DEVELOPMENT OF EDM TOOL FOR PRODUCING TITANIUM ALLOY AUTOMOTIVE VALVE APPLICATION

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A report submitted in partial fulfillment of the requirements for the award of Bachelor of Mechanical Engineering

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EXAMINER'S DECLARATION

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

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ABSTRACT

This paper presents the development of EDM tool for producing titanium alloy automotive valve application. Electric discharge machining (EDM) is a non-traditional machining processes that involved a transient spark discharges through the fluid due to the potential difference between the electrode and the work piece. The objective of this paper is to investigate how the peak current, servo voltage, pulse on- and off-time in EDM effect on Material Removal Rate (MRR), Tool Wear Rate (TWR). The experimental control parameters were being optimized according to their various machining characteristics namely Material Removal Rate (MRR), Tool Wear Rate (TWR) using copper as the electrode and also copper as the workpiece. Design of experiment (DOE) technique is used to determine the optimum machining parameters for this machining characteristic. Taguchi method has been used for the construction, layout and analysis of the experiment for MRR and TWR machining characteristic. The use of Taguchi method in the experiment saves a lot of time and cost of preparing and machining the experiment samples. Therefore, an L9 Orthogonal array which was the fundamental component in the statistical design of experiments has been used to plan the experiments, Analysis of Variance (ANOVA) is used to determine the optimum machining parameters for this machining characteristic. The result shown the peak current are most significant factor that affect material removal rate(MRR) and tool wear ratio (TWR) since the parameter bring major effect to MRR and TWR. As conclusion, the development of EDM tool is achieved and got the optimum parameter for MRR and TWR.

ABSTRAK

Kertas kerja ini membentangkan pembuatan alat EDM untuk menghasilkan aloi titanium untuk diaplikasikan kepada injap automotif. Pemesinan pelepasan elektrik (EDM) adalah satu proses pemesinan bukan tradisional yang melibatkan pelepasan percikan electrik melalui cecair kerana perbezaan potensi antara elektrod dan bahan kerja. Objektif kertas ini adalah untuk menyiasat bagaimana puncak semasa, voltan servo, nadi di dalam dan di luar masa dalam kesan EDM pada kadar pembuangan bahan (MRR), kadar penghakisan alat (TWR). Parameter kawalan eksperimen sedang dioptimumkan mengikut ciri-ciri pemesinan pelbagai mereka iaitu kadar pembuangan bahan (MRR), kadar penghakisan alat (TWR) menggunakan tembaga sebagai elektrod dan juga tembaga sebagai bahan kerja. Reka bentuk eksperimen teknik (DOE) digunakan untuk menentukan parameter pemesinan optimum untuk ciri-ciri mesin ini. Kaedah Taguchi telah digunakan untuk pembinaan, susun atur dan analisis eksperimen untuk MRR dan TWR pemesinan ciri. Penggunaan kaedah Taguchi dalam eksperimen menjimatkan banyak masa dan kos penyediaan dan pemesinan sampel eksperimen. Oleh itu, pelbagai ortogon L9 yang merupakan komponen penting dalam reka bentuk statistik eksperimen telah digunakan untuk merancang eksperimen dan Analisis Varian (ANOVA) digunakan untuk menentukan parameter pemesinan optimum untuk ciri-ciri mesin ini. Hasilnya ditunjukkan semasa puncak adalah faktor yang paling penting yang mempengaruhi kadar pembuangan bahan (MRR) dan nisbah memakai alat (TWR) sejak parameter membawa kesan yang besar kepada MRR dan TWR. Kesimpulanya penghasilan alat EDM telah berjaya dan parameter pemesinan optimum telah dapat untuk MRR and TWR.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Electrical Discharge Machine (EDM) is now become the most important accepted technologies in manufacturing industries since many complex 3D shapes can be machined using a simple shaped tool electrode. Electrical Discharge Machine (EDM) is an important 'non-traditional manufacturing method' and has been accepted worldwide as a standard processing manufacture of forming tools to produce plastics mouldings, die castings, forging dies and etc. New developments in the field of material science have led to new engineering metallic materials, composite materials, and high tech ceramics, having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by spark erosion.

At the present time, Electrical Discharge Machine (EDM) is a widespread technique used in industry for high precision machining of all types of conductive materials such as: metals, metallic alloys, graphite, or even some ceramic materials, of whatsoever hardness. Electrical Discharge Machine (EDM) technology is increasingly being used in tool, die and mould making industries, for machining of heat treated tool steels and advanced materials (super alloys, ceramics, and metal matrix composites) requiring high precision, complex shapes and high surface finish. Traditional machining technique is often based on the material removal using tool material harder than the work material and is unable to machine them economically. An Electrical Discharge Machining (EDM) is based on the eroding effect of an electric spark on both the electrodes used. Electrical Discharge Machining (EDM) actually is a process of utilizing the removal phenomenon of electrical-discharge in dielectric. Therefore, the electrode plays an important role, which affects the material removal rate and the tool wear rate.

1.2 PROJECT BACKGROUND

Electrical discharge machining or in short, EDM is based on the concept of using electrode to erode a work piece by using electrical sparks. An electrical spark is created between an electrode and a work piece. The spark is visible evidence of the flow of electricity. This electric spark produces intense heat with temperatures reaching 8000 to 12000 degree Celsius, melting almost anything. The spark is controlled very carefully and localized in order to prevent it from affecting other surfaces except for the surface. EDM process usually does not affect the heat treat below the surface. With EDM electrode, the spark always takes place in the dielectric of kerosene. The conductivity of the kerosene is controlled carefully to provide an excellent environment for the EDM process. Kerosene as coolant and flushes away the eroded metal particles.

There are a few types of flushing which are pressure flushing, jet flushing, injection flushing and suction flushing. Among those types of flushing there are advantages and disadvantages of them. In order to improve the flushing condition, it involves some form of relative motion between tool and work piece. Flushing is a very important function in any Electrical Discharge Machine (EDM) operation. It not only serves to remove the eroded debris from the spark-gap region but also has various other functions which highly influence the outcome of this machining process. Although the influence of flushing as a whole some requirement on the efficiency and stability of machining conditions in EDM has been extensively investigated, little has been reported concerning the effects of the various individual flushing techniques that are available in the industry. Improper flushing will cause erratic cutting and will increase machining time.

The Design of Experiment (DOE) using the Orthogonal Array is use to optimization of the single response characteristic. Consequently, Analysis of Variance (ANOVA) and the F test is also used to determine the significant machining parameter and obtain optimal combination levels of machining parameters. Therefore, some investigate needs to be for getting the best solution of the product by using the electrical discharge machining (EDM). The generally, the expected result that have been found that the higher material removal rate (MRR), the lower tool wear rate (EWR), better surface roughness and also no secondary machining.

1.3 PROBLEM STATEMENT

In electrical discharge machine (EDM), improper choose of the electrode material may cause of poor machining rate or performance. This is due to material removal rate (MRR) characteristic. Less material removal rate (MRR) needs more time for machining process and become waste and not goods for production. The second problem is it will decrease the accuracy of the product because influence of the tool wear rate (TWR) characteristic. The accuracy of the product occurs maybe because the tool wear rate (TWR) is high or material removal rate (MRR) is not suitable. Furthermore, electrode wear imposes high costs on manufacturers to substitute the eroded complicated electrodes by new ones for die making. In order to increase the machining efficiency, erosion of the work piece must be maximized and that of the electrode minimized in EDM process. Therefore, studying the electrode wear and related significant factors would be effective to enhance the machining productivity and process reliability.

1.4 OBJECTIVE OF THE PROJECT

The objective of this project is for design and fabrication mould to produce EDM tool for automotive valve application. There are some objectives of this research;

1) Design and fabrication of EDM tool for producing automotive valve application.
2) To optimize the materials removal rate and tool wear rate in the EDM process using Taguchi Method.

1.5 SCOPE OF THE PROJECT

This research will focus on how to design and fabrication mould to produce EDM tool for automotive valve application. In this research, I limited to machining by using CNC lathe machine to produce electrode and EDM die sinking is being used to make the mould. Also I am studying the parameters involve from both machine. The research scope is limited to machining parameters refers to electrical parameters on Electrical Discharge Machine (EDM) i.e. polarity, pulse-on-duration, discharge current, discharge voltage and non-electrical parameter like jet flushing pressure, machining diameter and machining depth . The scope should be limited in this experiment due to low cost and time. Besides, only cooper is the tool electrode that used. The reason for using this only copper electrode is regarding to cost limitation and availability. Beside, this paper project can gain a lot of knowledge and get more understanding about the Electric Discharge Machine (EDM).

1.6 SUMMARY

Chapter 1 has been discussed briefly about project background, problem statement, objective and scope of the project. This chapter is as a fundamental for the project and act as a guidelines for project research completion. Generally, this thesis consists of five chapters. Chapter 1 that has you read is the introduction about this study. Chapter 2 is the review of literature which discusses methods and findings previously done by other people which are related to the study. Chapter 3 is the Methodology which explains the approaches and methods used in performing the thesis. Chapter 4 is the chapter which reports the outcomes or results and discussion from the project and chapter 5 consists of the recommendation and conclusion.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

One of the scope studies is literature review. This analysis will run works as guide. It will give part in order to get the information about electrical discharge machine (EDM) and will give idea to operate the test. From the early stage of the project, various literature studies have been done. Research journals, books, printed or online conference article were the main source in the project guides. This part will include almost operation including the test, history, machining properties and results. History of the Electrical Discharge Machine (EDM) will be story little bit in this section. Literature review section work as reference, to give information and guide base on journal and other source in the media.

2.2 HISTORY OF ELECTRICAL DISCHARGE MACHINE (EDM)

In 1770 English scientist Joseph Priestly firstly invented the erosive effect of electrical discharge machining. After that in 1930s, the machining of metals and diamond with electrical discharges has been done. Due to evaluation of spark, erosion was caused by intermittent arc discharges occurring in air between the electrode and workpiece which is connected to a DC power supply. Overheating of the machining area restricts the applications of this process, so it is known as “arc machining” (Ho, K.H., Newman, S.T., 2003). In 1943 at the Moscow University revolutionary work on electrical discharge machining was carried out by two Russian scientists, B.R. and N.I.

Lazarenko (Lazarenko, B.R., 1943). Refined and a controlled process for machining of materials was developed by analyzing the destructive effects. It becomes easy to maintain and control gap between the electrode and workpiece with the introduction of RC (resistance–capacitance) relaxation circuit in 1950s, which provided the first consistent dependable control of pulse times and also a simple servo control circuit.

Later stage RC circuit used as the model for successive developments in EDM technology. In America at same time three employees came up with same results by using electrical discharges to remove broken taps and drills from hydraulic valves. With the reference of this work vacuum tube EDM machine and an electronic circuit servo system that automatically provided the proper electrode to- workpiece spacing (spark gap) for sparking, without contact between the electrode and the workpiece (Jameson, E.C., 2001).

In 1980s with the initiation of Computer Numerical Control (CNC) in EDM brings remarkable advancement by improving the efficiency of the machining operation. EDM machines have become so stable with the regular improvement in the process, so that these can be used for long interval of time under monitoring by an adaptive control system. This process enables machining of any material, which is electrically conductive, irrespective of its hardness, shape or strength (Abu Zeid O.A., 1997). The improvement of EDM have since then been intensely sought by the manufacturing sector yielding enormous economic benefits and generating keen research interests.

2.3 DIE-SINKING EDM MACHINE

In present study, the machine will be used is Die-sinking EDM. 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 Sodick AQ55L EDM. 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 Vitol-2 kerosene. The electrodes used were made of electrolytic copper 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.

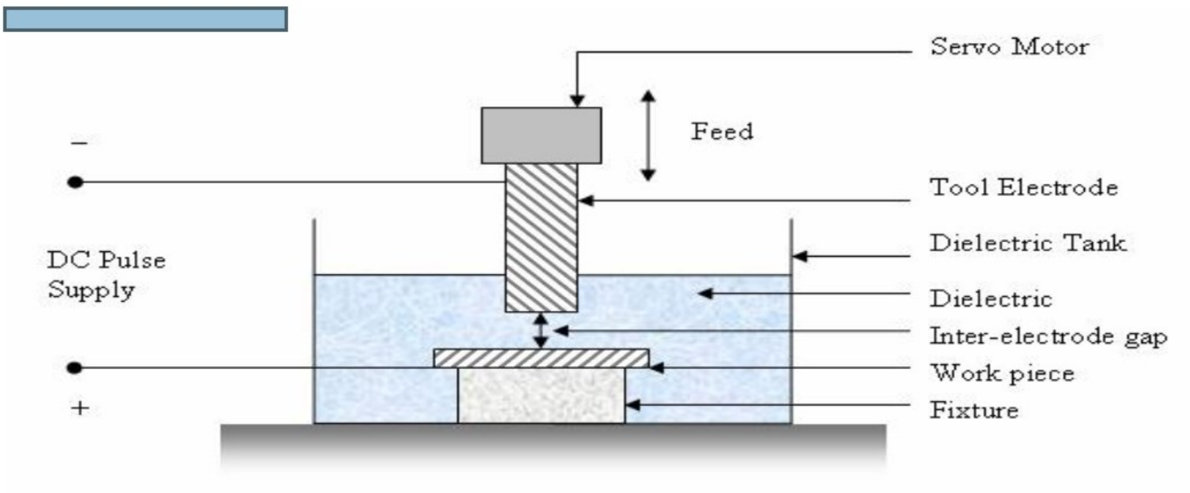


Figure 2.1: Schematic of an Electric Discharge Machining (EDM) machine tool.

Source: Sourabh Kumar Saha, May (2008)

The schematic of an EDM machine tool is shown in Figure 2.1. 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, May 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 300mm3/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, May 2008).

2.4 MACHINING PARAMETER SELECTION

The Process parameters can be divided into different categories i.e. electrical, non-electrical Parameters, electrode parameters, powder parameters etc. shown in Figure 2.2 below:

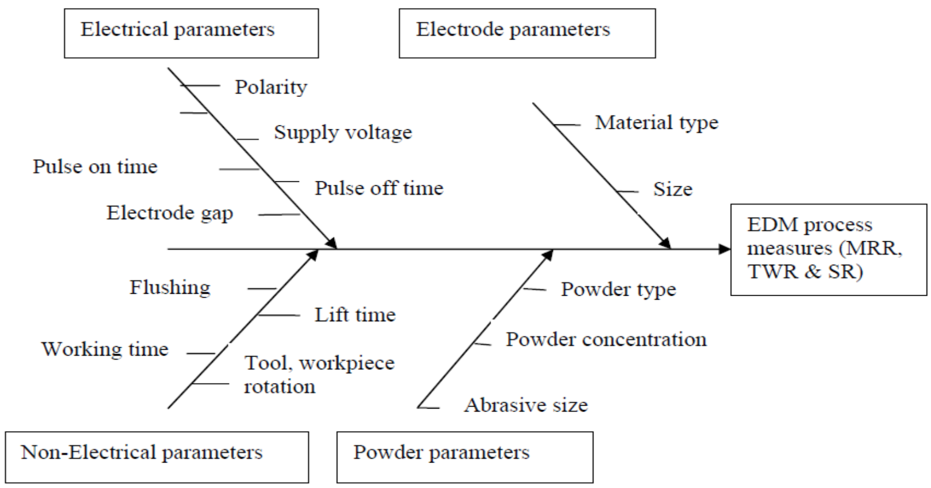


Figure 2.2: Process parameters and performance measures of EDM Process a cause and effect diagram

Source: Sharanjit Singh and Arvind Bhardwaj, (2011)

In the section, the elements considered in measuring EDM performance are MRR, electrode wear (EW), recast layer, surface quality (Ra) and effect of electrical and non-electrical parameter. Seven (7) factors are selected with a combination of four (4) electrical parameters and three (3) non-electrical parameters. Machining depth and machining diameter were selected for the control factors because they affected MRR, EWR and SR analysis.

There are two major groups of parameters that have been discovered and categorized:

1) Non-electrical Parameters

1). Pulse flushing pressure

2). Machining diameter

3). Machining Depth

2) Electrical Parameters

The input parameters considered in this study are defined as follows:

1) Polarity (A):
2) Pulse on time (B):
3) Peak current (C):
4) Power supply voltage (D)

Some of the important parameter implicated in the EDM manufacturing process are the following one:

1. Polarity (A): The polarity of the electrode can be either positive or negative. But the excess material is removed from side which is positive. When series discharge starts under the electrode area andpasses through the gap, which creates high temperature causing material evaporation at the faces of both the electrode

2. Pulse on time (B): The duration of time (μs), the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during on-time. Amount of energy is really controlled by the peak current and the length of the on-time.

3. Peak current (C): The Peak current (Ip) is a measure of the power supplied to the discharge gap. A higher current leads to a higher pulse energy and formation of deeper discharge craters. This increases the material removal rate (MRR) and the surface roughness (Ra) value. It is expressed in amperes.

4. Power supply voltage (D): 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 present voltage determines the width of the spark gap between the leading edge of the electrode and workpiece.

The output parameters considered are defined as follows.

1) *Metal removal rate (MRR)* can be express as:

$$\textbf{MRR (g/min)} = \frac{\textbf{WRW (workpiece removed weight)}}{\textbf{T (period of machining time in minuter)}} \tag{2.1}$$

2) For Tool Wear Rate (EWR) express as :

$$\mathbf{TWR} = \frac{\mathbf{1000 \times W_e}}{\boldsymbol{\rho_e} \times \mathbf{t}} \; (\mathbf{mm^3/min}) \tag{2.2}$$

2.5 FLUSHING

The most important in EDM is flushing because eroded particle must be removed from the gap for efficient cutting. Flushing also brings fresh dielectric oil into the gap and cools the electrode and the work piece. The deeper the cavity will bring the greater the difficulty for proper flushing. Improper flushing would cause erratic cutting. This in turn increases machining time. Under certain machining conditions, the eroded particles attach themselves to the workpiece. This prevents the electrode from cutting efficiently. It is then necessary to remove the attached particles by cleaning the workpiece. The danger of arcing in the gap also exists when the eroded particles have not been sufficiently removed. Arcing occurs when a portion of the cavity contains too man eroded particles and the electric current passes through the accumulated particles. This arcing causes an unwanted cavity or cavities which can destroy the workpiece. Arcing is most likely to occur during the finishing operation because of the small gap that is required for finishing. New power supplies have been developed to reduce this danger (http://www.reliableedm.com).

Proper flushing depends on the volume of oil being flushed into the gap, rather than the flushing pressure. High flushing pressure can also cause excessive electrode wear by making eroded particles bounce around in the cavity. Generally, the ideal flushing pressure is between 3 to 5 psi. (0.2 to 0.33 bars) Efficient flushing required a balance between volume and pressure. Rough operations, where there is a much larger arc gap; require high volume and low pressure for the proper oil flow. Finishing operations, where there is a small arc gap, requires higher pressure to ensure proper oil flow.Often flushing is not a problem in a roughing cut because there is a sufficient gap for the coolant to flow. Flushing problem usually occur during finishing operations. The smaller gap makes it more difficult to achieve the proper oil flow to remove the eroded particles, (Dorf,R.C, and Kusiak, Andrew, 1994).

In the EDM process, four type of flushing can be used. There are pressure, suction, external and pulse flushing. Each job needs to be evaluated to choose the best flushing method. For this project, the pulse flushing will be used. (http://www.reliableedm.com). Pressure flushing also called injection flushing is the most commen and preffered method for flusing shown in Figure 2.3. One great advantages of presure flusing is that the operator can visually see the amount of oil that is being used for flushing.

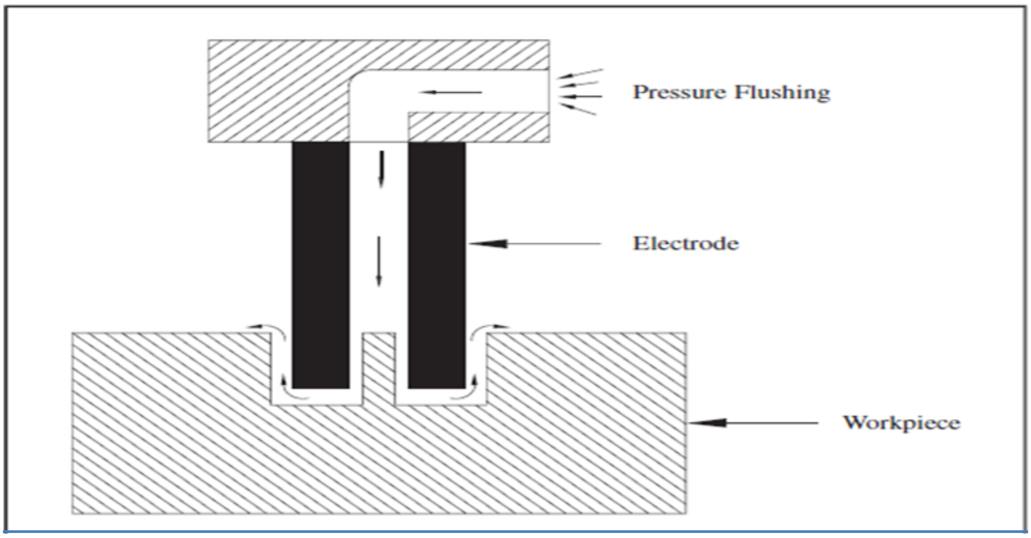


Figure 2.3: The electrode Orbit in the workpiece (http://www.reliableedm.com)

2.6 SUMMARY

This chapter discussed about the analysis that will run works as guide. It will give part in order to get the information about electrical discharge machine (EDM) and will give idea to operate the test. The Process parameters can be divided into different categories i.e. electrical, non-electrical Parameters, electrode parameters and powder parameters The some of the important parameter implicated in the EDM manufacturing processare are Polarity (A), Pulse on time (A) and Peak current (C). In the EDM process, four type of flushing can be used. There are pressure, suction, external and pulse flushing. For this project, the pulse flushing will be used.

CHAPTER3

METHODOLOGY

3.1 INTRODUCTION

In this chapter generally discusses about methodology of the project, with a focus on electric discharge machine (EDM) experiment and machining.. This section contains the methodology to conduct this study. Methodology involves the problem identification and solving, Design of Experiment (DOE), and detail experimental design. Roughly, this project consists of two semesters. For semester 1 will be doing the proposal, literature review and methodology planning. The study of electric discharge machine (EDM) also include in semester one. This all gather in the semester one. The semester two conclude the preparation of experimental tools and work pieces, running experiment, get data collection do the analysis. The documentation and report writing will be done after that.

3.2 FLOW CHART OF EXPERIMENT

Figure 3.1 shown the flow chart to run the experiment.

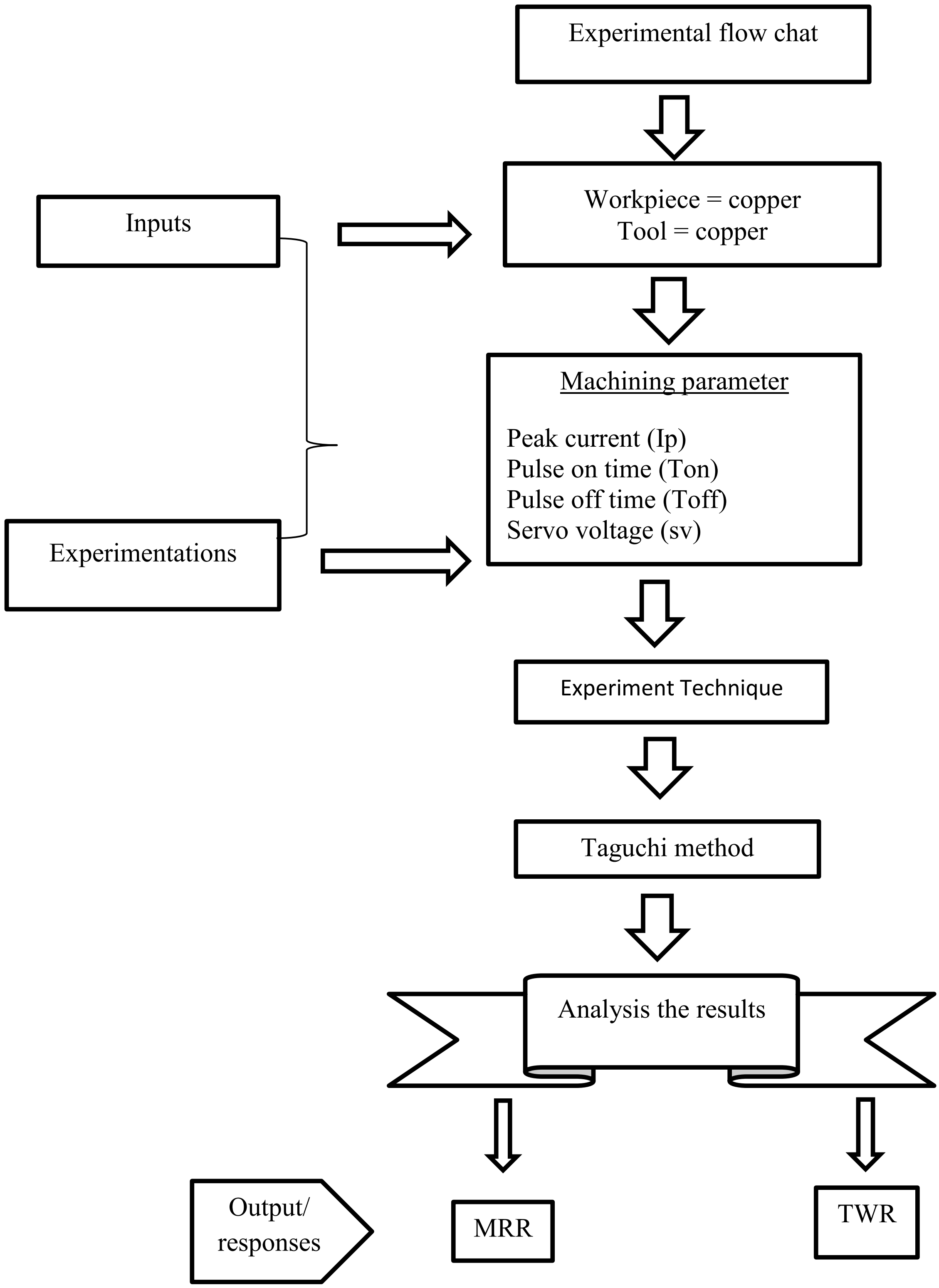


Figure 3.1: Flow Chart Of Experiment

3.3 MATERIAL SELECTION

Material selection is the most important to this experiment because different materials have different working parameters based of their properties. The right selection of the machining material is the most important aspect to take into consideration in processes related to the EDM. From the observation and discussion with partner and supervisor, the electrode material that has been selected is copper while their work pieces also copper.

3.3.1 Electrodes

The important factors in selecting cooper is their high strength-to-weight ratio, resistance to corrosion by many chemicals, high thermal and electrical conductivity, non-toxicity, reflectivity, appearance and ease of formability and of machinability; they are also nonmagnetic.

Copper is a chemical element with the symbol Cu (Latin: cuprum) and atomic number 29. It is a ductile metal with excellent electrical conductivity. Copper is rather supple in its pure state and has a pinkish luster which is (beside gold) unusual for metals, which are normally silvery white. It is used as a heat conductor, an electrical conductor, as a building material and as a constituent of various metal alloys. Copper is malleable and ductile, a good conductor of heat and, when very pure, a good conductor of electricity. Copper is malleable and ductile, a good conductor of heat and, when very pure, a good conductor of electricity. The physical properties of these electrode tools are presented in Table 3.1.

Table 3.1: Physical properties of copper

Property	Copper
Density (g/cm³)	8.904
Melting point (°C)	1084.6
Specific heat (J/Kg.°C)	385
Thermal conductivity (W/m.K)	400
Electrical resistivity (μΩ.cm)	1.678
CTE* linear (μm/m.°C)	16.5

Source: (hascalik and caydas,2007; Jahan et al.,2009; Lee and Li,2001; Lin et al., 2009)

3.3.2 Workpiece Material

Copper as work pieces are steels that are primarily used to make tools used in manufacturing processes as well as for machining metals, woods, and plastics. Copper are generally ingot-cast wrought products, and must be able to withstand high specific loads as well as be stable at elevated temperatures. In case of this project, copper also used as a workpiece to produce mould using EDM machine. The chemical composition of copper is displayed in Table 3.2.

Table 3.2: Chemical composition of copper

Element	**Cu**	**Pb**	**Fe**	**Si**	**Co**	**Sb**	**Zn**	**Sn**
Wt %	99.80	0.0327	0.497	0.0133	0.0102	0.0184	0.005	0.005
Element	**Ni**	**Be**						
Wt %	0.005	0.005						

Source: (hascalik and caydas,2007; Jahan et al.,2009; Lee and Li,2001; Lin et al., 2009)

3.4 MACHINING PARAMETER

EDM parameter can be classified as response parameters and process parameters. The response parameters represent the EDM performance characteristics and are the unknown function from the process variables (Montgomery, 2001). The process parameters, known as process variables, are the independent variables and are also considered as the machining input. The performance characteristic and process parameters are discussed in the following sub-section.

3.4.1 Performance Characteristics

The important and most common responses used to measure EDM characteristics are the material removal rate (MRR), tool wear rate (TWR),surface roughness (SR) and surface characteristics (Garg et al., 2010; MArafona and Wykes, 2000; Rival, 2005; Su et al.,2004).

1) Material Removal Rate

The MRR is the rate at which material is removed from the workpiece by EDM. It is expressed as the weight of material removed over a period of machining time in minutes (Wu et al., 2005). The amount of metal removed is measured by calculating the difference in weight of the workpiece before and after EDM. The MRR is expressed as in Eq. (3.1) (Chattopadhyay et al., 2009; Habib, 2009).

$$MRR = \frac{Reduction\ in\ weight\ of\ workpiece\ (g)}{Density\ of\ workpiece\ \ (g/min) \times Machining\ time\ (min)} \tag{3.1}$$

It can also write as:

$$MRR = \frac{1000 \times W_w}{\rho_w \times t} \qquad (mm^3/min) \tag{3.2}$$

Where $W_w = W_1 - W_2$ is the amount of met
al removed from workpiece (g)

W_1 is the weight of the workpiece before machining (g)

W_2 is the weight of the workpiece after machining (g)

ρ_w is the density of the workpiece material (g/cm^3)

t is the machining time (min)

In the EDM process, the maximum MRR is a significant factor for efficiency and cost effectiveness (Rival, 2005). However, fast material removal rates lead to rough surface finish. In this context, higher MRRs are not always required in EDM.

2) Tool Wear Rate

TWR can be defined in various ways. It is also called the electrode wear rate, and it is sometimes expressed as the tool wear ratio. In this study, the TWR is defined as the weight of material lost from the electrode over a period of machining time (Chattopadhyay et al., 2009: Dewangan, 2010; Mohan et al., 2002). The amount of tool wear is measured by calculating by Eq. (3.3) (Chattopadhyay et al., 2009; Habib, 2009; Mohan et al., 2002). A minimum value of electrode wear is an objective in many studies, where it denotes a minimum change in the shape of the electrode and result in better accuracy in the product (Rival, 2005).

$$TWR = \frac{Reduction\ in\ weight\ of\ electrode\ (g)}{Density\ of\ electrode\ (g/mm^3) \times\ machining\ time\ (min)} \quad (3.3$$

Eq. (3.3) can also be written as:

$$TWR = \frac{1000 \times W_e}{\rho_e \times t}\ (mm^3/min) \quad (3.4)$$

Where $W_e = W_1 - W_2$ is the weight loss of the electrode (g)

W_1 is the weight of the electrode before machining (g)

W_2 is the weight of the electrode after machining (g)

ρ_e is the density of the electrode material (g/cm^3)

t is the machining time (min)

3.5 DESIGN THE EXPERIMENT

For design the experiment, the orthogonal array was selected from the types of experimentation (orthogonal arrays, Greco-Latin squares, Placket-Burman Design, full factorial). This is because orthogonal arrays are the most versatile and are becoming more widely used. Table shows the standard of orthogonal arrays. Table shows the L9 orthogonal arrays that been choose for this experiment.

3.6 DATA COLLECTION

The data that will be taken is:

1) Machining time, t using timer meter at machine.
2) Mass of work piece before and after, g
3) Work pieces removal rate (WRR), g
4) Electrode wear weight (EWR), g

using electronic balance

Table 3.3 standard orthogonal arrays

Orthogonal Array	Number of Row	Maximum Number of Factors	Maximum Number of Columns at these level			
			2	3	4	5
L4	3	3	3	-	-	-
L8	8	7	7	-	-	-
L9	9	4	-	4	-	-
L12	12	11	11	-	-	-
L16	16	15	15	-	-	-
L16	16	5	-	-	4	-
L18	18	8	1	7	-	-
L25	25	6	-	-	-	6

3.6.1 Criteria for Optimization of Performances

The Taguchi Method using L9 orthogonal array is used in carrying out experiments for solving the optimization process. This approach can optimize the machining parameters with consideration of the multiple responses which is the machining characteristics Electrode Wear Ratio (EWR) effectively. Based on Taguchi's method DOE, an L9 orthogonal arrays table with 9 rows (corresponding to the number of experiments) was selected for the experimentation. Experimental layout of L9 orthogonal array is shown in Table 3.3.

Table 3.4: Machining Control Parameters and their respective levels

Factors	Description	Level 1	Level 2	Level 3	Units
A	Discharge Current	10	20	30	Ampere
B	Pulse on duration	150	300	450	Microsecond
C	Pulse off duration	13	26	39	Microsecond
D	Discharge Voltage	50	65	80	Volt

Table 3.5: L9 Orthogonal Array

Exp. No.	Factor				Result	
	A	B	C	D	MRR	EWR
1	30	150	13	50		
2	30	300	26	65		
3	30	450	39	80		
4	20	150	13	50		
5	20	300	26	65		
6	20	450	39	80		
7	10	150	13	50		
8	10	300	26	65		
9	10	450	39	80		

Source: Minitab software

3.7 CONCEPT

The concept of tool for EDM should fulfil the conditions as stated in problem statement.

It is should be able to function under good electrical conductivity of EDM beside high strength-to-weight ratio and resistance to corrosion. Moreover the tool should facilitate flushing during machining.

Finally, the tool should be easy to fabricate by considering laboratory machine and equipment capability and also cost of fabrication.

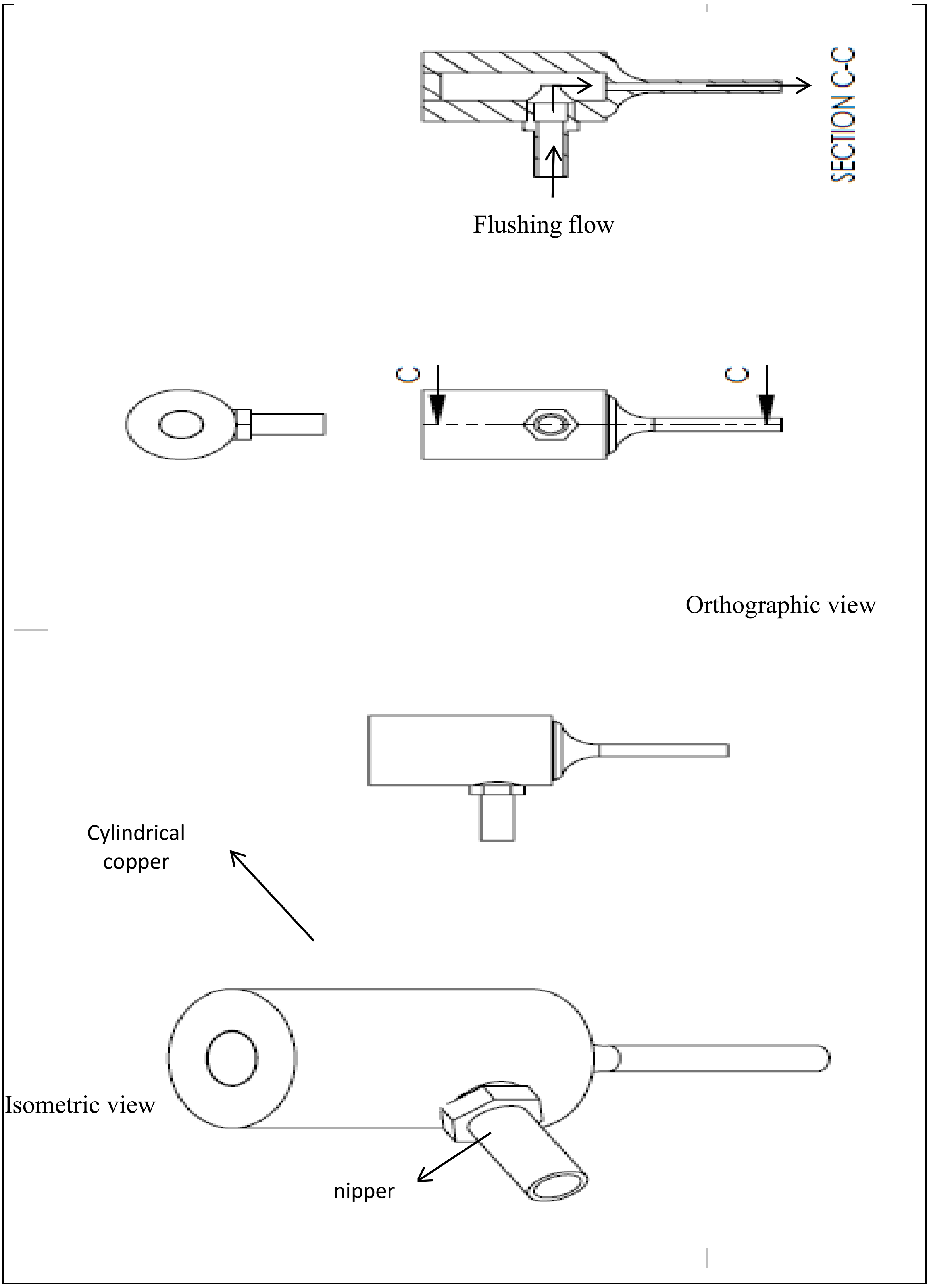


Figure 3.2: Concept of electrode

3.8 FABRICATION PROCESS STEPS

3.8.1 For Electrode

Firstly, the fabrication process is started with cutting down the 30mm diameter cylindrical copper into smaller part with 105mm length before machining. This is done using band saw machine which is located inside the main material store (Figure 3.3).

Figure 3.3: Cut material using band saw machine

After that is turning process. Turning process was run by CNC lathe machine. Before turning process can be done, workpiece must be climbed at chuck (Figure 3.4) and facing process must do to make sure the front of workpiece smoothly. Then the machine was run and the valve was shaped .

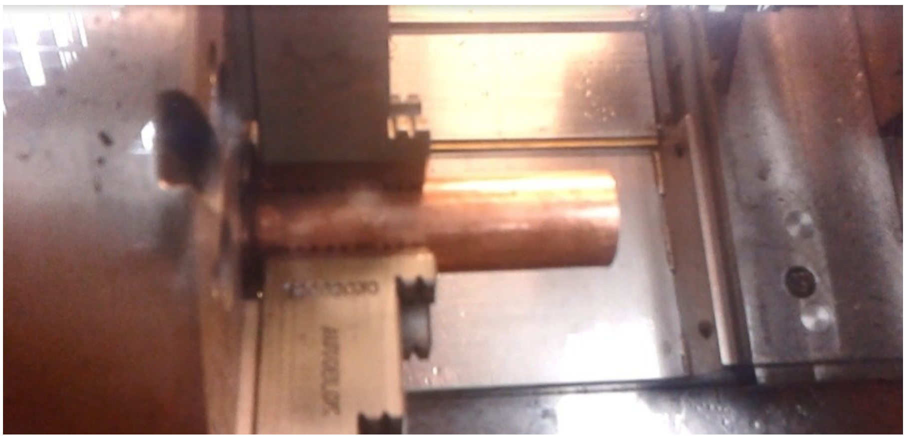


Figure 3.4: Climb material at chuck

Next is drilling process by CNC milling machine, this process required accurate positioning. Therefore an edge finder is used to locate and set origin at one edge of the workpiece. Centre drill is used drill pilot hole to guide the drill bit during drilling process. Then countersink is used to make chamfer around the hole to remove burr at same time provider a tapper surface that align screw during assemble process (Figure 3.5).

Figure 3.5: Centre drill and drill bit attached to drill chuck

Now machining process had end the following up fabrication process is carried out by hand. Before tapping is done, few drop of lubricant is applied onto hole. Tapper tap which has least threat is clamped onto tap wrench. By hold the tap in the line with the hole, turn it clockwise with both hands. Every half rotation turns counterclockwise to break up and remove the chip (Figure 3.6).

Figure 3.6: Internal thread is made using hand tap

Finally all the component is then assemble together and finish fabricated the electrode for EDM machine (Figure 3.7).

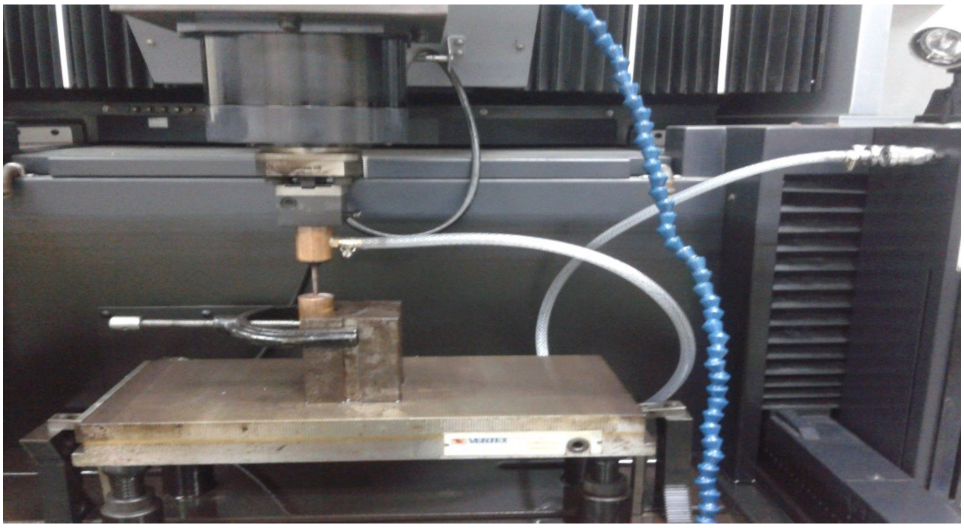


Figure 3.7: Assemble

Table 3.6: Cutting and Spindle speed of each tool.

Cutting Tool	Cutting speed/Spindle speed
Edge finder	200rpm
Center drill	1000rpm
Drill bit	18mm/min
Countersunk	200rpm

3.8.2 For Workpiece

Firstly, the fabrication process is started with cutting down the 30mm diameter cylindrical copper into smaller part with 60mm length before machining. This is done using band saw machine which is located inside the main material store (Figure 3.8).

Figure 3.8: Cylindrical copper for workpiece

After that, some finishing is done by using flat hand file to remove burr or sharp edges resulted from cutting and machining. Figure 3.9 was shown the workpiece was drill to make hole.

Figure 3.9: Drill the workpiece to make hole

Next is drilling process, this process required accurate positioning at the centre workpiece. Therefore an edge finder is use to locate and set origin at edge of the workpiece.

3.9 SUMMARY

Experiments were conducted according to Taguchi method by using the machining set up and the designed valve shaped electrodes with internal flushing. The control parameters like, discharge current (Ip), pulse on time(Ton), pulse off time (Toff) and servo voltage (sv) conductivity were varied to conduct 9 different experiments and the weights of the work piece and Tool before and after experiment were taken for calculation of MRR and TWR.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

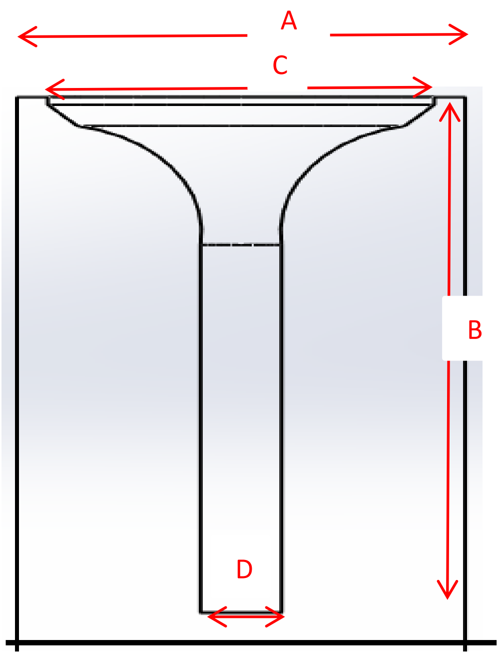
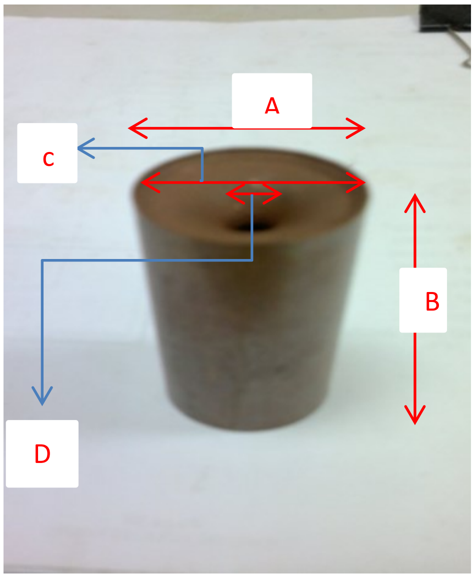
In this section, the result obtained from the experiment are discussed and studied using the S/N ratio and ANOVA analyses with the help of MINITAB software. Based on the results of the S/N and ANOVA analyses, optimal setting of the EDM parameter for material removal rate and Tool wear rate are obtained. Then, the conformation experiment is run for verification.

4.2 ANALYSIS OF THE S/N RATIO

In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (S.D.) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the S.D.

Table 4.1 showns the comparison between design and fabrication of the material. It shown that no error happen at outer diameter and depth of hole for material. For inner diameter and diameter hole, the error is 4% and 8% happen at the actual workpiece. This error happen because of peak current between tool and material is larger. To reduce the error, the peak current must decrease.

Table 4.1: Comparison between design and fabrication

Design	Fabrication	Error, %
		
Outer diameter, A = 30 mm Depth of hole, B = 43.08 mm Inner diameter, C = 28.94 mm Diameter hole, D = 5.42 mm	Outer diameter, A = 30 mm Depth of hole, B = 43.08 mm Inner diameter, C = 28.99mm Diameter hole, D = 5.5mm	A=0% B=0% C=5% D=8%

4.3 DATA COLLECTION

From Table 4.1 we can see the total number of experiment and its data result. Overall for experiment, the total time is taken to finish the machining is 43 hours 34 minutes and 3 second. This time is just the time of machining process and not including the time set-up for the experiment. This experiment looks fairly suitable for the limits of scope project due to the lack of time. In other words, more experiment can be done if there is no limited time and more accurate result can be obtained. The data collections that are taken are the mass of electrode before and after, mass of work piece before and after and time taken of every experiment.

Table 4.2: Mass of electrode and workpiece before and after machining

S. No.	Mass electrode (g) (before machining)	Mass electrode (g) (after machining)	Mass W/P (g) (before machining)	Mass W/P (g) (after machining)	Time machining (min)
1	362.874	345.147	369.148	344.898	180.07
2	367.796	363.067	367.421	361.802	61.87
3	370.061	365.472	367.532	362.459	74.06
4	351.321	345.029	360.412	356.473	84.43
5	369.618	364.962	360.931	356.300	74.28
6	383.230	372.605	367.466	355.348	241.42
7	367.361	365.682	369.717	361.513	426.8
8	368.378	366.598	364.120	357.355	570.12
9	345.147	342.467	368.488	357.919	961.85

There are many factor need to be consider during operating the machine to make sure the results produce are in good condition and increase productivity. The most important factor in making the production run faster is the time taken for machining product. The time taken for machining can be express in term of material removal rate (MRR). Material removal rate (MRR) is a value of time that calculated to determine the rate of production in industries. In order to increase the machining efficiency, erosion of the work piece must be maximized and that of the electrode minimized in EDM process. Roughly, from table 4.2 we can see the material removal rate (MRR) for the experiment 1 is more compare with other experiments. From the table 4.1 also we can easily find the less mass of electrode material which is experiment 9. Experiment 9 is less in weight due to its properties followed by experiment 8 and experiment 7. But, this only the rough data that cannot be make as conclusion. So, this data need to analyzed first in order to meet the objective of this project.

Table 4.3: Data collection

S. NO.	FACTOR				MRR mm^3/min	TWR mm^3/min
	A	B	C	D		
	PEAK CURRENT (A)	PULSE ON TIME (μs)	PULSE ON TIME (μs)	SERVO VOLTAGE (v)		
1	30	150	13	50	15.1246	11.0563
2	30	300	26	65	10.1835	8.5843
3	30	450	39	80	7.6930	6.9590
4	20	150	26	80	5.2397	4.3790
5	20	300	39	50	7.0019	7.0397
6	20	450	13	65	5.6373	4.9428
7	10	150	39	65	2.1588	0.4418
8	10	300	13	80	1.3327	0.3510
9	10	450	26	50	1.2341	0.3119

4.4 ANALYSIS OF MATERIAL REMOVAL RATE (MRR)

Taguchi uses the S/N ratio to measure the quality characteristics as mentioned earlier, there are three categories of quality characteristic, i.e. the-smaller-the-better, the higher-the better, and the-nominal-the-best. To obtain optimal EDM performance, the-higher-the-better quality characteristic for material removal rate must be taken. Table 4.3 show the result for the material removal rate, (MRR) average as measured by the electronics balance. From the overall nine experiments combination, experiment run number one produce the best material removal rate.

Table 4.4: Experimental result for material removal rate and S/N ratio

S. NO.	FACTOR				MRR mm^3/min	S/N ratio (dB)
	A	B	C	D		
	PEAK CURRENT (A)	PULSE ON TIME (μs)	PULSE ON TIME (μs)	SERVO VOLTAGE (v)		
1	30	150	13	50	15.1246	-23.5937
2	30	300	26	65	10.1835	-20.1579
3	30	450	39	80	7.6930	-17.7219
4	20	150	26	80	5.2397	-14.3861
5	20	300	39	50	7.0019	-16.9043
6	20	450	13	65	5.6373	-15.0214
7	10	150	39	65	2.1588	-6.6842
8	10	300	13	80	1.3327	-2.4946
9	10	450	26	50	1.2341	-1.8270

S/N ratio for each combination then calculated with the help of MINITAB software. The result for S/N ratio for each experiment is shown in Table 4.4. Then the mean S/N ratio for each level of the EDM parameters is summarized and called the mean S/N response table for material removal rate as shown in Table 4.5. In addition, the total mean S/N ratio for nine experiments is also calculated and listed in Table 4.5. Figure 4.1 shows the mean S/N ratio graph for material removal rate.

Table 4.5 Response table mean S/N ratio for material removal rate

Symbol	**EDM parameter**	**Mean S/N ratio**			**Max-min**
		Level 1	Level 2	Level 3	
A	Peak current	-3.669	-15.437	-20.491	16.822
B	Pulse on time	-14.888	-13.186	-11.523	3.365
C	Pulse off time	-13.703	-12.124	-13.770	1.646
D	Servo voltage	-14.108	-13.955	-11.534	2.574

Total mean S/N Ratio is -11.1783

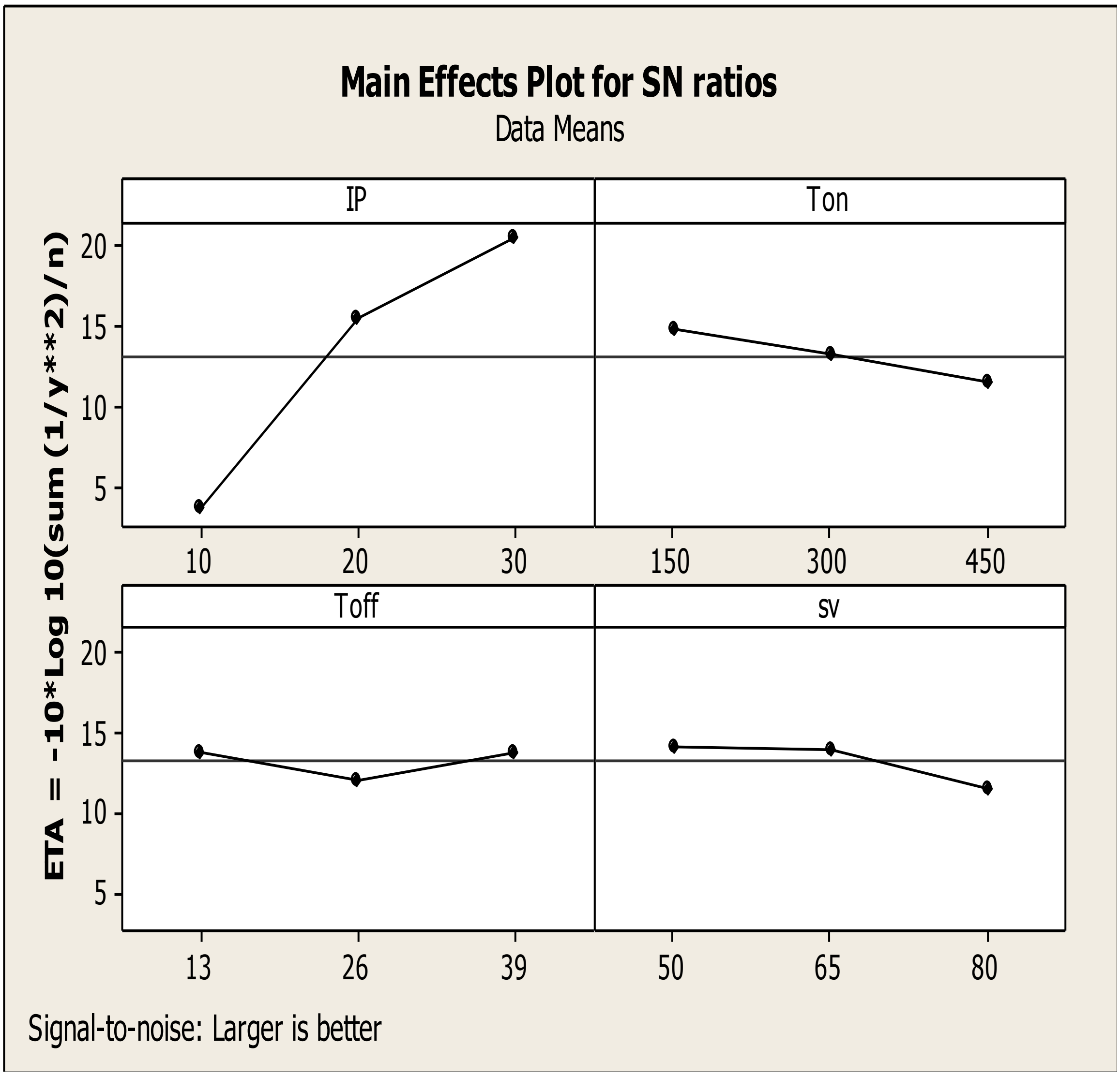


Figure 4.1: The mean of S/N ratio for each parameter at three levels

The greater S/N ratio corresponds to the smaller variance of the output characteristic around the desired value (higher-the-better). From the graph, figure 4.1 it can be concluded that the optimize EDM parameter for material removal rate is peak current at 30, pulse on time at 150 µs, pulse off time at 13µs and servo voltage at 50v. However, the relative important amongst the EDM parameter for material removal rate still needs to be known so that optimal combinations of the EDM parameter levels can be determined more accurately. This will be discussed in the next section using the analysis of variance.

4.5 ANALYSIS OF TOOL WEAR RATE (TWR)

Table 4.5 shows the result for Tool wear rate and the corresponding S/N ratio. Since the experimental design is orthogonal, it is then possible to separate out the effect of each EDM parameter at different levels. For example, the mean S/N ratio for the peak current at level 1, 2, and 3 can be calculated by averaging the S/N ratio for the experiment 1-3, 4-6, and 7-9, respectively. The mean S/N ratio for each level of the other EDM parameter can be computed in the similar manner. In addition, the total mean S/N ratio for the nine experiments is also calculated. Figure 2 shows the S/N response graph for tool wear rate, the greater is the S/N ratio, the smaller is the variance of tool wear rate around the desired (the-lover-the-better) value. However, the relative importance amongst the EDM parameter for tool wear rate still needs to be known so that optimal combinations of the EDM parameter levels can be determined more accurately.

Table 4.6: Result for tool wear rate and S/N ratio

S. NO.	**FACTOR**				**TWR** mm^3/min	**S/N ratio (dB)**
	A	B	C	D		
	Peak Current(A)	Pulse On Time(µs)	Pulse On Time(µs)	Servo Voltage (v)		
1	30	150	13	50	11.0563	-20.8722
2	30	300	26	65	8.5843	-18.6741
3	30	450	39	80	6.9590	-16.8509
4	20	150	26	80	4.3790	-12.8275
5	20	300	39	50	7.0397	-16.9511
6	20	450	13	65	4.9428	-13.8795
7	10	150	39	65	0.4418	7.0955
8	10	300	13	80	0.3510	9.0939
9	10	450	26	50	0.3119	10.1197

Table 4.7: Different between Max and Min S/N ratio response for tool wear rate

Symbol	EDM parameter	Mean S/N ratio			Max-min
		Level 1	Level 2	Level 3	
A	Peak current	8.770	-14.553	18.799	27.569
B	Pulse on time	-8.868	-8.844	-6.870	1.998
C	Pulse off time	-8.553	-7.127	-8.902	1.775
D	Servo voltage	-9.235	-8.486	-6.862	2.373

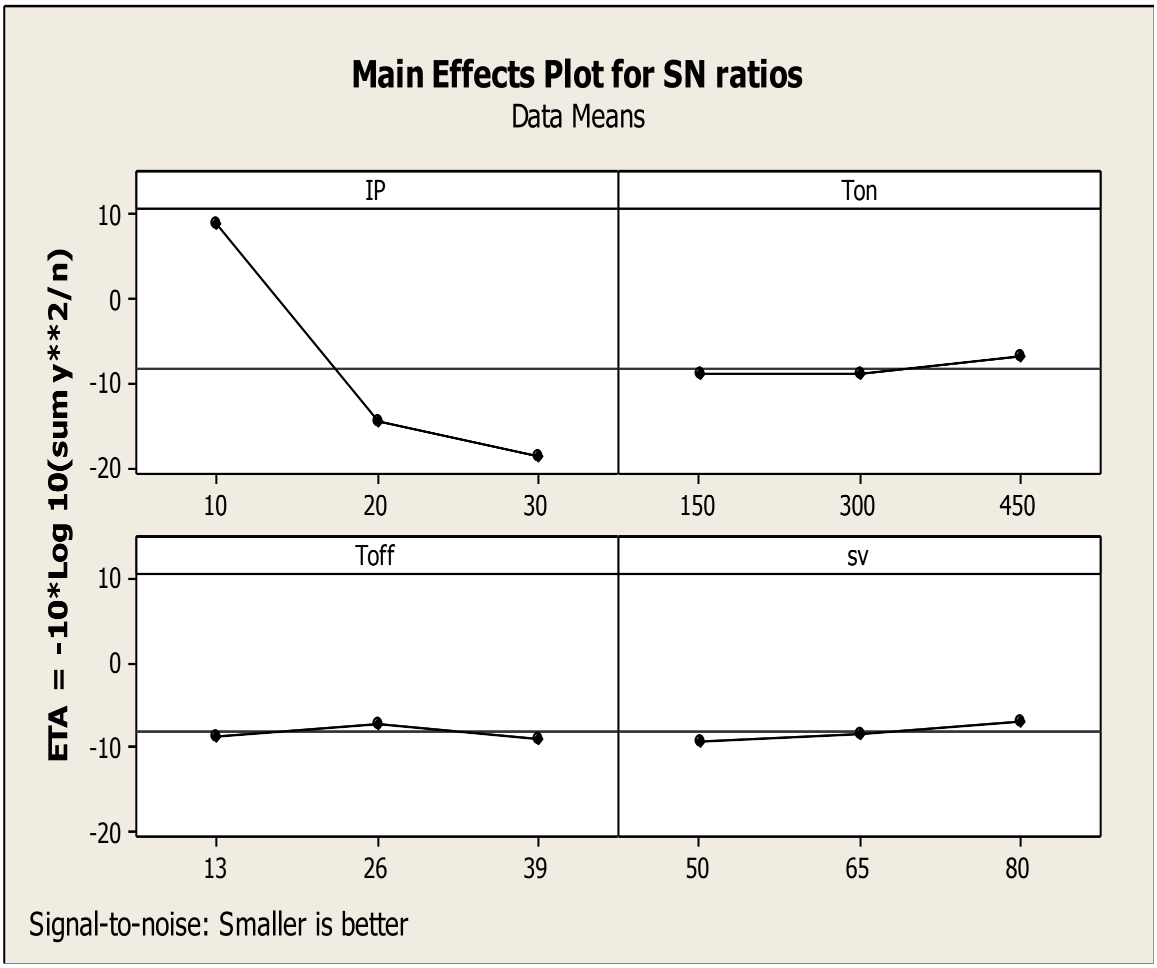


Figure 4.2: S/N ratios Graph for tool wear rate

From the graph, Figure 4.2 it can be concluded that the optimize EDM parameter for tool wear rate is peak current at 10A, pulse on time at 450µs, pulse off time at 26µs and servo voltage at 80v. However, the relative important amongst the EDM parameter for material removal rate still needs to be known so that optimal combinations of the EDM parameter levels can be determined more accurately. This will be discussed in the next section using the analysis of variance.

4.6 ANALYSIS OF VARIANCE (ANOVA)

The purpose of the analysis of variance (ANOVA) is to investigate which design parameter significant affect the quality characteristic. This is to accomplish by separating the total variability of the S/N ratio, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameter and the error. First, the total sum of squared deviations SST from the total mean S/N ratio ŋm can be calculated as:

$$SSt = \sum_{i=1}^{ŋ} (ŋ_{i} - ŋ_{\infty})^{2}$$

where ŋ is the number of experiments in the orthogonal array and $ŋ_i$ is the mean S/N ratio for the I th experiment.

The total sum of spared deviations SST is decomposed into two sources: the sum of squared deviations SSd due to each design parameter and the sum of squared error SSe. The percentage contribution ρ by each of the design parameters in the total sum of squared deviations SST is a ratio of the sum of squared deviations SSd due to each design parameter parameter to the total sum of squared deviations SST.

Statically, there is a tool called an F test named after Fisher to see which design parameters have significant effect on the quality characteristic. In performing the F test, the mean of squared deviations SSm due to each design parameter need to be calculated. The mean of squared deviations SSm is equal to the sum of squared deviations SSd divided by the number of degree of freedom associated with the design parameter.

Then, the F value for each design parameter is simply the ratio of the mean of squared deviations SSm to the mean of squared error. Usually, when F>4, it means that the change of the design parameter has a significant effect on the quality characteristic.

Table 4.8 shows the results of ANOVA for material removal rate. It can be found that the peak current are the significant parameters for affecting Material Removal rate (MRR). The change of the peak current, pulse on time and servo voltage in the range given in Table 4.8 has an insignificant effect on Material Removal Rate (MRR). Therefore, based on the S/N and ANOVA analyses, the optimal parameters for Material Removal Rate (MRR) are the peak current at level 1, the pulse on time at level 1, the pulse off time at level 1 and servo voltage at level 1.

Table 4.8: Result of the ANOVA for Material removal

Analysis of variance						
	SS	**df**	**MS**	**F**	**p**	**Contribution %**
{A}peak current	133.466	2	66.733	12.98	0.007	95.51
{B}pulse on time	10.557	2	5.278	0.21	0.819	1.54
{C}pulse off time	6.341	2	3.171	0.12	0.889	0.88
{D}servo voltage	13.941	2	6.971	0.28	0.76	2.06
Residual	0					

- P= (significant) if <0.05 is significant

Table 4.9 shows the results of ANOVA for Tool Waer Rate (TWR). The peak current is significant. Based on the S/N and ANOVA analyses the optimal parameter for tool wear rate are the peak current at level 3, the pulse on time at level 3, the pulse off time at level 2 and servo voltage at level 1.

Table 4.9: Result of the ANOVA for Tool wear rate

Analysis of variance						
	SS	df	MS	F	p	Contribution %
{A}peak current	109.731	2	54.8655	26.43	0.001	98.08
{B}pulse on time	3.064	2	1.5321	0.08	0.927	0.30
{C}pulse off time	1.607	2	0.8033	0.04	0.961	0.15
{D}servo voltage	7.783	2	3.8915	0.20	0.821	0.75
Residual	0					

- P= (significant) if <0.05 is significant

4.7 CONFIRMATION TEST

Table 4.12 shown the results of comfirmation test for Material Removal Rate (MRR). It shown that for the intial EDM parameter is peak current at level 2, pulse on time at level 2, pulse off time at level 3 and servo voltage at level 1. After did optimal parameter, the level was change with peak current at level 1, pulse on time at level 1, pulse off time at level 1 and servo voltage at level 1. The Improvement of S/N ratio is 6.6894dB and the Material Removal Rate (MRR) increase with 8.1227 mm^3/min

Table 4.10: Result of Confirmation Test for Material Removal Rate

	Initial EDM parameter	Optimal EDM parameter
Level	A2B2C3D1	A1B1C1D1
MRR	7.0019	15.1246
S/N ratio	16.9043	23.5937

- Improvement of S/N ratio = 6.6894dB
- The Material Removal Rate increase = 8.1227 mm^3/min

Table 4.12 shown the results of comfirmation test for Tool Wear Rate (TWR). It shown that for the intial EDM parameter is peak current at level 2, pulse on time at level 2, pulse off time at level 3 and servo voltage at level 1. After did optimal parameter, the level was change with peak current at level 3, pulse on time at level 3, pulse off time at level and servo voltage at level 1. The Improvement of S/N ratio is 23.9992dB and the Tool Wear Rate (TWR) decrease with 6.7278 mm³/min.

Table 4.11: Result of Confirmation Test for Tool Wear Rate

	Initial EDM parameter	Optimal EDM parameter
Level	A2B2C3D1	A3B3C2D1
TWR	7.0397	0.3119
S/N ratio	-13.8795	10.1197

- Improvement of S/N ratio = 23.9992
- The Tool Wear Rate decrease = 6.7278 mm^3/min

4.8 SUMMARY

Experiments were conducted according to Taguchi method by using the machining set up and the designed valve shaped electrodes with internal flushing. Finding the result of MRR peak current is most influencing factor and then servo voltage and the last is pulse duration time of the tool. In the case of Tool wear rate(TWR), peak current is most influencing factor and then servo voltage and the last is pulse duration time of the tool.

CHAPTER 5

CONCLUSION AND RECOMMENTATION

5.1 CONCLUSION

Chapter 1 has been discussed briefly about project background, problem statement, objective and scope of the project. This chapter is as a fundamental for the project and act as a guidelines for project research completion. Generally, this thesis consists of five chapters. Chapter 1 that has you read is the introduction about this study. Chapter 2 is the review of literature which discusses methods and findings previously done by other people which are related to the study. Chapter 3 is the Methodology which explains the approaches and methods used in performing the thesis. Chapter 4 is the chapter which reports the outcomes or results and discussion from the project and chapter 5 consists of the recommendation and conclusion.

The use of the orthogonal array with Taguchi method analysis to optimize the EDM process with the multiple characteristics of the material removal rate (MRR) and Tool wear rate (TWR) has been reported in this chapter. In this study, it is shown that the performance characteristics of the EDM process are improved by using the method proposed in this study.

The main conclusions that can be found from this research are fabrication and design of EDM tool for producing automotive valve application is achieved. The fabrication of tool was used the EDM die sinking. After run the experiment, the error of dimensional not happen at outer diameter and depth of hole but was happen at inner diameter, and diameter hole which the error is 5% and 8%.

The higher material removal rate (MRR) will result in better machining performance rate. In this experiment, the higher material removal rate (MRR) obtained is 15.1246 mm^3/min at experiment 1 and less Tool wear rate (TWR) is 0.3119 mm^3/min at experiment 9. Peak current are most significant factor that affect material removal rate (MRR) and tool wear ratio (TWR) since the parameter bring major effect to MRR,TWR and SR. Increasing the peak current, pulse-on time and servo voltage increase the rate of MRR while reduce TWR and SR.

5.2 RECOMMENDATION

There are some recommendations to be considered in improving the details of this project. Do comparison which method gives more accurate mathematical model between Taguchi method, Grey Relational Analysis (GRA) and response surface method (RSM) in term of MRR and TWR result. There were various software that can be used in designing experiment such as MINITAB, STATISTICA and so on rather than construct it manually. This will reduce time and increase the efficiency in doing the project. The data can be convert to multiple optimization paramater,so we will get more various of result that affecting the MRR and TWR parameter.

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APPENDIX A1

Figures of machine

Band Saw Machine

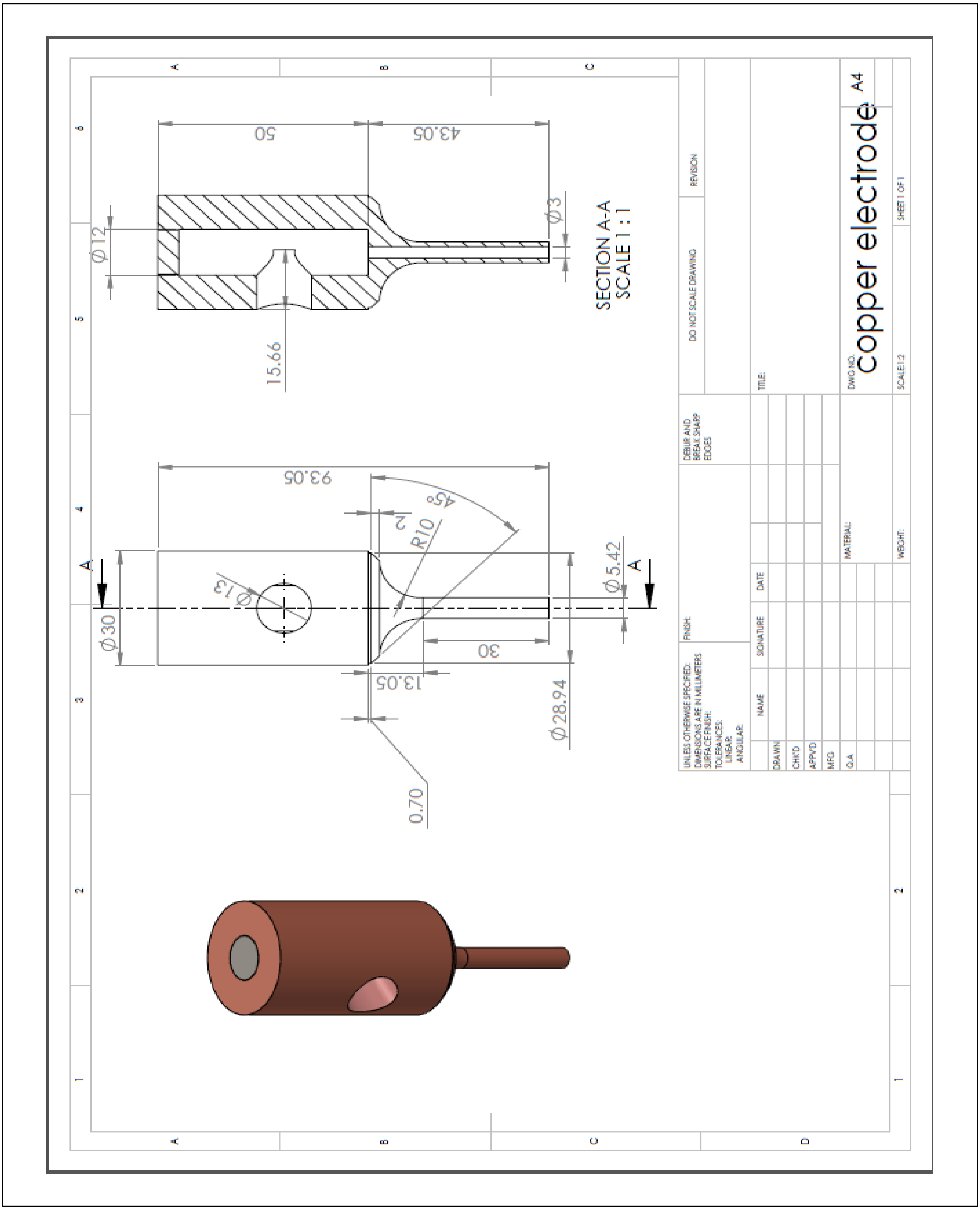
CNC Lathe Machine

CNC Milling Machine

EDM machine

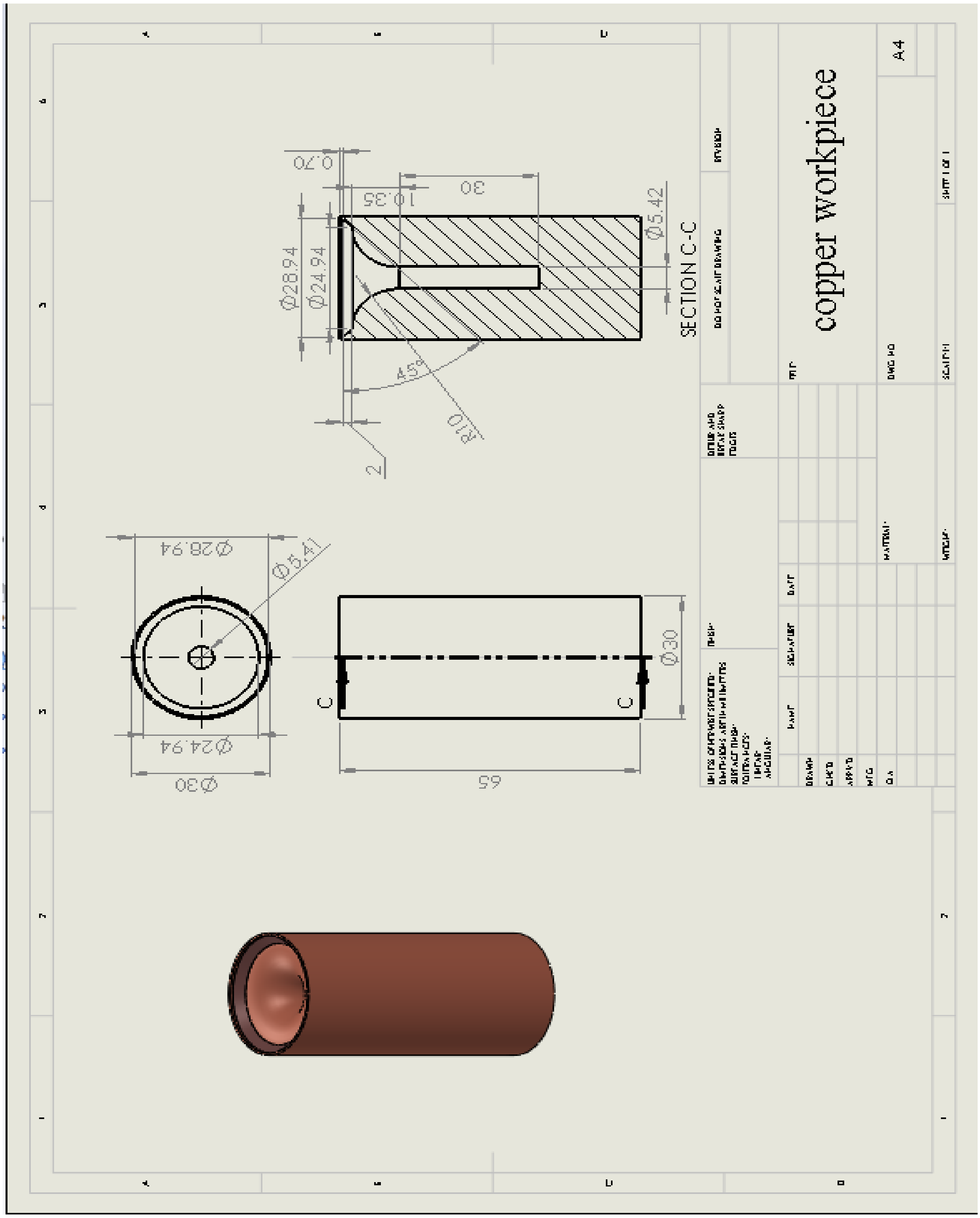
APPENDIX A2

Design Of Electrode



APPENDIX A3

Design Of Material



APPENDIX A4

GANTT CHART

No.	Weeks / Activities		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Briefing from supervisor	Plan															
		Actual															
2	Literature review	Plan															
		Actual															
3	Introduction	Plan															
		Actual															
4	Objective	Plan															
		Actual															
5	Problem statement	Plan															
		Actual															
6	Gantt Chart	Plan															
		Actual															
7	Scopes of project	Plan															
		Actual															
8	Sketch and Design concept	Plan															
		Actual															
9	3D design	Plan															
		Actual															
10	Fabrication	Plan															
		Actual															
11	Run the experiment	Plan															
		Actual															
12	Analysis the data	Plan															
		Actual															
13	Final report	Plan															
		Actual															
14	Presentation	Plan															
		Actual															