OPTIMIZATION OF MICRO EDM DRILLING PROCESS USING TAGUCHI METHOD

YAZID BIN YAHYA

UNIVERSITI MALAYSIA PAHANG

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YAZID BIN YAHYA

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SUPERVISOR DECLARATION

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

Signature:
Name of Supervisor: Mr. Fadzil Faisae Bin Abd. Rashid
Position: Lecturer
Date: 22 November 2009

STUDENT DECLARATION

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

Signature:
Name: Yazid Bin Yahya
ID Number: MG04021
Date: 22 November 2009

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ABSTRACT

This thesis deals with optimization of micro Electrical Discharge Machining (EDM) drilling process using Taguchi method. EDM is a thermal process that utilizes spark discharges to erode a conductive material. The objective of this thesis is to study the effect of independent variable to accuracy of micro EDM drilling process and to optimize it by using Taguchi method. Taguchi Method is used to find the optimal drilling parameters for hole diameter in drilling operation. The orthogonal array, the signal-to-noise ratio, and analysis of variance are employed to study the performance characteristics in drilling operations of mild steel (50mm length x 75mm width x 5mm height) as workpiece by using 1mm copper (Cu) pipe electrode. Three drilling parameters namely, pulse off time, peak current, and servo standard voltage, are optimized with considerations of hole diameter. It is found that Taguchi's robust orthogonal array design method is suitable to analyze the hole diameter problem. Also parameter design of Taguchi method provides a simple, systematic and efficient methodology for the optimization of drilling process. The result concluded that use of greater pulse off time, greater peak current and medium servo standard voltage give the better hole diameter for the specific test range. The results also significantly reduce the cost and time market and improve product reliability and customer confidence. There are several suggestions that could be implanted as to improve results and obtained more accurate finding. For example, the experiment should be run repeatedly in order to gain more accurately ANOVA table. In addition, further study could consider more factor such as pulse on time, material removal rate (MRR), coolants and etc in the research to see how the factors would affect hole diameter.

ABSTRAK

Tesis ini membentangkan pengoptimuman mesin mikro EDM dengan menggunakan kaedah Taguchi. EDM adalah proses terma yang menggunakan percikan api untuk mengikis bahan keras. Objektif tesis ini adalah untuk mengkaji pembolehubah bersandar terhadap kejituan proses penebukan mikro EDM dan untuk mengoptimumkannya dengan menggunakan kaedah Taguchi. Kaedah Taguchi telah diguna pakai untuk mencari parameter penebukan yang optimum bagi diameter lubang untuk proses penebukan. Susunan orthogonal, nisbah signal-to-noise, dan variasi analisis telah digunakan untuk mengkaji pencirian prestasi dalam operasi penebukan bagi kepingan besi (50mm panjang x 75mm lebar x 5mm tinggi) dengan menggunakan 1mm elektrod kuprum (Cu). Tiga parameter penebukan iaitu, pulse off time, puncak saat, dan servo voltan piawai telah dioptimumkan dengan mengambil kira diameter lubang. Didapati bahawa kaedah Taguchi susunan orthogonal sesuai untuk menganalisis permasalahan diameter lubang disampingkaedah ini juga mudah, sistematik dan metodologi yang effisien untuk mengoptimumkan proses penebukan. Kesimpulanya, dengan menggunakan pulse off time yang tinggi, puncak saat yang tinggi dan medium servo voltan piawai dapat memberikan diameter lubang yang lebih baik untuk specifik lingkunagn ujian. Keputusan juga berupaya menurunkan kos dan masa ke pasaran, memperbaiki kepercayaan produk dan keyakinan pelanggan. Terdapat beberapa cadangan yang dapat menberikan keputusan yang lebih baik dan jitu. Sebagai contoh, ekperimen hendaklah dijalankan berulang kali untuk mendapatkan kejituan ANOVA. Selain itu, kajian lanjutan yang mengambil kira factor lain seperti pulse on time, material removal rate (MRR), system penyejukan dan sebagainya untuk melihat sama ada factor-faktor ini member kesan terhadap diameter lubang dalam kajian ini,

TABLE OF CONTENTS

LIST OF TABLES

Table No. **Page**

LIST OF FIGURES

LIST OF SYMBOLS

μs	Micro second
μF	Micro farad
mm	Milimeter
A	Ampere
V	Volt
K	Kelvin
SS_T	Total sum of the squared deviations
SS_p	Sum of the squared deviation parameter
SS_e	Sum of the squared deviation error
S_p	Correction sum of squares
p	Parameter
j	Level number
$s\eta_j$	Sum of the signal to noise ratio
D_t	Degree of freedom
D_p	Degree of tested parameter
V_p	Variance of the parameter tested
V_e	Variance of the error
F_p	*F*-value
ρ	Percentage contribution
y	Observed data
$\bar{y}$	Average of observed data
S_y^2	Variance of y
n	Number of observation
Ø	Diameter
$\hat{\eta}$	Signal to noise ratio
η_m	Total mean of S/N
$\bar{\eta}_i$	Mean S/N ratio at the optimal level
q	Number of the process parameters

LIST OF ABBREVIATION

ANOVA	Analysis of variance
EDM	Electrical discharge machining
C	Carbon
Cu	Cuprum
CNC	Computer numerical control
DOE	Design of experiment
IP	Peak current
OFF	Pulse off time
S/N	Signal to noise ratio
SVR	Servo standard voltage
TiC	Titanium carbide
TaC	Tantalum carbide
WC	Tungsten carbide

LIST OF APPENDIXES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Electrical Discharge Machining, commonly known as EDM, is a process that is used to remove metal through the action of an electrical discharge of short duration and high current density between the tool or electrode and the workpiece. This principle of removing metal by an electric spark has been known for quite some time. In 1989, Paschen explained the phenomenon and advised a formula that could predict its arching ability in various materials (S.Bigot, 1999). The EDM process can be compared to a miniature version of a lightning bolt striking a surface, creating a localized intense heat, and melting away the work surface.

Electrical discharge machining has proved valuable and effective in machining of super tough, hard, high strength and temperature resistance of conductive material. These metals would have been difficult to machine by conventional methods.

In drilling hard, tough, high strength and temperature resistance material, people can not run traditional drilling. Electro discharge machining (EDM-Drill) is one of the best ways in drilling this kind of material especially

in term of getting micro-hole. Material is removed by means of rapid and repetitive spark discharge across gap between electrode and work piece.
The basic physical characteristics of the micro-EDM process is essentially similar to that of the conventional EDM process with the main difference being in the size of the tool used, the power supply of discharge energy, and the resolution of the X-, Y- and Z- axes movement.

Growing popularity of micro EDM depends on the its advantages including low set-up cost, high aspect ratio (depth/diameter ratio) of the holes, enhanced precision and large design freedom. In addition, EDM does not make direct contact between the tool electrode and workpiece material, hence aliminating mechanical stress, chatter and vibration problems during machining. Therefore, relying on the above advantages, micro-EDM is very effective to machine any kind of small holes such as small diameter holes down to 10 µm and blind holes with 20 aspect ratio.

Today, in mold making, EDM no longer can be neglected. In recent years, rapid development of defense industry, telecommunication, entertainment, etc which can't run from producing micro-component such as integrated circuit (IC) component, ink jet nozzle, hand phone chip do really need EDM. Reported by Nexus market analysis, over the next four years, the Microsystems market, including Micro-Structure Technologies (MST) and Micro-Electro-Mechanical Systems (MEMS), is predicted to grow at a rate of 16% per year from $12 billion in 2004 to $25 billion in 2009 across a spectrum of 26 MEMS/MST products (NEXUS, 2006). Conventional processes are increasingly being improved for use in micromachining. The most common processes are micro milling, laser machining and more specifically micro EDM, which is being applied in many micro applications.

This project will study the optimal parameter in SODICK EDM micro hole drill in term of machine accuracy on mild steel by using 1mm copper (Cu) pipe electrode. In EDM-drill, most problems faced are, hole accuracy which is crucial element in mould and die construction which play a big role in order to minimize production cost. Talking about optimal parameter, the parameters yet must be select first which consider as control factor which consist of pulse off time (OFF), peak current (IP) and servo standard voltage parameter (SVR).

Taguchi method is utilized in this study as Design of Experiment (DOE) to get optimal parameter. This method is chosen because it can perform analyze of more than one factor at a same time while reducing number of experiment which indirectly reduce cost and time in finding optimal parameter.

1.2 OBJECTIVE OF THE STUDY

The objective that must be carried out by this study in order to get the optimum parameter of EDM micro drill by utilization of Taguchi methods are:

1. To study the effect of independent variable to accuracy of micro EDM drilling process by using 1mm copper electrode.

2. To optimize micro EDM drilling process using Taguchi method.

1.3 SCOPE OF THE STUDY

In order to get the best result, this research must be scoped narrower where it consists of:

1 The parameters that to be study are Pulse Off Time (OFF), Peak Current (IP), and Servo Standard Voltage Parameter (SVR).
2 This project will study the optimal parameters in SODICK EDM micro hole drill in term of machine accuracy on mild steel (50mm length x 75mm width x 5mm height) as a workpiece by using 1mm copper (Cu) pipe electrode.
3 As the analysis tool to determine global solution for the optimal parameter, Taguchi method will be employed by using L_9 orthogonal array.

1.4 PROBLEM STATEMENT

As what world can not deny today, practical is not as perfect as theory which due to large number of variable and the uncertain nature of the process, even highly skilled operator is difficult in archive optimal performance of machining. Even tough likely most EDM machine today have process control, but selecting and maintaining optimal setting is still an extremely difficult job. Machining accuracy of the workpiece is one of the main problems to achieve since this characteristic determine hole accuracy. In order to achieve the objectives, optimum parameter of pulse off time, peak current, and servo standard voltage parameter have to determine where Taguchi method will be employed.

1.5 PROJECT FLOW CHART

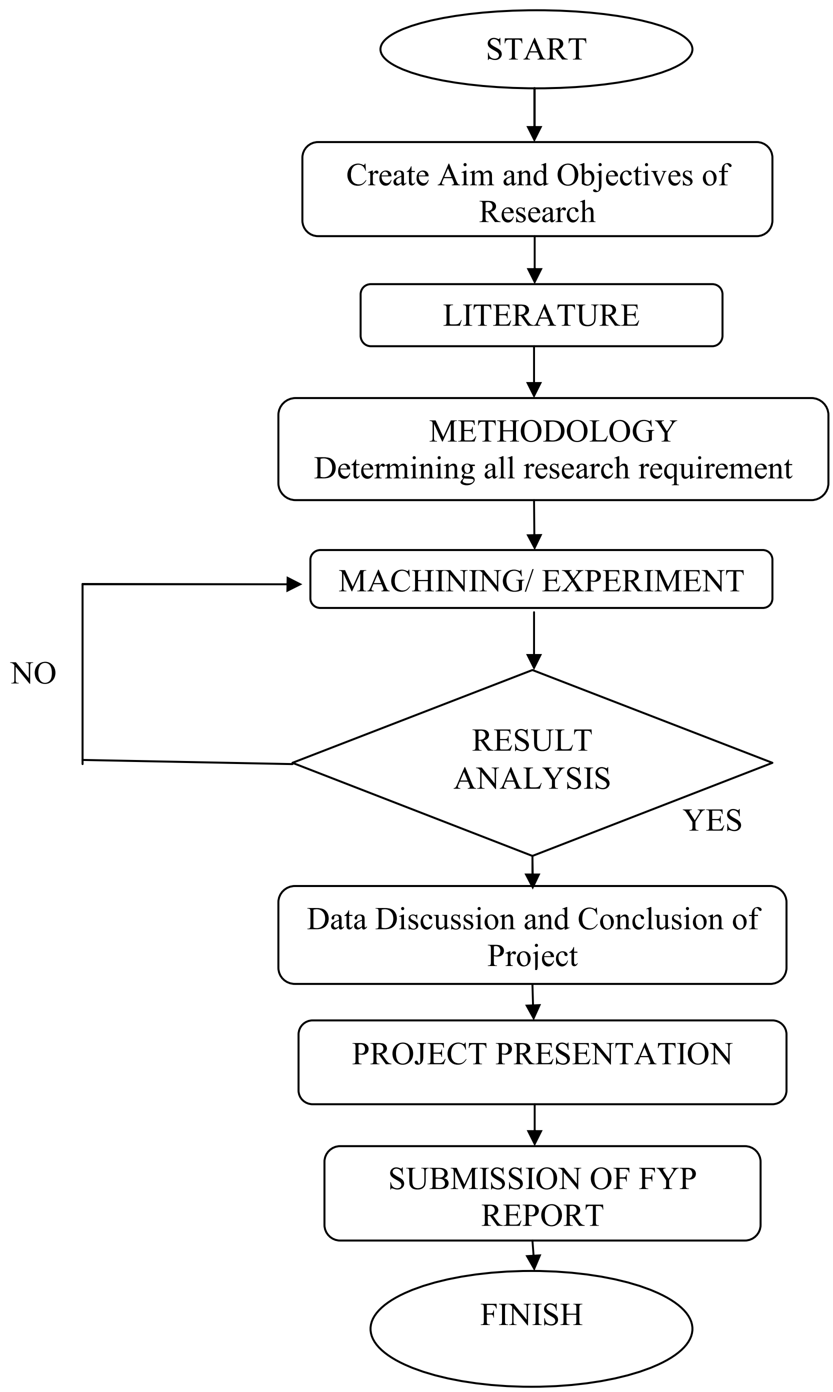


Figure 1.1: Project flow chart

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION TO EDM AND ITS DEMAND IN INDUSTRY

Electrical Discharge Machining (EDM) is a non-contact machining process for conductive materials that has been applied for more than 40 years (D.T Pham, 2004). It has been proved particularly useful such as in mold making, tool making industry micro-structures including micro-shaft, micro-holes, specially shaped micro-holes, and micro-slots. Due to its high accuracy and the good surface quality that it can be produced, EDM is potentially very suitable for micro-fabrication. The EDM process utilizes the thermo-electric energy released between a workpiece and a highly charged electrode. A pulsed electrical discharge across the small gap (known as the “spark” gap) between the workpiece and the electrode removes material from the workpiece through melting and evaporation. Clearly, due to the contactless nature of EDM, there are only very small process forces. This complied with the availability in recent years of advanced computer controlled spark generators such as Sodick® that help improve machined surface roughness, promises to make EDM the preferred method for producing micro features. In order to get clear view of how EDM work, their basic operation is illustrated in Figure 2.1.

Day to days, the markets demand of small and compact product such as microchip in computer, handphone, electrical part in car, accurate fuel injection nozzle, surgery equipment and other micro electro-machanical system has been increase significantly. That is why we need to study on how to make micro component such as micro hole more efficient, low production time as long as low manufacturing cost. This project is a study on how to get optimum parameter of EDM drill in order to drill small hole on rectangular solid mild steel by utilization of Taguchi method.

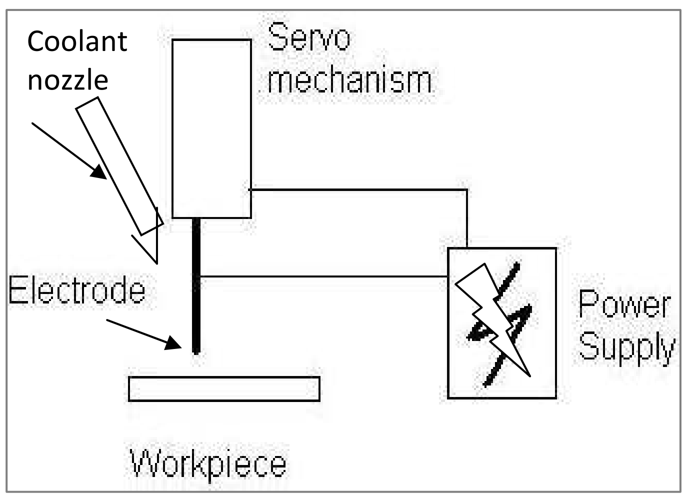


Figure 2.1: Schematic diagram of EDM-drill

2.2 PROBLEM FACED IN EDM DRILL

Traditionally, small or micro hole will be done by skilled machinist by using a sensitive drill but this technique is hard to operate and cause broken tool. Broken drill and scraped part may lead this process as expensive operation since micro drill tool is a costly product. However, as the process of drilling by EDM-drill is more relevant, somehow electrode price is expensive. That is why electrode wear must be set as minimum as possible. One thing we should know is that, even electrode price is high but it is still lower compare to other machining tool. One more problem in EDM-drilling is when wrong parameter is set, the electrode will tend to retract up and down position continuously, which cause the hole won't be drill though. Even tough getting optimum parameter in EDM is a hard process but, with proper DOE technique such as Taguchi, the process becomes easier.

2.3 INTRODUCTION TO EDM PARAMETER

Electrical discharge machining parameter can be categorizing into two major group; electrical and non-electrical parameters (S.H Lee, 1999). The electrical parameter consist of electrode polarity, peak current, pulse duration, and capacitance meanwhile, non-electrical parameter are servo parameters such as gap and gain. For the EDM machine itself can be spread into four main components which are a machine tool, power supply, servo computer and servo mechanism. However, the parameters that we going to study are pulse on time, peak current and capacitance.

2.3.1 Machining Voltage, V

One of the components of EDM-drill is power supply. This is one of important system where it transform the AC supply from main power to provides rectangular voltage pulse as illustrated in Figure 2.1 .The AC source is converted by rectifier to DC source. The voltage is usually in range of 40 to 400Volts. The sequence of the rectangle is a graphic representation of the opening and closing of the switch, or can be simplify as the pulse duration and pulse interval, or of the discharge time and pause, also of the voltage and current at the spark gap.

2.3.2 Peak Current, IP

Peak current is momentary maximum current to be placed to discharge gap or in easy word, peak current is best defined as the highest electrical current that can occur during the discharge. This is the amount of power used in discharge machining, measured in unit of ampere, A. The discharge current is proportional to the height of the rectangle as shown in Figure 2.2 below.

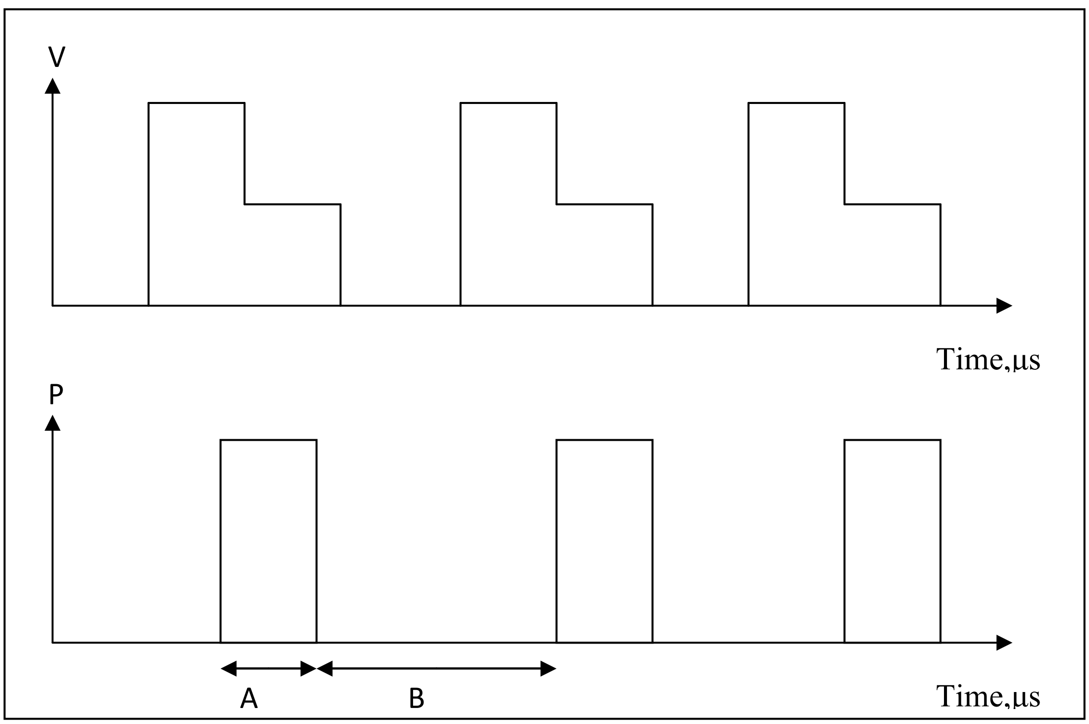


Figure2.2: EDM electrical parameter characteristic

V = Machining Voltage

P = Peak current

A = Pulse duration (spark)

B = Interval time (time that current is switch off)

2.3.3 Pulse-off Time, OFF

The time between two impulses is call pulse-off time. While most of the machining takes place during on time of the pulse, the off time during which the pulse rests and the re-ionization of the die-electric takes place, can affect the speed of the operation in a large way. This parameter also measured by µs. Longer the off time will cause longer machining time. But this is an integral part of the EDM process and must exist. The Off time also governs the stability of the process. An insufficient off time can lead to erratic cycling and retraction of the advancing servo and result slowing down the operation cycle.

2.3.4 Servo Standard Voltage, SVR

It is important that there be no physical contact between the electrode (tool) and the workpiece; otherwise arcing will occur, causing damage to both the electrode and the workpiece. That is why servo mechanism is very important. This system will automatically maintain constant gap of approximately 0.01 to 0.02 mm between the electrode and workpiece. The mechanism also advance the tool into the workpiece as the operation progress, and sense and correct any shorted condition by rapidly retracting and returning the tool. Precise control of gap is important to obtain successful machining operation. The mechanism of servo parameter is actually a set of parameter that determine the standard voltage to be used as the reference; When the gap voltage is greater than this value, the electrode advances; when less than this value or equal to zero volt because of short-circuit, the electrode retract to widen the gap.

2.4 SODICK® K1C HIGH SPEED SMALL HOLE DRILLING MACHINING CONDITION SETTING

All parameter that have more than two variable is assign as one to nine and A to F (hexadecimal) key. Table bellow show the value of each setting for example setting for peak current number one is equal to 2µs. Meanwhile for capacitance setting, there are six capacitor on-off switches which each capacitor consist of different capacitance value. For example, setting number seven mean we have to switch on capacitor one two and three where the total value is 0.07µF. For two level parameters which is servo speed, there is only on and off button.

Table 2.1: Machine setting condition

Parameter			
N0.	**ON (µs)**	**OFF (µs)**	**IP (A)**
1	2	2	2
2	4	4	4
3	6	6	6
4	8	8	13
5	10	10	15
6	12	12	17
7	14	14	19
8	16	16	33
9	18	18	35
A	20	20	37
B	22	22	39
C	24	24	47
D	26	26	49
E	28	28	51
F	30	30	53

2.5 ADVANTAGES AND LIMITATION OF EDM-DRILL

Every machining process has advantages and limitation. In EDM-drill the advantages are:

- Any material that is electrically conductive can be drill regardless of its hardness, thickness and brittleness. EDM-drill is well suit for drilling on super tough space-age alloy that are extremely difficult to undergo other traditional machining process.
- Work can be done on hardened steel, thereby overcome the deformation caused by the hardening process.
- No more broken tap or drill problem.
- It does not create stresses in the work material since electrode never comes in to any physical contact with the workpiece.
- Secondary finishing is generally eliminated.
- Process is automatic since the servo system advance the electrode into workpiece by constant gap.
- One person can operate several EDM machine at one time.

The limitations of EDM-drill are:

- Metal removal rates slower compare to laser drill
- The material to be drill must be electrically conductive
- Rapid electrode wear.
- A slight case hardening occurs. This however may be classed as an advantage in some instance.

2.6 ELECTRODE MATERIAL

Electrode is one of crucial tool in EDM. The workpiece will replace the shape of the electrode as it been discharge. Electrode material must be an electrical conductive and high melting point. The lower the melting point the easier the electrode wears. Common electrode materials are copper, tungsten, brass, copper graphite and steel. In EDM drill the available electrode are in the form of solid rod and hollow tube.

2.6.1 Brass Electrode

Brass materials are used to form EDM wire and small tubular electrodes. Brass does not wear as well as copper or tungsten, but brass is much easier to machine and can be die cast or extruded for specialized applications. EDM wire does not need to have the EDM wear or arc erosion resistance because new wire is continually fed during the EDM wiring cutting process.

2.6.2 Carbide Electrode

Carbides are compounds of a metal or metalloid (B, Si) and carbon. Metal carbides are also known as hard metals such as tungsten carbide (WC), titanium carbide (TiC) or tantalum carbide (TaC). Metal carbides have high hardness and high melting points. Metal carbides often used cobalt, nickel or intermetallic metal bond between grains (cemented carbides) which results in increases toughness compared a pure carbide or ceramic. Carbide can give fine finishing but its cost is very expensive.

2.6.3 Graphite Electrode

Graphite is the most common EDM electrode because of its good machinability, EDM wear resistance and low cost. Graphite is a form of carbon (C) with an anisotropic hexagonal crystal structure. Graphite or carbon is a non-metallic element with an extremely high sublimation temperature, which provides resistance to high temperature arcs. Fine grain sized graphite tend to have better erosion and wear performance, but higher cost.

2.6.4 Copper electrode

Copper has better EDM wear resistance compared to brass, but the material is more difficult to machine than brass or graphite. The melting point for copper is a 1420K. Copper is also more expensive than graphite. Copper is useful in EDM machining of tungsten carbide or in applications requiring a fine finish. Copper also suitable for machining high hardness workpiece such as pre-hardened steel. In this study, 2mm copper electrode will be use for drill the micro hole. This is because of the ability of copper electrode to provide fine finishing and low electrode wear.

2.7 COMPARISON OF EDM-DRILL, ELECTRON BEAM AND LASER DRILL

Below are the advantages and disadvantages of other machining process. From the comparison here we can see the difference of each process.

2.7.1 Laser Drilling

This is advance technique where hole is cut by mean of laser beam on the workpiece and melt away the workpiece. The workpiece may be conductive or nonconductive material. Laser drilling is a versatile process in drilling micro holes.

2.7.2 Electron Beam Drilling

Electron Beam drilling, EB-drill is a drilling process by mean of concentrates energy on a workpiece to trigger highly localized melting. In this process, an electron beam is focused onto the part through an electromagnetic lens the power densities reach 100 million watts or greater per square centimeter. The pulse duration and beam current level is regulates by CNC.

2.7.3 Considering the Three

Laser drilling is the most versatile of the three which it able to make holes in materials ranging from pliant plastics to the hardest metals or even diamonds. However this process is very expensive and need high maintenance and the hole produced will have tapped. Although both EB-drills and EDM drilling can only handle conductive materials, EB drilling excels at producing many holes quickly while EDM drilling offers the highest precision (Leo Rakowski, 2002). Since pre-hardened steel characteristic is perfect for mold and die production and these things need an accurate machining. EDM-drill is the best to fulfill the requirement of machining fine surface of micro hole with low tooling cost.

Table2.2: Comparison of EDM-drill, electron beam drill and laser drill

EDM-drill	Electron Beam Drill	Laser Drill
• Highest accuracy • Low cost	• Quick Process (mass production) • Low accuracy	• Versatile process • High cost • High maintenance

2.8 TAGUCHI METHOD

Dr. Genichi Taguchi's methods are a product of the Japanese post-World war II era. This method is a type of statistical technique called Design of Experiments (DOE) that makes it possible to analyze the effect of more than one factor at the same time while reducing the number of experiment. Thus, using the Taguchi approach, design of experiments and analysis of results can be done with less effort and expenses. However, since the method considerably reduces the number of experiments, quality loss of results could appear. In order to present an overview of the evolution of Taguchi method technique, the fundamental philosophy must be considered which (Glen Stuart, 1999) is:

- The emphasis of the methodology is on functional variation, which can be measured in term of product performance such strength, pressure, shrinkage, response time, taste and mean time between failure.
- Viewed as the enemy of the producer and its customer, functional variation can related to the performance of the end product or to the process that manufacture the end result
- The purpose of experimentation using Taguchi is to identify those key factors that have the greatest contribution to variation and to ascertain those setting values that result in the least variability.

Bigot et.al (2004) applied the Taguchi method in order to get optimum EDM supper drill parameter. The orthogonal array of L18 is applied and the correspondent results are MRR, Ra and Electrode wear. In this study, a method for machining parameters optimization in micro EDM was proposed. Two sets of optimum parameters for roughing and finishing in micro EDM were successfully defined for a specific electrode/workpiece combination.

Antony write in journal of manufacturing engineering December 1997 released state that systematic experiment in improving the quality of industrial process can yield better understanding of the process and all-round improvement. The application of Taguchi method in term of improving the manufacturing quality is extremely relevant.

Nalbant et.al (2005), study on optimization of cutting parameter for surface roughness in turning process by Taguchi method. The orthogonal array, the signal to noise ratio and analysis of variance are employed in this study in order to study the performance characteristic in turning operation of AISI1030 steel bars using TiN coated tools. He concludes that, Taguchi's robust orthogonal array design method is suitable to analyze the surface roughness (metal cutting) problem. He found that the parameter design of the Taguchi method provides simple, systematic, and efficient methodology for optimization of the cutting parameter. The improvement on surface roughness that he study was 335% compare to initial parameter which is without optimal value.

Nutek Inc. in their web site state that Dr. Genechi Taguchi carried out significant research with DOE techniques in the late 1940's. He spent considerable effort to make this experimental technique more user-friendly (easy to apply) and applied it to improve the quality of manufactured products. Dr. Taguchi's standardized version of DOE, popularly known as the Taguchi method or Taguchi approach, was introduced in the USA in the early 1980's. Today it is one of the most effective quality building tools used by engineers in all types of manufacturing activities. The DOE using Taguchi approach can economically satisfy the needs of problem solving and product/process design optimization projects. By learning and applying this technique, engineers, scientists, and researchers can significantly reduce the time required for experimental investigations.

2.8.1 Orthogonal Array

The foundation for designing an experiment using Taguchi methodology is the orthogonal arrays. Although more classical types of designs, such as the full factorial and any of the wide variety of fractional, could be employed, the orthogonal array has traditionally been associated with Taguchi experimentation techniques. The orthogonal array is so efficient in obtaining only relatively small amount of data and being able to translate it into meaningful and verifiable conclusions (Glen Stuart, 1999). Furthermore, the designs of experiments utilizing orthogonal arrays are basically simple to understand and the guidelines are easy to follow.

The origin of the development of the orthogonal array is attributed to Sir R. A. Fisher of England. His early efforts in applying orthogonal arrays were to control error in an experiment (D.C Montgomery, 1997). Dr Taguchi has since adapted the orthogonal array to measure not only the effect of a factor under study on the average result, but also to determine the variation from the average result.

Orthogonal means being balanced and not mixed. In the context of experimental matrices, orthogonal means statistically independent. If we examine a typical orthogonal array (Table 2.3) we will note that each level has an equal number of occurrences within each column. For each column of the array in Table 2.3, level 1 occurs three times, level 2 occurs three times and level 3 occurs three times as well. Although different orthogonal arrays may have more than three levels within each column and each array has a different number of columns, the same rule applies. Within each column, we will find an equal number of occurrences for each level.

Table 2.3: L_9 orthogonal array

L_9			
No	**1**	**2**	**3**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Taguchi methods are statistical methods to improve the quality of manufactured goods and, more recently, to biotechnology, marketing and advertising. Taguchi has developed a methodology for the application of designed experiment, including a practitioner's handbook (G.Taguchi, 1988). This methodology has taken the design of experiment from the exclusive world of the statistician and brought it more fully into the world of manufacturing. His contributions have also made the practitioner work simpler by advocating the use of fewer experimental designs, and providing a clearer understanding of the variation nature and the economic consequences of quality engineering in the world of manufacturing (Glen Stuart, 1999). Taguchi introduces his approach, using experimental design for (P.J.Ross, 1988):

- Designing products/processes so as to be robust to environmental condition
- Designing and developing products/process so as to be robust to component variation.
- Minimizing variation around a target value.

Taguchi proposed that engineering optimization of a process or product should be carried out in three-step approach:

1 System design
2 Parameter design
3 Tolerances design

2.8.2 System Design

The conceptual stage of any new product development or process innovation is system design. This is the "idea" stage where something revolutionary or perhaps an offshoot of previous developments is conceived and tested. The concepts may be based on their on past experience, experience, scientific/engineering knowledge, a new revelation, or any combination of three. The strategy behind system design is to take these new ideas and convert them into something that can work (Glen Stuart, 1999).

For example, we can look at the Wright Brother's airplane flown at Kitty Hawk. Their accomplishments were achieved based on their prior experience and technical know-how with engines and bicycles. Although their invention flew under a certain set of wind conditions, this did not mean that the plane could operate in diverse weather. Neither did this prove that all aircraft that they could construct with the same design would perform successfully. This only meant that the airplane could operate satisfactorily under the right conditions. In the manufacturing or design environment, this typically relates to nominal conditions or the center of specifications. Making products and process that can operate consistently well is the subject of the next design stage.

In system design there two design stage, this design including the product design stage and the process design stage (M.Nalban, 2006). In product design stage, the selection of materials, components, tentative product parameter values, etc., are involved. For process design stage, the analysis of processing sequences, the selections of production equipment, tentative process parameter values, etc., are involved.

2.8.3 Parameter Design

The objective of parameter design is to take the innovation which has been proven to work in System Design and enhance it so that it will consistently function as intended. Usually by using classical parameter design there are a large number of experiment have to be carried out when the number of the process parameter increases. To solve this task, Taguchi come out with a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. Taguchi recommends the use of the loss function to measure the performance characteristics deviating from the desired value (Glen Stuart, 1999). The value of the loss function is further transformed into a signal-to-noise ratio η. There are three categories of the performance characteristics in the analysis of the S/N ratio, that is

1 The smaller- the- better
2 The nominal-the-better
3 The larger-the-better

The S/N ratio for each level of process parameters is computed based on the S/N analysis (Yuin Wu, Alan Wu, 2000). Regardless of the category of the performance characteristic, the larger S/N ration corresponds to the better performance characteristics. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio η.

Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With the S/N and ANOVA analyses, the optimal combination of the process parameters can be predicted (Glen Stuart, 1999).

2.8.3.1 The Smaller-the-Better

The smaller-the-better characteristics is one in which the desired goal is to reduce the measured characteristics to zero. This applies, for instance to the porosity, vibration, fuel consumption of an automobile, tool wear, surface roughness, response time to customer complaints, noise generated from machine or engines, percent shrinkage, percent impurity in chemicals, and product deterioration.

2.8.3.2 The Larger-the-Better

The opposite of the lower-the-better is the larger-the-better characteristics. This is one in which the ideal value is infinity. This type characteristics applies to tensile strength, pull strength, car mileage per gallon of fuel, reliability of a device, efficiency of engines, life of components, corrosion resistance and others.

2.8.3.3 The Nominal-the-Better

The nominal-the-better characteristics is one where a target value is specified and the goal is minimal variability around the target. This type of characteristics is generally considered when measuring dimensions such as diameter, length, thickness, width etc. Other examples include pressure, area, volume, current, voltage, resistance, and viscosity.

2.9 PARAMETER DESIGN AND DATA ANALYSIS

The type of parameter and analysis to be performed on the experiment data will be dictated by the design of experiment. By making proper decision of parameter design, optimize setting parameter can be obtain in order to improve process performance characteristic. Data analysis which is S/N analysis and Analysis of variance (ANOVA) is applied to measure performance characteristics given by the desired experiment value. In ANOVA, the principal of this method is to compare for each output function. Finally confirmation test if compulsory to verify the optimal parameter obtained. This is the reason why Taguchi method is utilized since it having the capabilities of designing experiment method and use statistical method to analysis and for the main reason, Taguchi method can design an experiment into more organized in short time, small number of experiment but give precise and accurate result.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Oxford dictionary define methodology as procedure or way of doing something. In spite of that, four main categories are made in this study method which is design of experiment (DOE), variable selection, instrumentation and experiment procedure.

For DOE, Taguchi approach was applied as the main tool for both design of experiment and then the data analysis, ANOVA method will be apply. Next is calculating the estimation result at optimum condition. The confirmation test will be taken after getting the optimum parameter result from this analysis in order to verify the value. The variables of machining parameter are pulse on time, peak current and capacitance. Instrumentation categories is create to simplify the major machining instrument method and measuring instrument such as Vernier caliper and profile projector. Then pilot testing such as handling EDM-drill and horizontal band saw is done in order to confirm the facilities is in good condition and to get best result when doing actual experiment. For better overview, Figure 3.1 illustrate the methodology involve in this study.

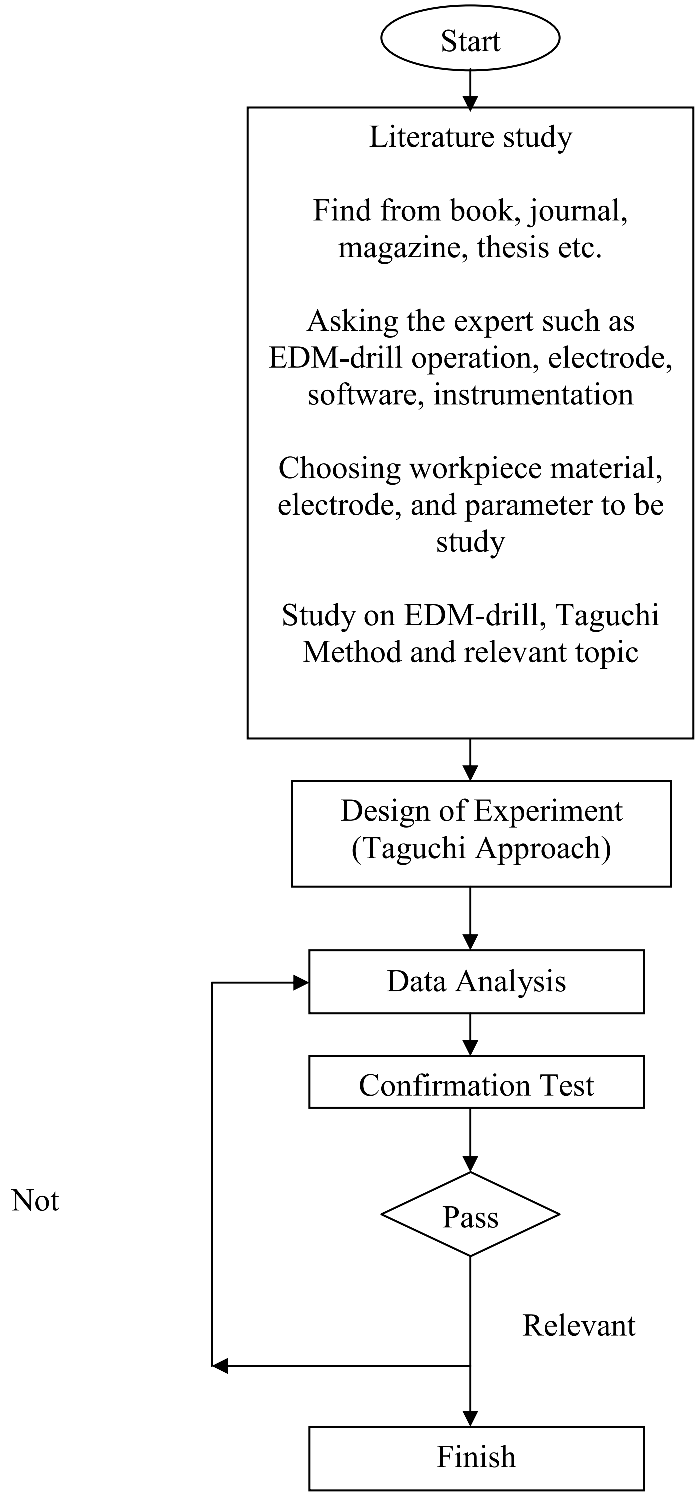


Figure 3.1: Procedure flow diagram

3.2 DESIGN OF EXPERIMENT

In order to obtain optimum parameter, Taguchi method was applied for overall research design and data analysis. This covers three element which is; Taguchi DOE, Taguchi data analysis which consist of ANOVA and lastly is confirmation test.

3.2.1 Mechanism of Taguchi

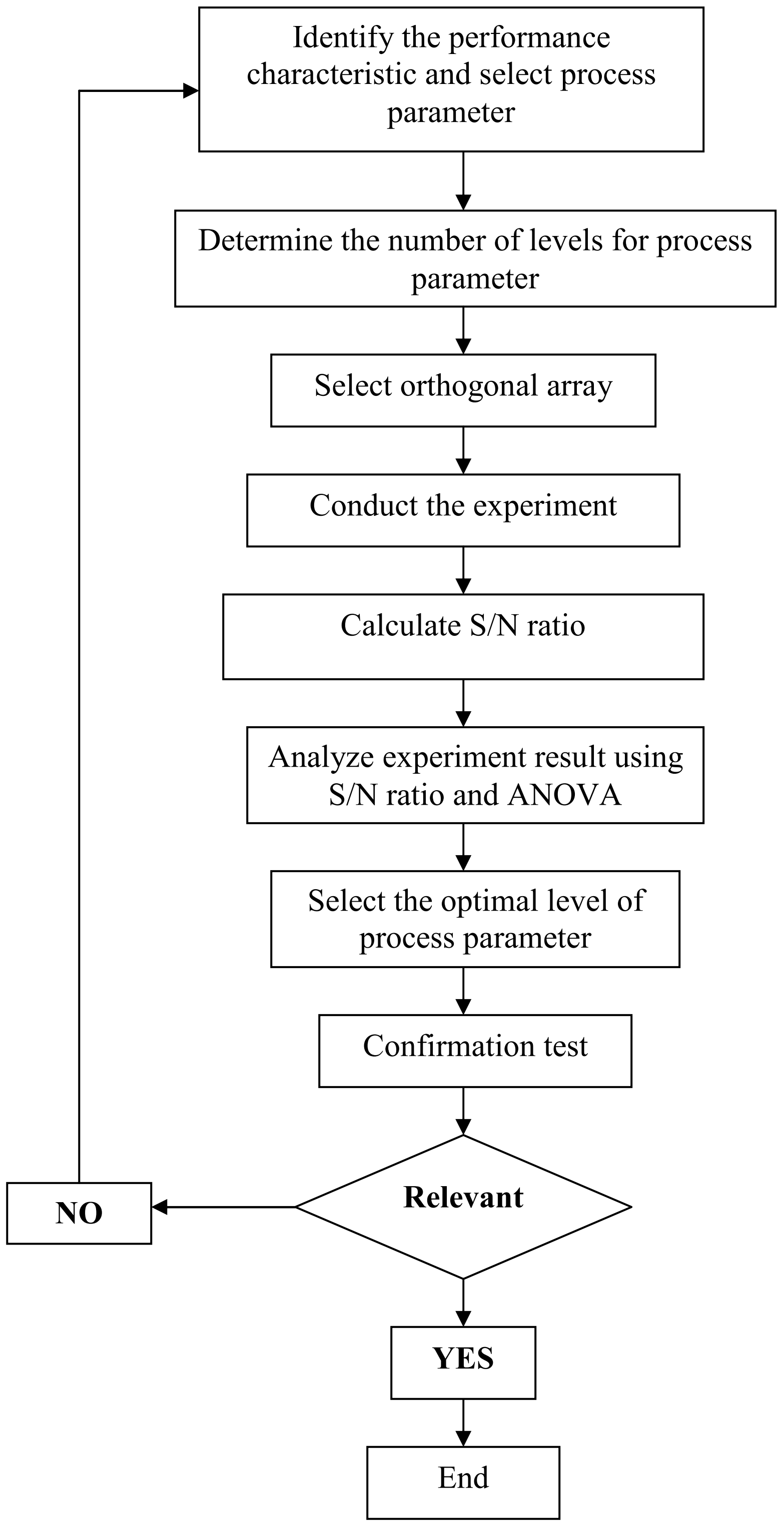


Figure 3.2: Mechanism of Taguchi

3.2.2 Taguchi Design of Experiment

In Taguchi DOE, first step is determining the controllable factor and level to be investigated follow by determination of number of repetition and orthogonal array. Meanwhile, analysis of result is to determine the best possible factor that been studied. Lastly, confirmation test as the proof of the result found.

3.2.3 Orthogonal Array

To select an appropriate orthogonal array for experiments, the total degrees of freedom need to be computed. The degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is. For example, a three-level process parameter counts for two degrees of freedom. The degrees of freedom associated with interaction between two process parameters are given by product of the degrees of freedom for the two process parameters. In the present study, the interaction between the drilling parameters is neglected. Therefore, there are six degrees of freedom owing to the three drilling parameters in drilling operations.

Once the degrees of freedom required are known, the next step is to select an appropriate orthogonal array to fit the specific task. Basically, the degree of freedom for the orthogonal array should be greater than or at least equal to those for the process parameter. In this study, a L_9 orthogonal array was used. This array has twenty six degrees of freedom and it can handle three-level process parameters. Each drilling parameter is assigned to a column and twenty seven drilling parameter combinations are available. Therefore, only twenty seven experiments are required to study the entire parameter space using the L_9 orthogonal array. The experiment layout for the three drilling parameters using the L_9 orthogonal array is shown in Table 3.1.

Table 3.1: Experimental layout using L 9 orthogonal arrays

No. of Exp.	**Drill parameter level**			**Hole diameter ø (mm)**			
	Pulse Off Time	Peak Current	Standard Voltage	Exp. 1	Exp. 2	Exp. 3	Average
1	1	1	1				
2	1	2	2				
3	1	3	3				
4	2	1	2				
5	2	2	3				
6	2	3	1				
7	3	1	3				
8	3	2	1				
9	3	3	2				

Table 3.2: Drilling parameter and their levels

Symbol	Drilling Parameter	Level 1	Level 2	Level 3
A	Pulse of time	8	12	16
B	Peak current	35	37	39
C	Standard voltage	12	14	16

Table 3.3: Machine setting condition

Parameter		
N0.	**OFF (µs)**	**IP (A)**
1	2	2
2	4	4
3	6	6
4	8	13
5	10	15
6	12	17
7	14	19
8	16	33
9	18	35
A	20	37
B	22	39
C	24	47
D	26	49
E	28	51
F	30	53

3.2.4 Research Procedure

Overall research procedure will be explained in this chapter. First step is preparation of workpiece and electrode material. The workpiece is mild steel 50mm x 75mm x 5mm for each experiment to enable it to be clamp by vise. The material was cut into a small size by using the horizontal band saw machine (Figure 3.3). In this process, the cutting speed and feed rate must be set depends on the material. The electrode material that will be used in this project is copper pipe electrode with diameter of 1mm.

Figure 3.3: Horizontal band saw machine

Next is pilot testing of instrument that needs to be use such as EDM-drill machine and profile projector. The profile projector (Figure 3.4) is used to get the diameter of the hole. Until then the actual experiment can be done by repetition. After each drilling process, machine parameter should be record and the data is measured in term of machine characteristic. Next step is Analysis of Variance (ANOVA) and calculate for optimum parameter result. As the optimum parameter obtained, confirmation test is compulsory to verify the result. The project is ended by record the final result.

Figure 3.4: Profile projector

3.3 TAGUCHI DATA ANALYSIS

In Taguchi data analysis, it is dividing into two main elements which are ANOVA and signal to noise ratio result at optimum condition. Each element will be explained under below subchapter.

3.3.1 Analysis Of Variance (ANOVA)

The objective of ANOVA is to investigate which of the process parameters significantly affect the performance characteristics. This is accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean of the S/N ratio, into contribution by each of the process parameters and the error. First, the total sum of the squared deviations SS_T from the total mean of the S/N ratio η can be calculated as:

$$SS_T = \sum_{i=1}^{m}(\eta_i - \overline{\eta})^2 = \sum_{i=1}^{m}\eta_i^2 - \sum_{i=1}^{m}2\eta_i\overline{\eta} + \sum_{i=1}^{m}\overline{\eta}^2$$

$$= \sum_{i=1}^{m}\eta_i^2 - 2m\overline{\eta}^2 + m\overline{\eta}^2 = \sum_{i=1}^{m}\overline{\eta}^2 - m\overline{\eta}^2$$

$$= \sum_{i=1}^{m}\eta_i^2 - \frac{1}{m}\left[\sum_{i=1}^{m}\eta_i\right]^2 \qquad \text{(Equation 3.1)}$$

Where m is the number of experiment in the orthogonal array, e.g., m = 9 and η is the mean S/N ratio for the i th experiment. The total sum of the squared deviations SS_T is decomposed into two sources: the sum of the squared deviations SS_p due to each process parameter and the sum of the squared error SS_e. SS_p can be calculated as:

$$SS_p = \sum_{j=1}^{t}\frac{(s\eta)^2}{t} - \frac{1}{m}\left[\sum_{i=1}^{m}\eta_i\right]^2 \qquad \text{(Equation 3.2)}$$

Where p represent one of the experiment parameters j the level number of this parameter p , t the repetition of each level of the parameter p , sη_j the sum of the S/N ratio involving this parameter p and level j .The sum of squares from error parameters SS_e is:

$$SS_e = SS_T - SS_A - SS_B - SS_C \qquad \text{(Equation 3.3)}$$

The total degree of freedom is $D_t = m - 1$, where the degrees of freedom of the tested parameter $D_p = t - 1$.The variance of the parameter tested is $V_p = \frac{SSp}{Dp}$. Then, the F-value for each design parameter is simply the ratio of the mean of squares deviation to the mean of the squared error ($F_p = V_p/V_e$). The corrected sum of squares S_p can be calculated as:

$$\hat{S}_p = SS_p - D_p V_e \quad \text{(Equation 3.4)}$$

The percentage contribution ρ can be calculated as:

$$\rho = \frac{\hat{S}_p}{SS_T} \quad \text{(Equation 3.5)}$$

Statistically, there is a tool called the F -test named after Fisher to see which process parameters have a significant effect on the performance characteristic. In performing the F - test, the mean of the squared SS_m due to each process parameter needs to be calculated. The mean of the squared deviations SS_m is equal to the sum of the squared deviations SS_d divided by the number of degrees of freedom associated with the process parameter. Then, the F - value for each process parameter is simply a ratio of the mean of the squared deviations SS_m to the mean of the squared error SS_e. Usually the larger F -value, the greater the effect on the performance characteristics due to the change of the process parameter.

3.3.2 Signal to Noise (S/N) Ratio.

As mentioned earlier, there are three categories of performance characteristic, i.e., the smaller-the-better, the higher-the-better, and the nominal-the-better. The S/N ratio for each level of process parameter is computed based on S/N analysis. The equation is as bellow:

Nominal-the-best: $S/N = 10\log \frac{(\overline{y})}{S^2{}_y}$ (Equation 3.6)

Higher-the-better: $S/N = -10\log (\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_1^2})$ (Equation 3.7)

Smaller-the-better: $S/N = -10\log (\frac{1}{n}\sum_{i=1}^{n} y_i^2)$ (Equation 3.8)

Where $\overline{y}$, is the average of observed data, S_y^2 is the variance of y, n is the number of observations and y is the observed data.

Notice that these S/N ratios are expressed on a decibel scale. We would use nominal-the-better if the subject is to reduce variability around a specific target, higher-the-better if the system is optimized when the response is as large as possible and smaller-the-better if the system is optimized when the response is as small as possible. Factor levels that maximize the appropriate S/N ratio are optimal. The goal of this research was to produce minimum diameter, Ø in a drilling operation. Smaller *Ø* values represent better or improved accuracy. Therefore, a smaller-the-better quality characteristic was implemented and introduced in this study.

3.4 CONFIRMATION TEST

Once the optimal level of the process parameters is selected, the final step is to predict and verify the improvement of the performance characteristic using the optimal level of the process parameters. The estimated S/N ratio $\hat{\eta}$ using the optimal level of the process parameters can be calculated as

$$\hat{\eta} = \eta_m + \sum_{i=1}^{q} (\overline{\eta}_i - \eta_m) \qquad \text{(Equation 3.9)}$$

Where η_m the total mean of the S/N ratio is, $\overline{\eta}_i$ is the mean S/N ratio at the optimal level, and q is the number of the process parameters that significantly affect the performance characteristic. The estimated S/N ratio using the optimal drilling parameters for hole accuracy can then be obtained and the corresponding hole accuracy can also be calculated by using (Equation 3.1).

As stated before, confirmation test is done to verify the optimum result obtained. Confirmation test is compulsory in Taguchi method as it is a proof of the research. In Taguchi, error margin for conformation test should be less than 10%.

Error Margin (%) = [(Confirmation test result – Prediction result)/ Prediction result] x 100

Table 3.4: Table of confirmation test

	Optimal Machining Parameter		**Error Margin (%)**
	Prediction (Calculation)	**Experiment (Confirmation Test)**	
Setting Level	OFF, IP, SVR	OFF, IP, SVR	

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

Experiment has been done by using orthogonal array as experimental design and the hole diameter measured by profile projector as state earlier. The parameter of the experiment has been state on Table 3.1.

This chapter covers on experimental result and data analysis. First, we will go through experimental result, follow by analysis of result using signal-to-noise ratio and then ANOVA. After that, we go to confirmation test in order to prove that our estimation value is correct.

4.2 EXPERIMENTAL RESULT

Table 4.1 shows the experimental results for hole diameter and the corresponding S/N ratio using (Equation 3.8). By understanding Table 4.1 it's proved that by using orthogonal array as a design of experiment we can save time and cost.

Table 4.1: Experimental results for hole diameter and S/N ratio

No. of Exp.	**Drill parameter level**			**Measured hole diameter ø (mm)**	**Calculate S/N ratio for hole diameter**
	Pulse Off Time	Peak Current	Standard Voltage		
1	1	1	1	1.117	-0.9611
2	1	2	2	1.104	-0.8594
3	1	3	3	1.092	-0.7645
4	2	1	2	1.077	-0.6443
5	2	2	3	1.102	-0.8436
6	2	3	1	1.113	-0.9300
7	3	1	3	1.107	-0.8830
8	3	2	1	1.113	-0.9300
9	3	3	2	1.072	-0.6039

4.3 DATA ANALYSIS

As stated in chapter 3, in order to get optimal drilling parameter performance, analysis by signal-to-noise ratio and then ANOVA need to be done and discussed in this chapter.

4.3.1 Analysis of the Signal-to-Noise (S/N) Ratio

Since the experimental design is orthogonal, it is then possible to separate out the effect of each drilling parameter at different levels. For example, the mean S/N ratio for the pulse off time at level 1, 2 and 3 can be calculated by averaging the S/N ratios for the experiments 1-3, 4-6, and 7-9, respectively. The mean S/N ratio for each level of the other drilling parameters can be computed in the similar manner. The mean S/N ratio for each level of the drilling parameters is summarized and called the mean S/N response table for hole diameter (Table 4.1). In addition, the total mean S/N ratio for the nine experiments is also calculated and listed in Table 4.2.Figure 4.1 shows the mean S/N ratio graph for hole diameter. The S/N ratio corresponds to the smaller variance of the output characteristics around the desired value.

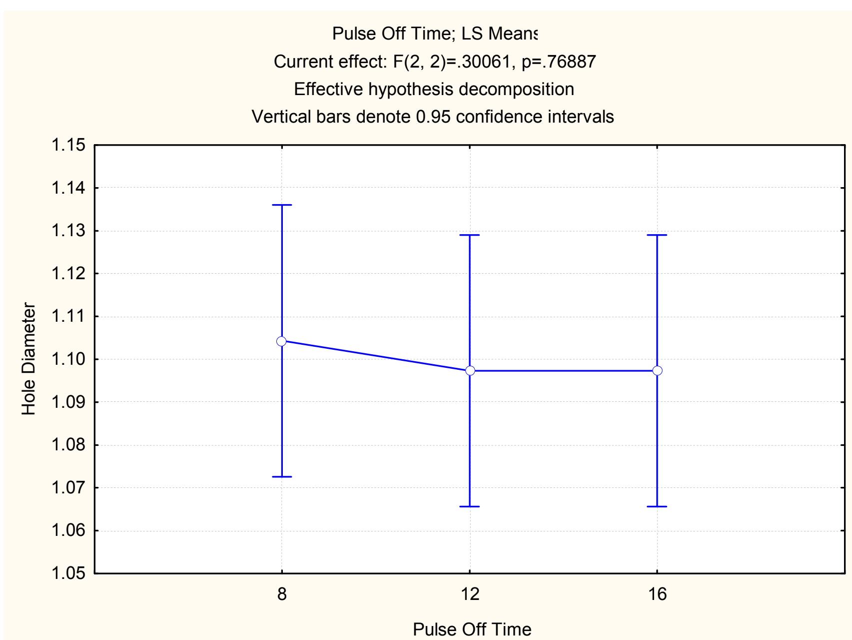
From the table 4.2 below the mean S/N ratio for pulse off time at level 3, peak current at level 3, and standard voltage at level 2 has a greater increase in S/N. Translated, this means that our goal in conducting parameter design type experiments involving a smaller-the-better characteristic should be to identify those factor setting that will produce optimal drilling parameter for hole diameter.

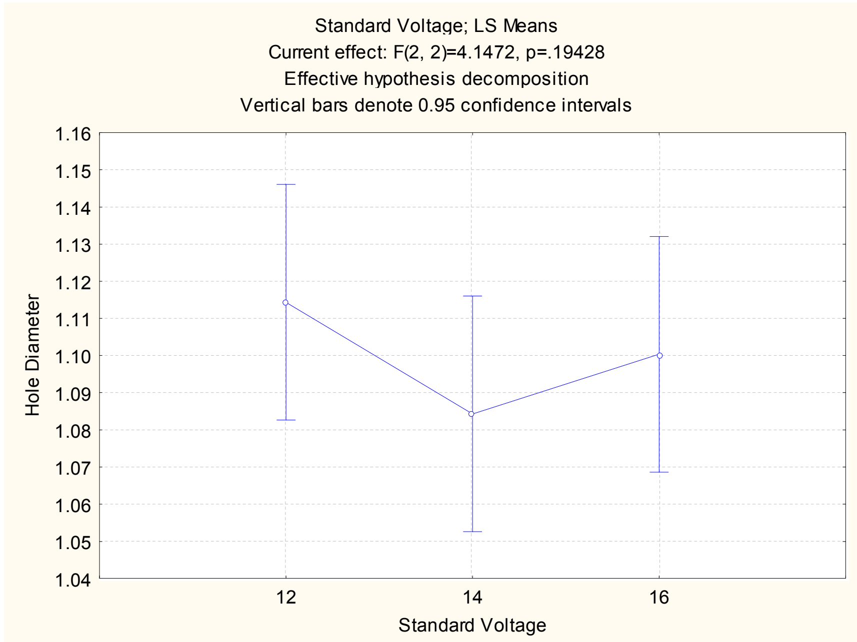
Table 4.2: Response table mean S/N ratio for hole diameter factor and significant interaction

Symbol	Drilling parameter	Mean S/N ratio			
		Level 1	Level 2	Level 3	Max - Min
1	Pulse off time	-0.8617	-0.8060	-0.8056	0.0561
2	Peak current	-0.8295	-0.8777	-0.7661	0.0634
3	Standard voltage	-0.9404	-0.7025	-0.8304	0.11

Total mean S/N ratio = - 0.8267

Figure 4.1 shows the mean S/N ratio graph for hole diameter. The S/N ratio corresponds to the smaller variance of output characteristics around the desired value.





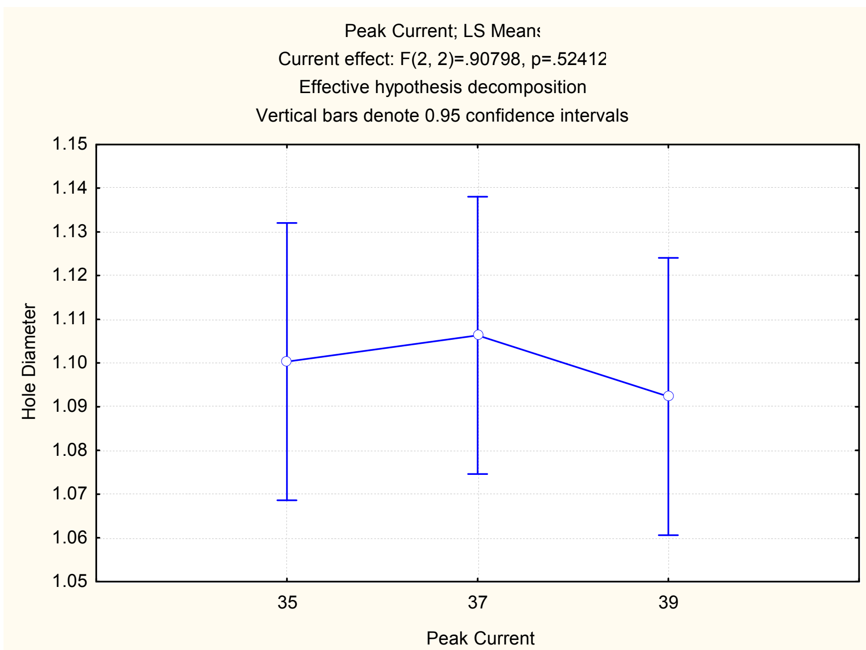


Figure 4.1: The mean signal-to-noise graph for hole diameter

4.3.2 Analysis of Variance (ANOVA)

Table 4.3 shows the result of ANOVA for hole diameter by using the statistica software or manual calculation. From this table the peak current and standard voltage has a highest percent contribution. It means this parameter is the significant drilling parameters for affecting the hole diameter. The change of the pulse off time in the range given by Table 4.3 has an insignificant effect on hole diameter.

Therefore, based on the S/N ratio and ANOVA analyses, the optimal drilling parameters for hole diameter are the pulse off time at level 3, the peak current at level 3, and the servo standard voltage at level 2.

Table 4.3: Result of the analysis of variance for hole diameter

Source of variation	**Degree of Freedom, D_p**	**Sum of Squares, SSp**	**Mean Square**	**F Ratio**	**Contribution, ρ (%)**
Pulse off time	2	0.00010	0.00005	0.00078	4.81
Peak current	2	0.00030	0.00015	0.00233	14.42
Standard voltage	2	0.00135	0.00068	0.01047	64.90
Error	2	0.00033	0.00016	0.00256	15.87
Total	8	0.00208			100

4.3.3 Result Calculation

S/N ratio (Refer Table 4.1)

$$S/N = -10 \log \left| \frac{y_1^2 + y_2^2 + ... + y_n^2}{n} \right|$$

$$S/N_1 = -10 \log \left[\frac{(1.117)^2}{1} \right]$$

$$= -0.9611$$

$$S/N_2 = -10 \log \left[\frac{(1.104)^2}{1} \right]$$

$$= -0.8594$$

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$$S/N_9 = -10 \log \left[\frac{(1.072)^2}{1} \right]$$

$$= -0.6039$$

ANOVA (Refer Table 4.1)

*Note that calculation sample is just for pulse off time parameter only; the rest will apply the same method

$$CF = \frac{1}{m}\left[\sum_{i=1}^{m}\eta_i\right]^2$$

$$= \frac{1}{9}[(-0.9611)+(-0.8594)+(-0.7645)+(-0.6443)+(-0.8436)+(-0.9300)+$$

$$(-0.8830)+ (-0.9300) + (-0.6039)]^2$$

$$= 6.11705$$

$$SS_p = \sum_{j=1}^{t}\frac{(s\eta_i)^2}{t} - CF$$

$$= [((-0.9611)+(-0.8594)+(-0.7645)+(-0.6443)+(-0.8436)+(-0.9300)+$$

$$(-0.8830)+ (-0.9300) + (-0.6039))^2 /3] – 6.11705$$

$$= 0.00010$$

$SS_T = \sum_{j=1}^{m} \eta^2$ - CF

= $[(-0.9611)^2+(-0.8594)^2+(-0.7645)^2+(-0.6443)^2+(-0.8436)^2+(-0.9300)^2+$

$(-0.8830)^2+ (-0.9300)^2 + (-0.6039)^2]$ - 6.11705

= 0.13066

$SS_e = SS_T – SS_A – SS_B – SS_C$

= 0.13066 - 0.00010 - 0.00030 - 0.00135

= 0.12891

D_p = t – 1

= 3 -1

= 2

$V_p = \frac{SS_p}{D_p}$

$= \frac{0.00010}{2}$

= $5x10^{-5}$

$$V_e = \frac{SS_e}{D_p}$$

$$= \frac{0.12891}{2}$$

$$= 0.064455$$

$$F_{ratio} = \frac{V_p}{V_e}$$

$$= \frac{0.00005}{0.064455}$$

$$= 7.75735\text{x}10^{-4}$$

$$\hat{S} = SS_p - D_pV_e$$

$$= 0.00010 - 2(0.064455)$$

$$= -0.12881$$

$$\rho = \frac{\hat{S}\rho}{SS_T}$$

$$= \frac{-0.12881}{0.13066}$$

$$= -0.98584$$

Confirmation Test (Refer Table 4.4)

$$\hat{\eta} = \eta_m + \sum_{i=1}^{q} (\overline{\eta_i} - \eta_m)$$

= - 0.8267+ [(-0.8056-(-0.8267)) + (-0.7661-(-0.8267)) + (-0.7025-(-0.8267))]

= 0.9904

$$S/N = -10 \log \left| \frac{y_1^2 + y_2^2 + ... + y_n^2}{n} \right|$$

$$0.9904 = -10 \log \left(\frac{y^2}{1} \right)$$

y = 0.8922

4.4 CONFIRMATION TEST

The confirmation test is the final step for verifying the conclusions from the previous tasks of experimentation. In order to ensure that confirmation test result is in the range of theoretical prediction value, comparison of error margin must be done. The confirmation test is accepted if only the error margin is less then 10% comparing to prediction value. The calculation for error margin is as below:

Error Margin (%) = [(Confirmation test result – Prediction result)/ Prediction result] x 100

Table 4.4 shows the results of the confirmation test using the optimal cutting parameters of surface roughness. Based on the result of the confirmation test, error margin is less than 10 percent. That's means our analysis to find optimal drilling parameter by using Taguchi method can be accepted.

Table 4.4: Results of the confirmation experiment for hole diameter

	Optimal drilling parameter		**Error margin (%)**
	Prediction	Experiment	
Level	A3B3C2	A3B3C2	1.21
Hole diameter	0.8922	0.903	
S/N ratio (dB)	0.9908	0.886	

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 SUMMARY

Electrical Discharge Machining (EDM) is a thermal process that utilizes spark discharges to erode a conductive material. This machine is widely used in tool room for machining of dies with fine details and for the production of unusually shaped or sized. The advantages of EDM including low set-up cost, high aspect ratio (depth/diameter ratio) of the holes, enhanced precision and large design freedom.

In this project, the parameters that want to be study are Pulse Off Time (OFF), Peak Current (IP), and Servo Standard Voltage (SVR) which is to get optimal parameters in SODICK K1C EDM micro hole drill in term of machine accuracy on mild steel (50mm length x 75mm width x 5mm height) as workpiece by using 1mm copper (Cu) pipe electrode. Taguchi method is utilized as Design of Experiment (DOE) by using L_9 orthogonal array. The reasons why Taguchi method is utilized because the capability of designing experiment method and use statistical method to analysis and can design an experiment into more organized in short time, small number of experiment but give precise and accurate result. Analysis of variance (ANOVA) was used in this study to investigate which of the process control parameters significantly affect the performance characteristics. The goal of this research was to produce minimum diameter, Ø in a drilling operation. Smaller Ø values represent better or improved accuracy. Therefore, a smaller-the-better quality characteristic was implemented and introduced in this study.

Confirmation test is done to verify the optimum result obtained. Confirmation test is compulsory in Taguchi method as it is a proof of the research. In Taguchi, error margin for conformation test should be less than 10%.

5.2 CONCLUSION

The main objective of this project to find optimum drilling parameter for hole diameter by using Taguchi method has been successfully obtained and analyze. The confirmation test showed error margin is below 10 percent as predict. It is found that Taguchi's robust orthogonal array design method is suitable to analyze the hole diameter problem as described in this thesis. Also, parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for the optimization of drilling parameters.

From the experimental results demonstrate that the peak current and standard voltage are the main parameters among the three controllable factors (pulse off time, peak current, and servo standard voltage) that influence the hole diameter in drilling mild steel (50mm length x 75mm width x 5mm height). The percentage contributions of pulse off time, peak current and servo standard voltage are 4.81, 14.42 and 64.90, respectively. In drilling, use of greater pulse off time (16 μs), greater peak current (39 A) and medium servo standard voltage (14 V) are recommend to obtain better hole diameter for the specific test range. It can be concluded that, this research was successfully demonstrates how to use Taguchi for optimizing machining parameters to achieve particular goal.

5.3 SUGGESTION FOR IMPROVEMENT

From the previous experiment, there are several suggestions that could be implanted as to improve results and obtained more accurate finding. First, the experiment should be run repeatedly in order to gain more accurately ANOVA table.

Further study could consider more factors such as pulse on time, materials removal rate (MRR), coolants and etc in the research to see how the factors would affect hole diameter.

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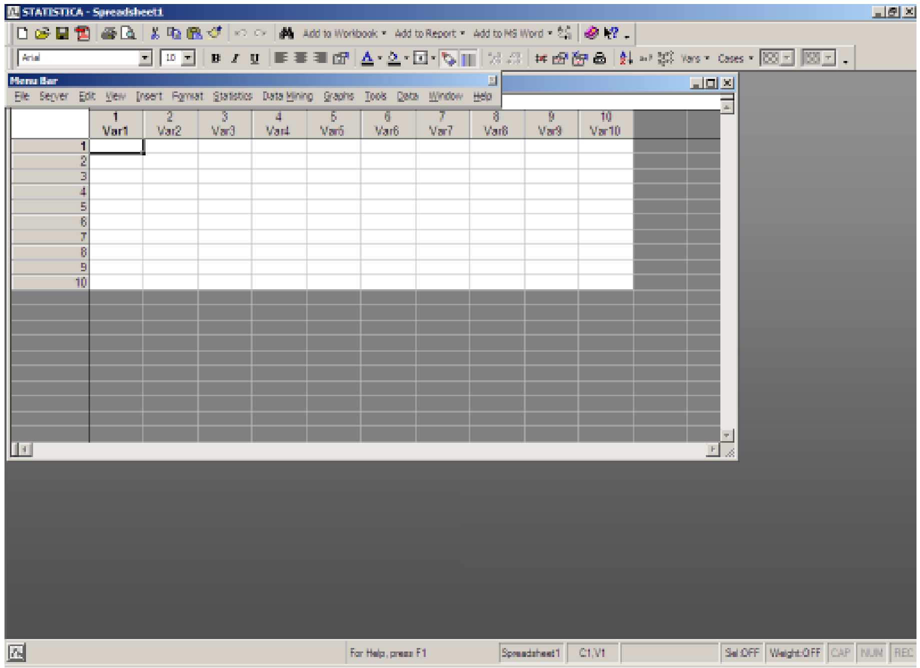
APPENDIX A

STATISTICA STEP

1. **Step 1**

2. **Step 2**



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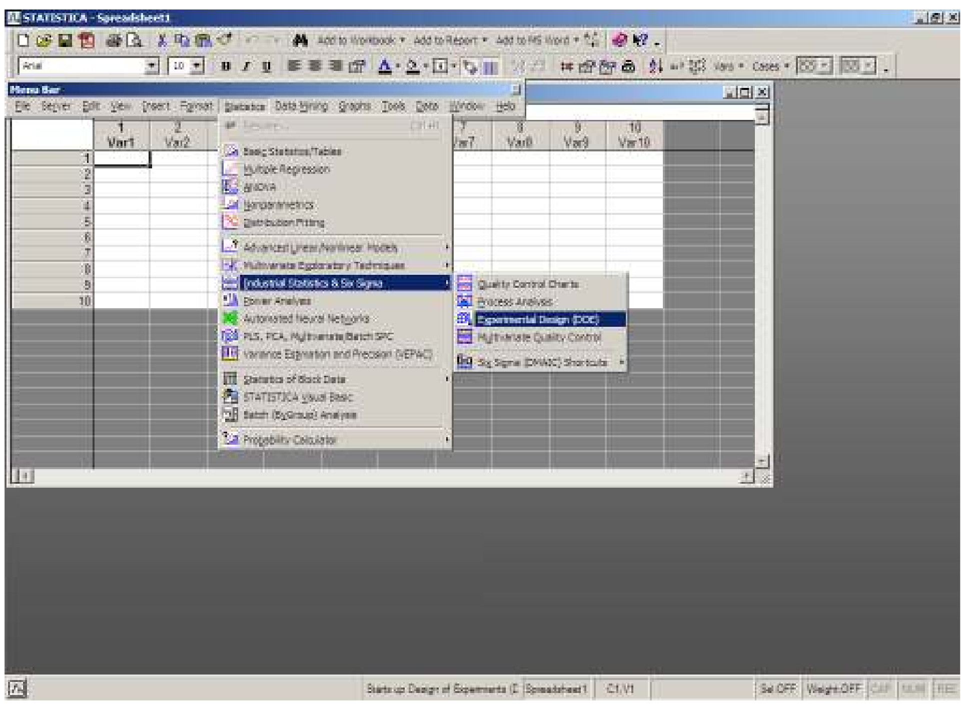
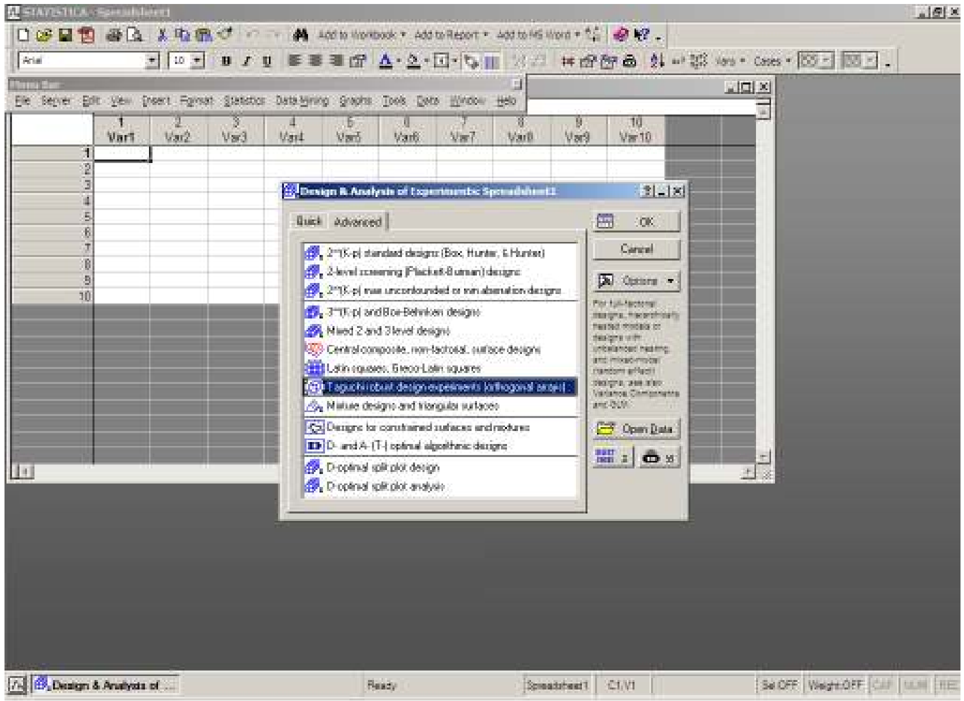


4. Step 4



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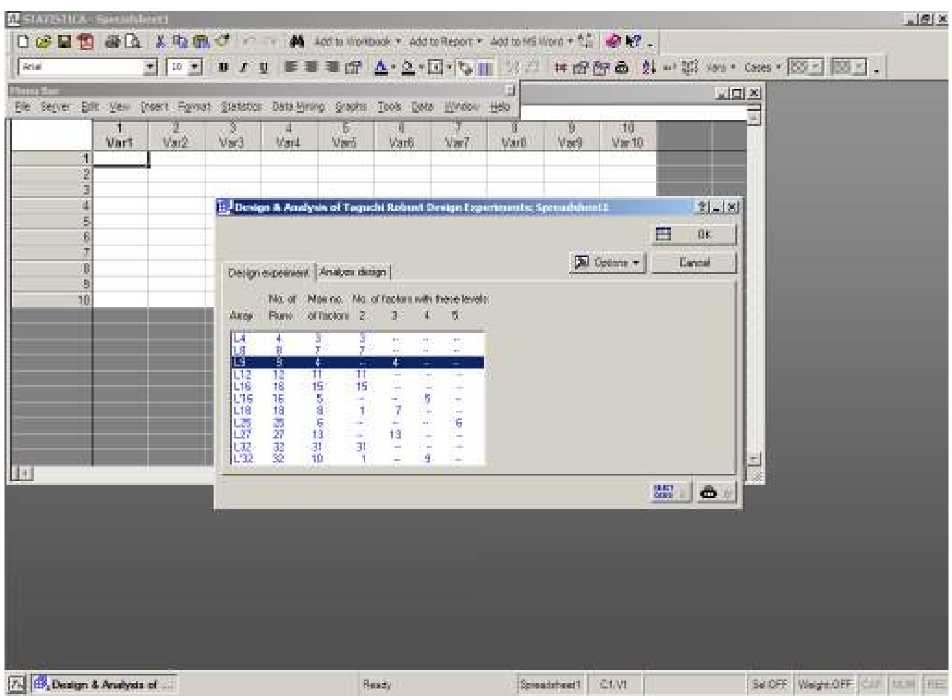

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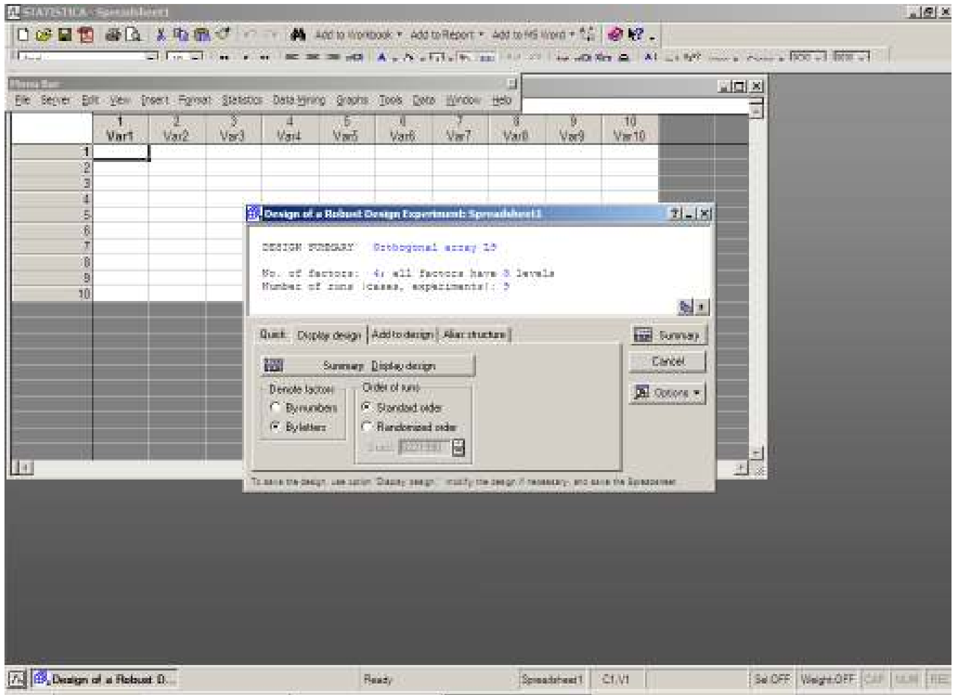

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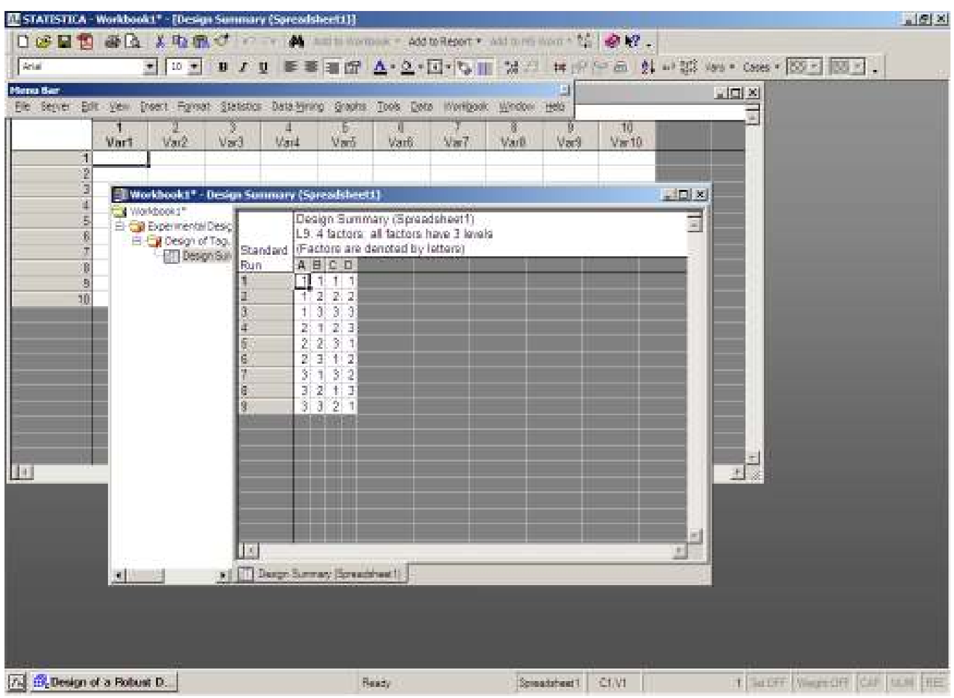

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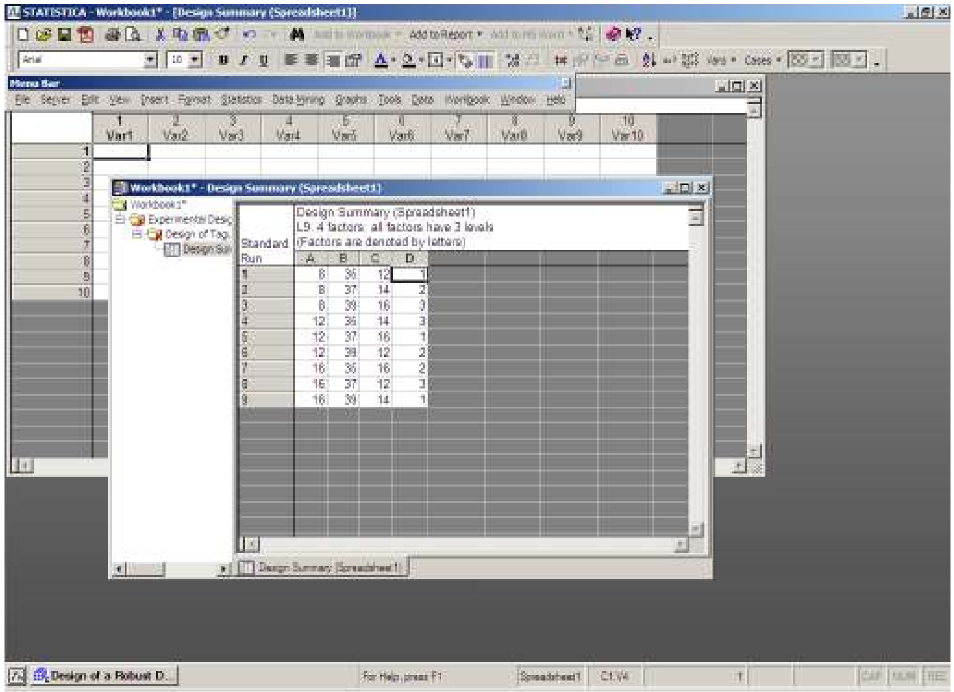

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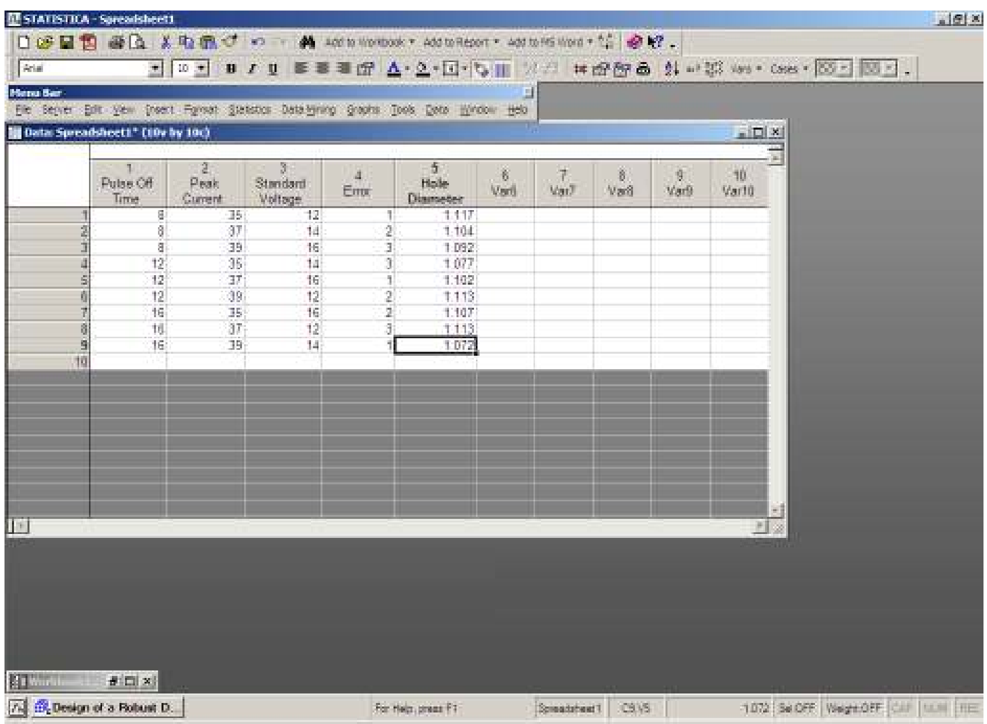

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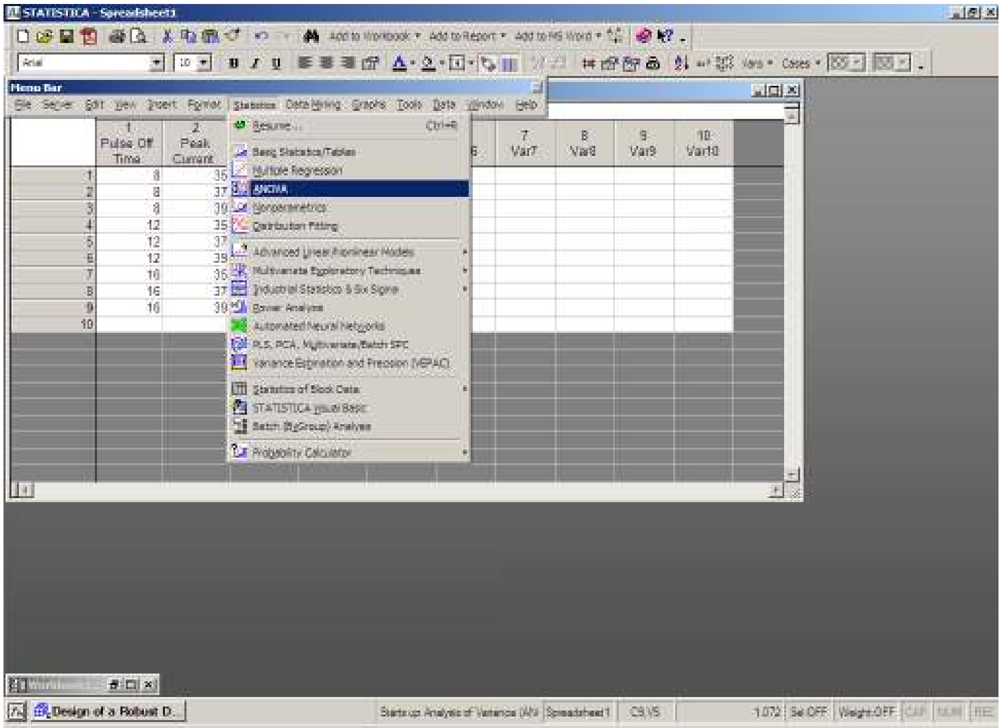

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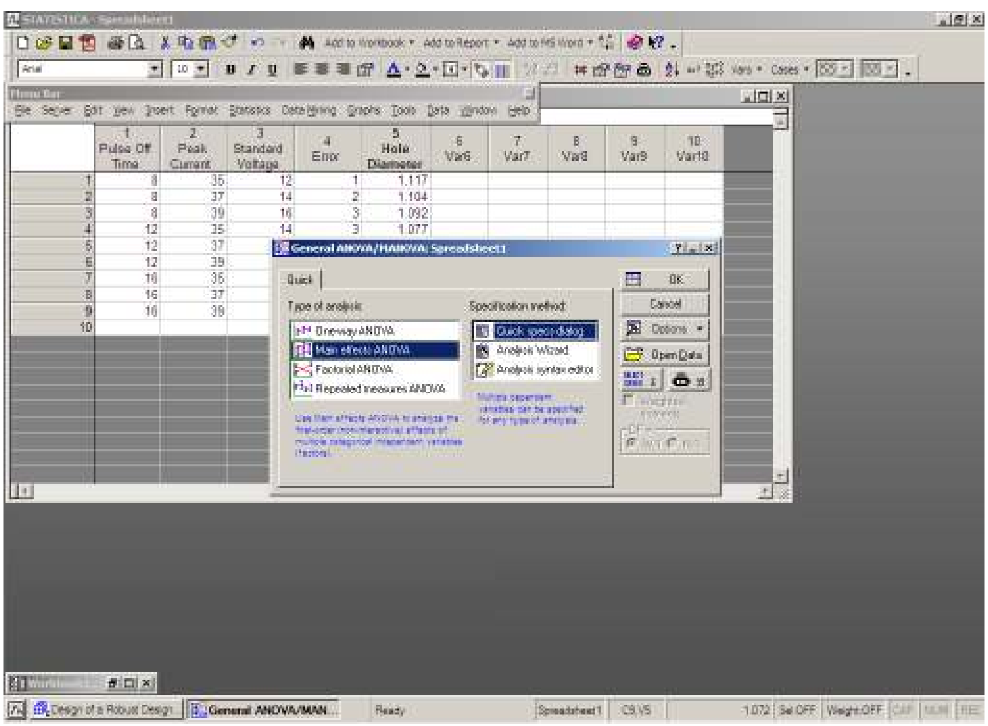

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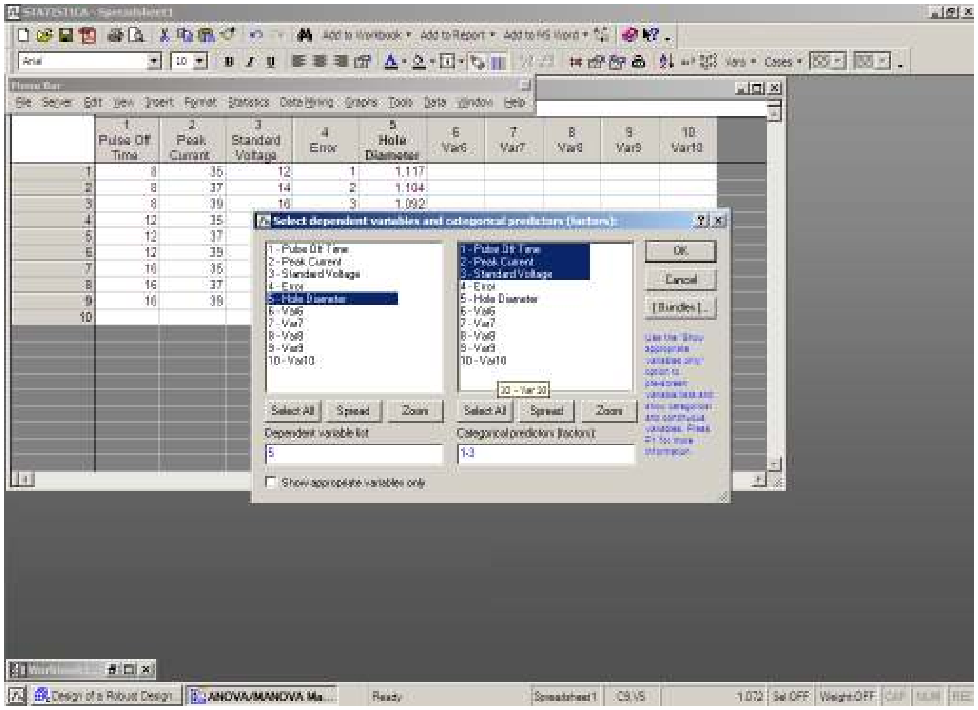

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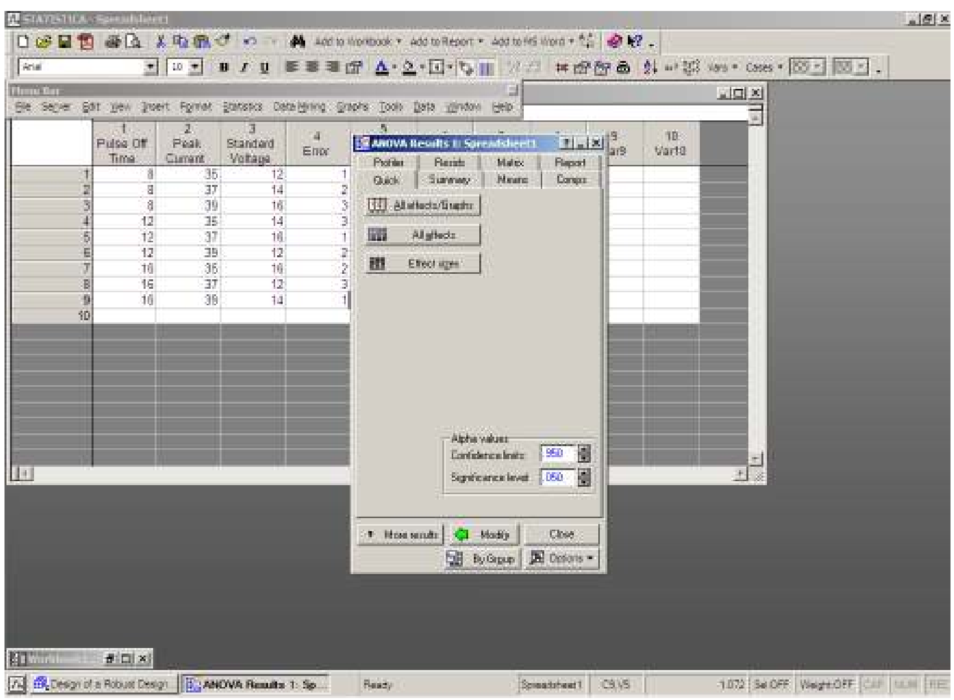

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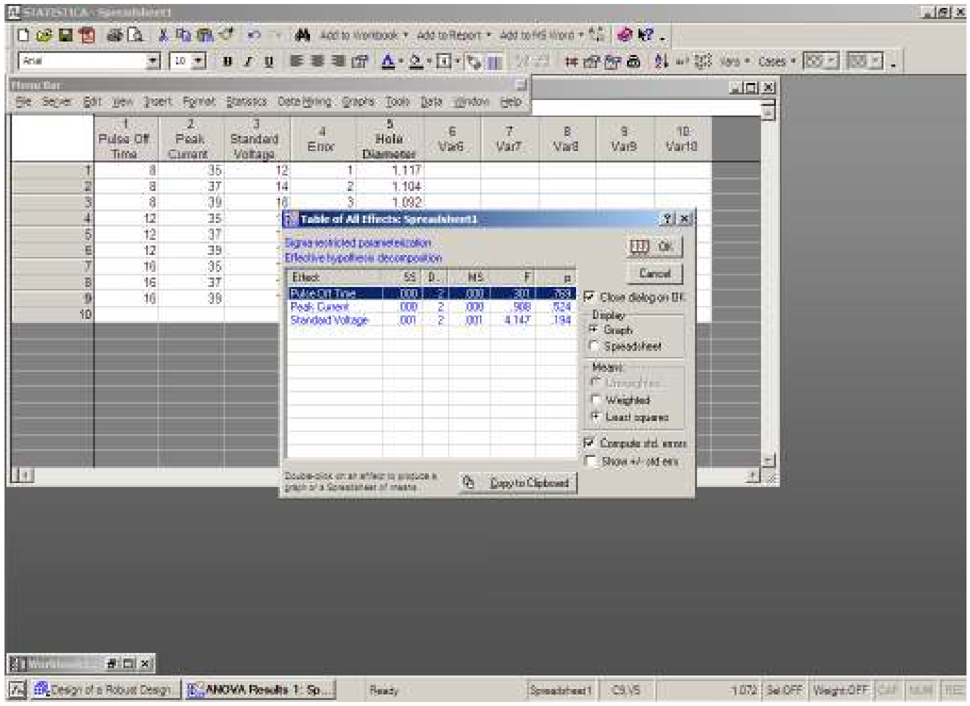

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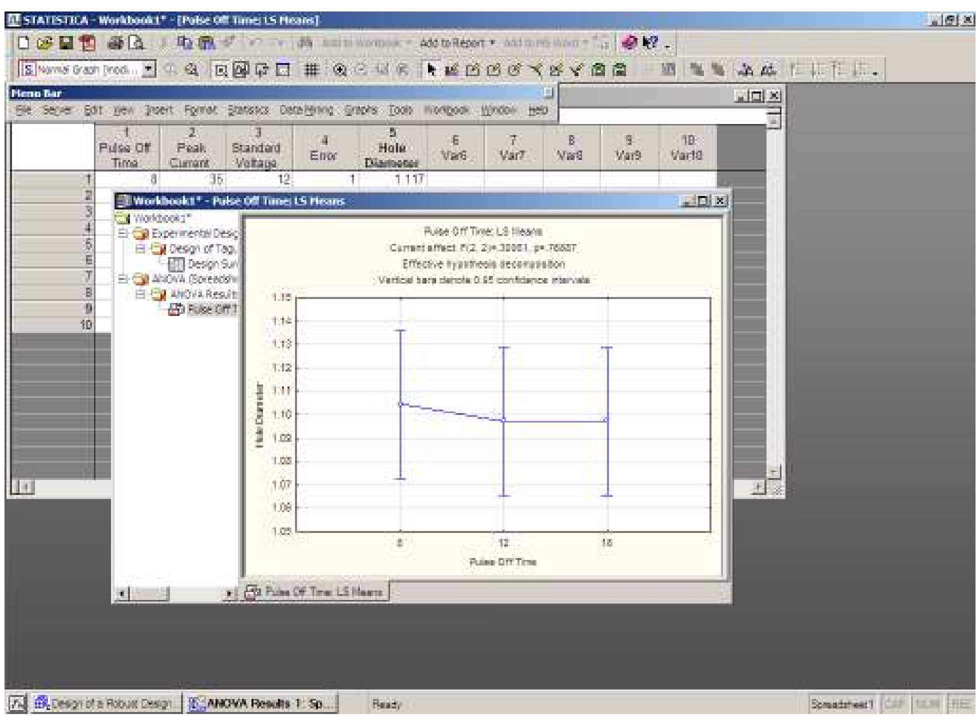

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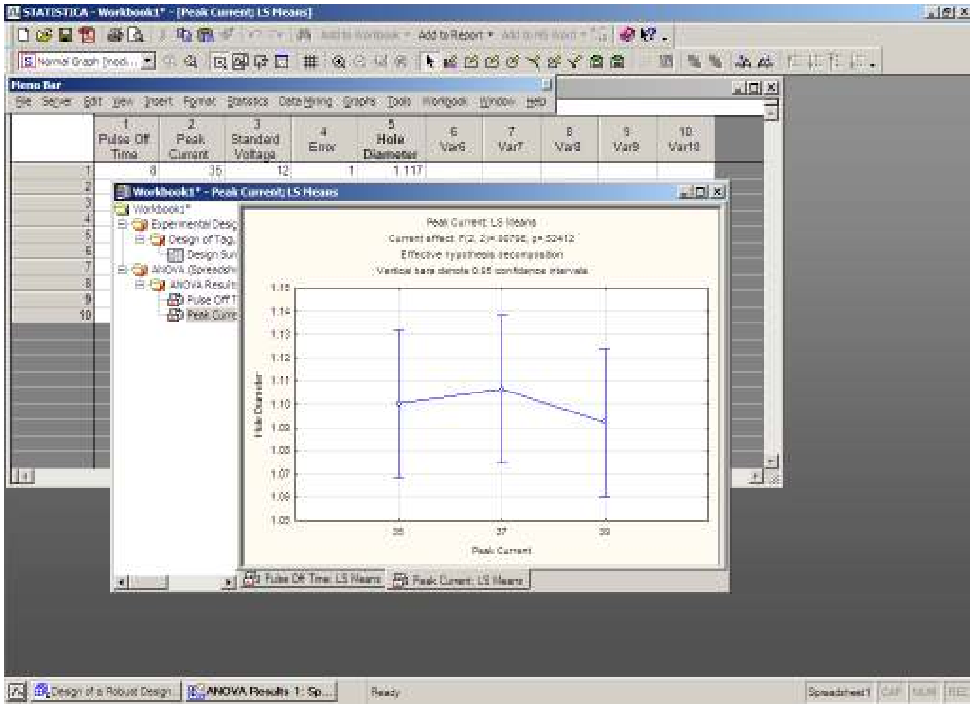

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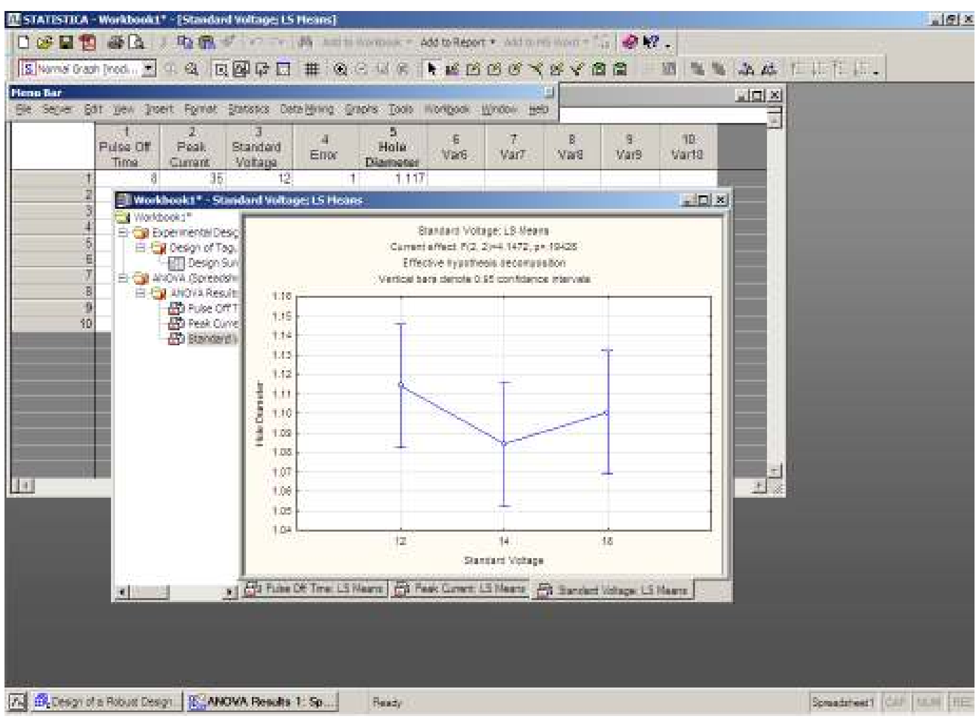

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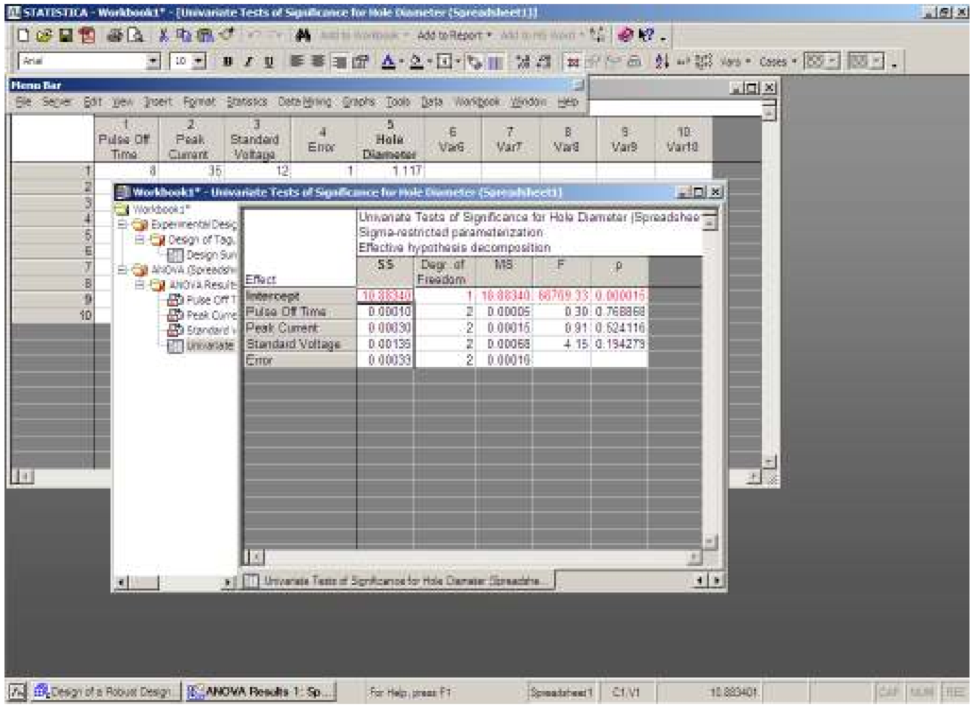

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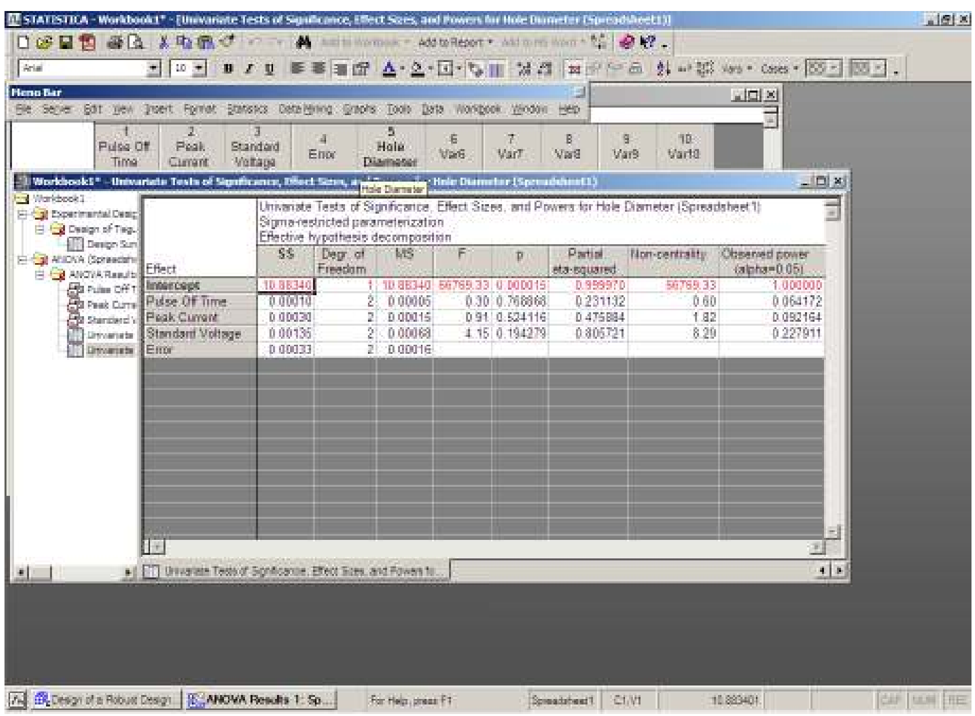


APPENDIX B

INSTRUMENTATION

Figure 1: SODICK K1C EDM Micro Hole Drill Machine Installed at the Universiti Malaysia Pahang Laboratory

Figure 2: Horizontal Band Saw Machine

Figure 3: Profile Projector

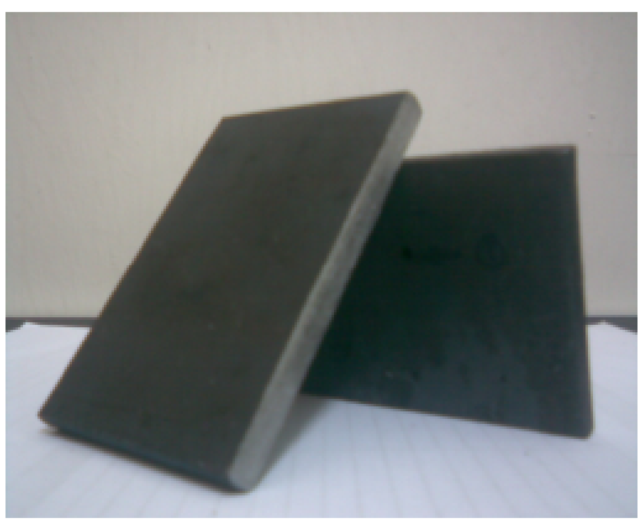
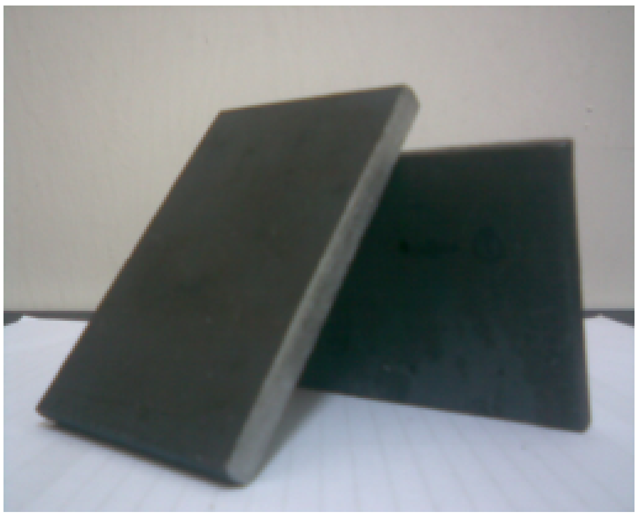
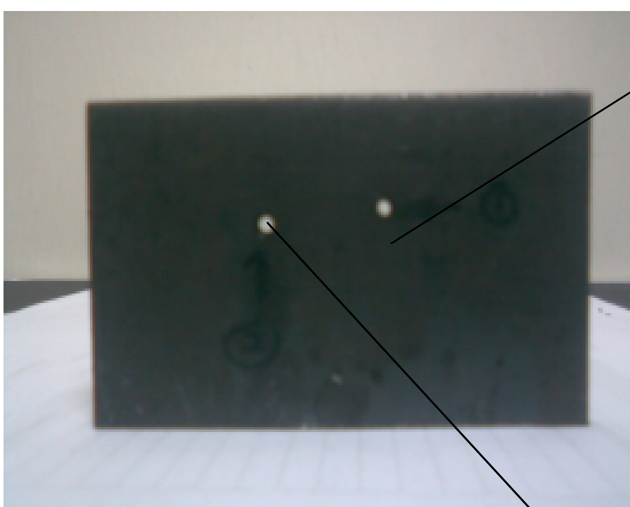


Figure 4: Mild Steel

APPENDIX C

PILOT TESTING





Hole 1

Hole

Table 1: Pilot testing result

Hole	Hole diameter (mm)			
	Reading 1	Reading 2	Reading 3	Average
1	2.186	2.174	2.204	2.188
2	2.437	2.459	2.446	2.447

APPENDIX D

OVERALL PROJECT FLOW CHART