.5420	-0.698	0.500
Off time*Flushing Pressure	0.22785	0.4683	0.487	0.636
Off time*Peak current	-0.17408	0.2717	-0.641	0.535
Off time*Servo Voltage	0.57490	0.5134	1.120	0.287
Flushing Pressure*Peak current	0.59612	0.4733	1.260	0.234
Flushing Pressure*Servo Voltage	1.61534	0.5092	3.172	0.009
Peak current*Servo Voltage	0.42521	0.5743	0.740	0.475

Table C1: Estimated Regression Coefficients for SR using data in uncoded units

Term	Coef
Constant	9.79529
On time	-0.116657
Off time	0.112948
Flushing Pressure	-104.751
Peak current	0.110998
Servo Voltage	-0.913006
On time*On time	0.000242427
Off time*Off time	-1.85300E-04
Flushing Pressure*Flushing Pressure	-91.5792
Peak current*Peak current	-0.00235453
Servo Voltage*Servo Voltage	0.00640237
On time*Off time	7.83532E-05
On time*Flushing Pressure	-0.0128582
On time*Peak current	0.000294702
On time*Servo Voltage	-3.78096E-04
Off time*Flushing Pressure	0.0455704
Off time*Peak current	-1.45069E-04
Off time*Servo Voltage	0.000574902
Flushing Pressure*Peak current	0.993529
Flushing Pressure*Servo Voltage	3.23068
Peak current*Servo Voltage	0.00354343

APPENDIX D

Machining Process

Figure D1: Bandsaw Machine

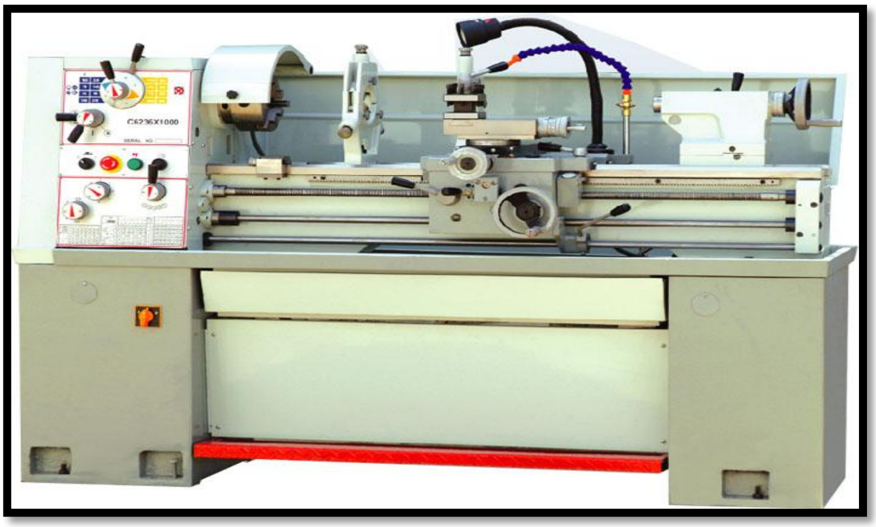

Figure D2: Lathe Machine

Figure D3: Milling Machine

Figure D4: Digital Scale

Figure D5: Electrical Discharge Machine Die-Sinking

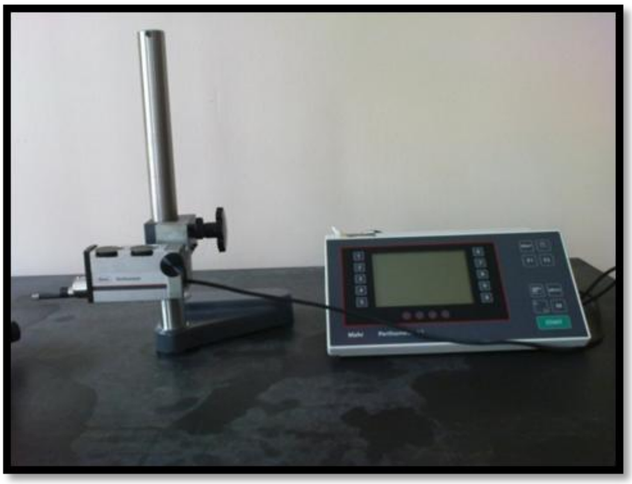

Table D6: Perthometer S2 Mahr