# OPTIMIZATION OF CYLINDRICAL GRINDING PARAMETER FOR THE HIGH PRODUCT QUALITY SUBJECT TO ROUNDNESS CONSTRAINT

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Thesis submitted in fulfilment of the requirements
for the award of the degree of
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## SUPERVISOR'S DECLARATION

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

Signature

| | |
|---|---|
| Name of Supervisor: | MR KUMARAN A/L KADIRGAMA |
| Position: | LECTURER |
| Date: | 6 DECEMBER 2010 |

## STUDENT'S DECLARATION

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

Signature

Name: MOHD MUHYIDDIN BIN IBRAHIM

ID Number: ME07061

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**Dedicated to my beloved parents**

ENCIK IBRAHIM BIN MAT LAZIM

PUAN SITI ZAUYAH BINTI ISHAK

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# ABSTRACT

In the manufacturing cylinder rod industry, final roundness of a product is very important to determine the products quality. Good roundness not only ensures good quality, but also reduces manufacturing costs. Final roundness is a important aspect of tolerance, it reduce installation time and reduce operating hours at the same time to reduce the overall cost. In this study, the main objective is to study the effect of work piece diameter, work speed and cutting depth of the roundness error in the process of cylindrical grinding by using outside cylindrical grinding machines. Roundness errors measure by using roundness measuring machine. The results of experimental analyze by using statistical methods with the help of DOE software. Based DOE method, the experiment was run by using the full factorial method and the results were analyzed using the Statistica software. The correlation for roundness error with the cutting parameters satisfies a reasonable degree of approximation. Depth of cut is the most significant parameter in affecting the roundness error work piece. The optimal parameters are, for work piece diameter is 18.71mm, for speed is 74.96rev/min and for depth of cut is 15.91μm.

# ABSTRAK

Dalam industri pembuatan rod silinder, kebulatan akhir sesuatu produk adalah sangat penting dalm menentukan mutu produk. Kebulatan yang baik bukan sahaja menjamin kualiti, malah mengurangkan kos penbuatan. Kebulatan akhir penting dalam aspek toleransi, ia mengurangkan masa pemasangan dan mengurangkan waktu operasi sekaligus dapat mengurangkan kos keseluruhan. Dalam kajian ini, tujuan utama adalah untuk mempelajari pengaruh diameter bahan kerja, kelajuan kerja dan kedalaman pemotongan terhadap kesalah kebulatan bahan kerja dalam proses menggiling berbentuk silinder dengan menggunakan mesin giling silinder. Kesalahan kebulatan dikira menggunakan mesin mengukur kebulatan. Hasil keputusan eksperimen dikaji menggunakan kaedah statistika dengan bantuan perisian DOE. Berdasarkan kaedah DOE, eksperimen yang dijalankan ialah menggunakan kaedah faktoran penuh dan keputusan yang diperoleh dianalisis menggunakan perisian Statistica. Pengaruh kesalahan kebulatan dengan parameter pemotongan memenuhi tahap pendekatan yang sewajarnya. Kedalaman pemotongan merupakan parameter yang paling signifikan dalam mempengaruhi kesalahan kebulatan bahan kerja. Parameter yang optimum adalah, untuk diameter benda kerja ialah 18.71mm, untuk kelajuan kerja ialah 74.96rev/min dan untuk kedalaman potong ialah 15.91µm.

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# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

Grinding is a finishing process used to improve surface finish, abrade hard materials, and tighten the tolerance on flat and cylindrical surfaces by removing a small amount of material (Savington, 2009). Grinding is an essential process for final machining of components requiring smooth surfaces and precise tolerances.

According to Bianchi et al. (1999), the grinding process is known as one of the most complexes tooling processes, due to the great number of variables involved, whereas such process should be employed in finishing operations, in which good final quality, low roundness errors of the piecework are expected, being that the reduction of the diametrical wear of grinding wheel should always be looked for to reduce the costs of the process. (Souza and Catai, 2004)

According to Malkin (1989), the grinding process requires a significant energy quantity for the material removal. Such energy, once transformed into heat, is concentrated within the cutting region. The high temperature may provides situation in which the surface burning, the superficial heating and micro-structural transformations might occur, allowing the retemper of the material, since most grinding processes occur in tempered steels, with the formation of non-retempered martensite, providing undesirable and uncontrollable residual tensions, reducing the strength limit to the exhaustion of the tooled component. Besides, the uncontrolled expansion and retraction of the mechanical piece during the grinding operation are the most outstanding cause of roundness errors.

The cylindrical grinder is a type of grinding machine used to shape the outside of an object. The cylindrical grinder can work on a variety of shapes. However, the object must have a central axis of rotation. This includes but is not limited to such shapes as a cylinder, an ellipse, a cam, or a crankshaft. (De Souza and Catai, 2004)

Grinding is a costly machining process which should be utilized under optimal conditions. The usual optimization objective in cylindrical plunge grinding is to minimize production time while satisfying work piece quality constraints. The time for a typical cycle (figure 1.1) includes t; for roughing with a fast programmed infeed velocity u1, and t2 for finishing with a slower velocity u2, and t3 for spark-out (u3=0). Additional production time is required for wheel dressing, part loading/unloading, set-up, and wheel change. (Xiao and Malkin, 1996)

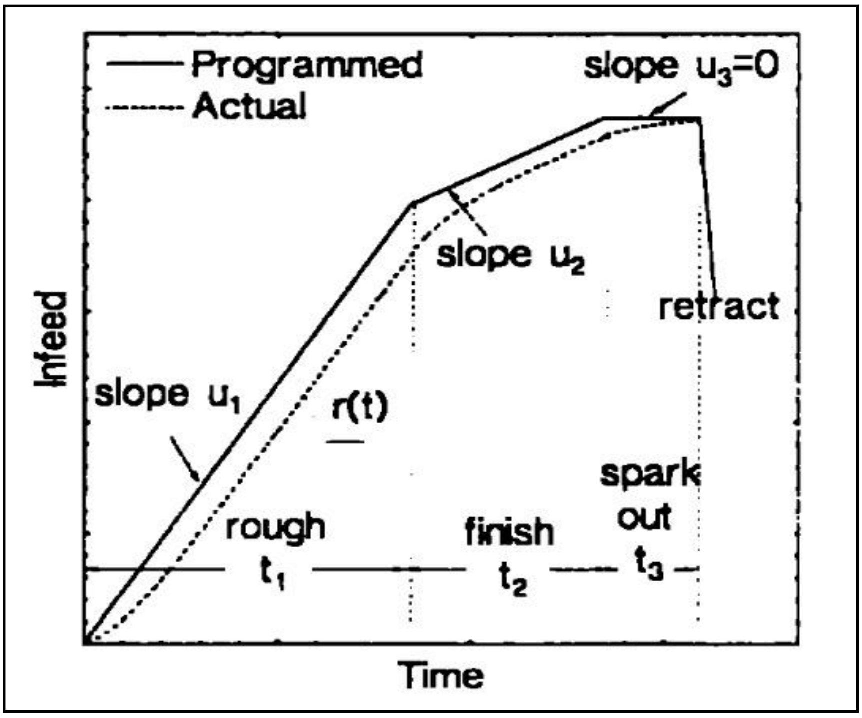


**Figure 1.1:** Grinding cycle with roughing, finishing and spark out stages

Source: Xiao and Malkin (1996)

### 1.1.1 Cylindrical Grinding is defined as having four essential actions (Walker and John, 2004)

i. The work (object) must be constantly rotating
ii. The grinding wheel must be constantly rotating
iii. The grinding wheel is fed towards and away from the work
iv. Either the work or the grinding wheel is traversed with the respect to the other.

### 1.1.2 Reasons for Grinding

Reasons for grinding are:

i. The material is too hard to be machined economically. The material may have been hardened in order to produce a low-wear finish, such as that in a bearing raceway. (Richard and John, 2002)
ii. Tolerances required preclude machining. Cylindrical grinder can produce tolerances of 0.0002 mm with extremely fine surface finishes. (Walker and John, 2004)
iii. Machining removes excessive material.

## 1.2 PROBLEM STATEMENT

Establishment of cylindrical grinding machine parameter has been confronted a problem in manufacturing industries for nearly a century and is still the subject of many studies. In industrial, high quality surface finish of cylinder product is important. Roundness is a part of surface finish quality. In industry, rod or cylinder product is an important product. Many products want high precision of roundness. The examples rod uses in industrial are automotive production, machine production and medical product production.

Surface roundness plays an important role on the required tolerance and fit especially during part assembly. Optimization parameters of machine to make good quality for surface roundness are of great concern in manufacturing environments, where economic of machining operation plays a key role in competitiveness in the market. The optimization parameters can produce maximize production rate.

Student has a problem in attempt to identify the optimum of parameter cylindrical grinding process by use cylindrical grinding machine. Parameters that student must identify for roundness effect are diameter of work piece, cutting speed and depth of cut. Other parameters of cylindrical grinding machine are constant. The quality that study is subject to roundness constrain.

## 1.3 OBJECTIVE OF STUDY

The objectives of these studies are:

i. To determine roundness error of cylindrical grinding via experiment
ii. To determine optimum cylindrical grinding process parameters

## 1.4 SCOPE OF THE STUDY

The scopes of this project are:

i. Use carbon steel to run cylindrical grinding process
ii. Use aluminum oxide grinding wheel in cylindrical grinding process
iii. Use roundness measuring machine to measure roundness of work piece
iv. Determine optimum values of parameters there are diameter, speed and depth of cut for cylindrical grinding machine.
v. The experiments and analysis with software prove the exactitude of optimum parameters.

## 1.5 PROJECT BACKGROUND

In order to achieve the objective of this project, there is some guideline need to be understood. Chapter 1 discussed about of the scope, objective and problem statement of this project. Chapter 2 discussed more about literature review in which discusses overall about case study. Methodology of this study had been discussed on chapter 3 in which the methods and equipment that need to be apply in this project.

Chapter 4 shows the experiment’s data or result of experiment. The results were analysis by using statistic software and the result is discussed. Lastly, chapter 5 is to make conclusion and recommendation for the experiment.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

This chapter discussed about the cylindrical grinding process, cylindrical grinding parameter and the previous study that involved the optimization technique. Here, the optimization technique, full factorial method is review to get fully understanding before applied to the study.

According to Shaw (1994), one single work piece is never perfectly cylindrical, since all work pieces might show roundness errors, which are the main causes for such non-perfect cylindrical situation. The roundness error may be understood as any divergence between the built work piece and the work piece theoretically required with specified tolerance (Jedrzejewski and Modrzycki, 1997), whereas the amount of errors in a machine expresses a measurement of its accuracy. (De Souza and Catai, 2004)

From the type of errors usually found in a work piece, the roundness error (Figure 2.1), according to ASME (1982), the one that occurs when it's opposite radiuses are different at any position from the surface of the work piece. They are present in the cylindrical work piece, which passed through some manufacturing stage; many of them ready to be used**.**

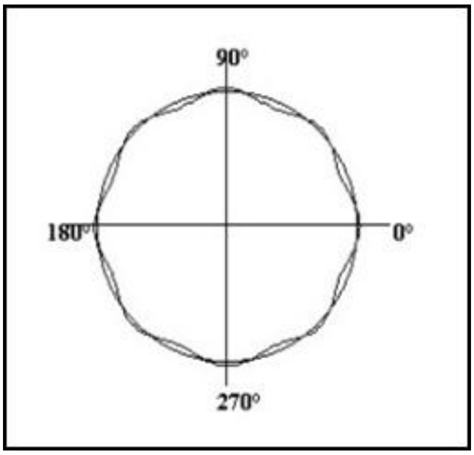


**Figure 2.1:** Example of a work piece with roundness error

Source: Taylor-Hobson (2001)

## 2.2 SURFACE ROUNDNESS

One of the most important fundamental forms for engineering components is the circular cross-section. Circular forms arise in many applications, particularly in bearing surfaces.

The measurement of out-of-roundness (usually referred to simply as "roundness") is an extremely important assessment. For example, a rotational bearing whose components are not accurately round will tend to be noisy and is likely to fail prematurely. Accurate roundness measurement is therefore vital to ensure correct function of such parts.

## 2.3 ROUNDNESS MEASURING METHOD

### 2.3.1 Diameter measurement

Perhaps the first and simplest approach to gauging the roundness of a component is to measure the consistency of its diameter at a number of different orientations.

This is often done in-process for checking machine setup and can be adequate for assessing a component where the roundness is a cosmetic, rather than functional, requirement. It can be functionally relevant of course, and a good example of this is the UK fifty-pence piece. One of the requirements for the coin is that it is able to be used in a coin-operated slot machine. The design as shown works very well in this application as it has a constant diameter. However it is clearly evident that the coin is not round.

At this stage it is useful to look at the ISO definition of roundness. Roundness is defined in ISO 1101 as the separation of two concentric circles that just enclose the circular section of interest. It is clear that measurement of diameter as shown above will not yield the roundness of the component in accordance with this definition.

### 2.3.2 Vee-Block Method

Vee-block method that is the method that place the part in a vee-block and rotate it in contact with a dial gauge or similar indicator. This is essentially a three-point method rather than the two-point method above. If the part is truly round, with negligible irregularity, the pointer of the gauge will not move.

Errors in the form will cause the dial indicator to show a reading, however the part will also move up and down as the irregularities contact the vee-block. Moreover, in the case of a shaft, the contact with the vee-block is not restricted to the plane being measured. This means that irregularities of the component along its length will affect the dial indicator reading.

However the three-point method is applied, it will always suffer from the limitation that the results may vary according to the vee angle and the spacing of the irregularities. (Mike, 2007)

### 2.3.3 Coordinate Measuring Machine (CMM)

Another way to measure roundness is to use a coordinate measuring machine (CMM). A standard CMM has three accurate, orthogonal axes and is equipped with a touch-trigger probe. The probe is brought into contact with the component being measured and its position is recorded. A number of points are taken around the component and these are then combined in a computer to calculate the roundness of the component.

Typically the number of data points is very small because of the time taken to collect them. As a result the accuracy of such measurements is compromised. (Mike, 2007)

### 2.3.4 Rotational Datum Method

The most accurate method for determining roundness of a component is to measure the variation of radius from an accurate rotational datum using a scanning probe (one that remains in contact with the surface and collects a high-density of data points).A circle can then be fitted to this data and the roundness calculated from knowledge of the component centre. (Mike, 2007)

## 2.4 CYLINDRICAL GRINDING MACHINE

Cylindrical grinding is used to grind the external or internal diameter of rigidly supported and rotating work piece. Although the term cylindrical grinding may also be applied to centerless grinding, it generally refers to work which is ground in a chuck or between supporting centers. Cylindrical grinders can be used to grind all types of hard or soft work pieces to a high degree of accuracy and very-fine surface finishes. (Youssef and Helmi, 2008). There are few parts of cylindrical grinding.


**Figure 2.2:** Cylindrical Grinding Machine

Source: First Machinery (2010)

### 2.4.1 Headstock

The headstock is mounted on the left end of the table and contains a motor for rotating the work. A dead center is mounted in the headstock spindle. When work is mounted between centers, it is rotated on two dead centers. (Youssef and Helmi, 2008)

### 2.4.2 Grinding Wheel

Grinding wheel is the most important products made from abrasives, are composed of abrasive material held together with a suitable bond. The basic functions of grinding wheels in a machine shop are make generation of cylindrical, flat and curve surface, to removal of stock, produce high finished surfaces, as cutting-off operations and make sharp edges and points production.

For grinding wheel function properly, they must be hard and tough. The material components of grinding wheel are abrasive grain and the bond. That must be considered in grinding wheel manufacture and selection. (Hassan, 2007)

Grinding wheels use several types of abrasive grains. Aluminum oxide, the most common industrial mineral in use today, is used either individually or with other materials to form ceramic grains. Silicon carbine, a synthetic abrasive that is harder than aluminum oxide, is typically used with nonferrous materials such as brass, aluminum, and titanium. Alumina-zirconia grains fuse aluminum oxide and zirconium oxide and are used to improve grinding performance on materials such as stainless steel. Synthetic diamond superabrasives are used for grinding nonferrous metals, ceramics, glass, stone, and building materials. Cubic boron nitride (CBN), another type of superabrasive, provides superior grinding performance on carbon and alloy steels. CBN is second only to diamond in terms of hardness.

Crushed tungsten carbide grits are used in metal-bonded products to abrade tough materials such as composites, fiberglass, reinforced plastics, and rubber. (Malkin and Cook, 1971)

### 2.4.3 Coolant System

Coolant or lubrication is essential in metal-cutting operation to reduce the heat and friction created by the deformation of metal and the chip sliding along the chip-tool interface. This heat and friction cause metal to adhere to the tool’s cutting edge and causing the wheel to break down. The finishing results will poor and inaccurate work. (Hassan El-Hofy, 2007)

**Table 2.1:** Cutting Fluid

| Work Material | Cutting Fluid | Application |
|---|---|---|
| Aluminum | Light duty oil | Flood |
| Brass | Light duty oil | Flood |
| Cast Iron | Heavy duty emulsifiable oil, light duty chemical oil, synthetic oil | Flood |
| Mild Steel | Heavy duty water soluble oil | Flood |
| Stainless Steel | Heavy duty emulsifiable oil, heavy duty chemical oil, synthetic oil | Flood |
| Plastics | Water soluble oil, dry, heavy duty emulsifiable oil, dry, light duty chemical oil, synthetic oil | Flood |

Source: Hassan El-Hofy (2007)

## 2.5 TYPE OF CYLINDRICAL GRINDING

There are a few different types of cylindrical grinding. There are outside diameter grinding, inside diameter grinding and center less grinding.

### 2.5.1 Outside Diameter (OD) grinding

Outside diameter grinding (figure 2.3a) is grinding occurring on external surface of an object between the centers. The centers are end units with a point that allow the object to be rotated. The grinding wheel is also being rotated in the same direction when it comes in contact with the object. This effectively means the two surfaces will be moving opposite directions when contact is made which allows for a smoother operation and less chance of a jam up. (Kocherovsky and Eugene, 2005)

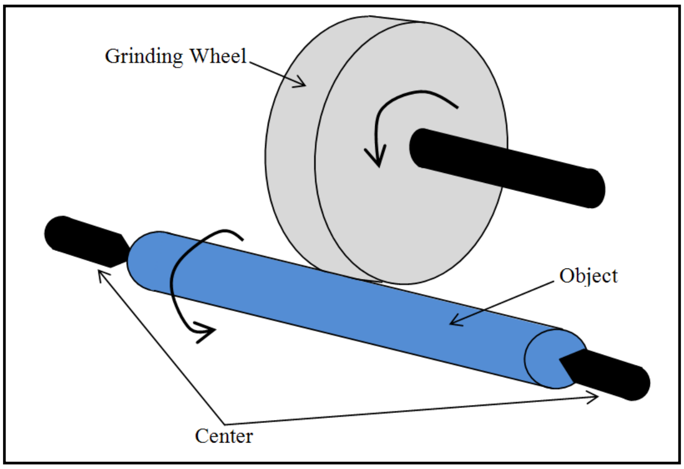


**Figure 2.3a:** Outside Grinding Process

### 2.5.2 Inside Diameter (ID) grinding

Inside diameter grinding (figure 2.3b) is grinding occurring on the inside of an object. The grinding wheel is always smaller than the width of the object. The object is held in place by a collet, which also rotates the object in place. Just as with OD grinding, the grinding wheel and the object rotated in the same direction giving reversed direction contact of the two surfaces where the grinding occurs. (Kocherovsky and Eugene, 2005)

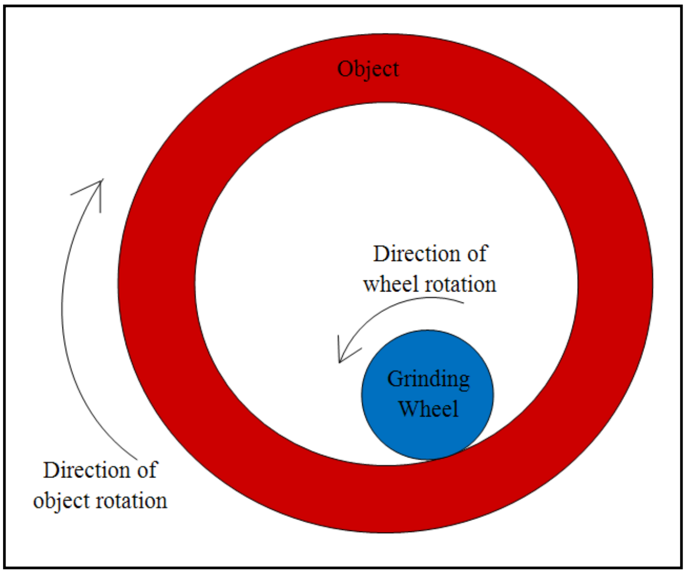


**Figure 2.3b:** Inside Grinding Process

### 2.5.3 Centerless grinding

Centerless grinding (figure 2.3c) is a form of grinding where there is no collet or pair of centers holding the object in place. Instead, there is a regulating wheel positioned on the opposite side of the object to the grinding wheel. A work rest keeps the object at the appropriate height but has no bearing on its rotary speed.

The work blade is angled slightly towards the regulating wheel, with the work piece centerline above the centerlines of the regulating and grinding wheel; this means that high spots do not tend to generate corresponding opposite low spots, and hence the roundness of parts can be improved. Centerless grinding is much easier to combine with automatic loading procedures than centered grinding; through feed grinding, where the regulating wheel is held at a slight angle to the part so that there is a force feeding the part through the grinder, is particularly efficient. (Houghton and Phillip, 1963)

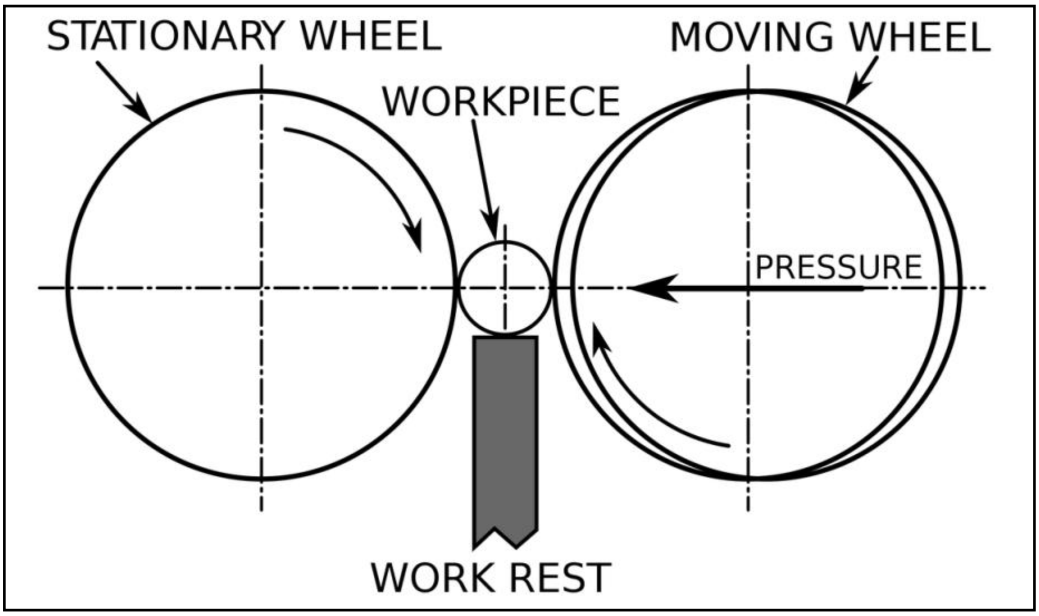


**Figure 2.3c:** Centerless Grinding Process

Source: Efunda (2010)

## 2.6 TYPES OF ABRASIVES

Abrasives may be divided two classes: natural and manufactured. Natural abrasives such as sandstone, garnet, flint, emery, quartz and corundum, were used extensively prior to the early of the $20^{th}$ century. One of the best natural abrasives is diamond.

Manufactured abrasives are used extensively because their grain size, shape and purity can be closely controlled. The uniformity of grain does its share work, is not possible with natural abrasives. There are several of manufactured abrasives: aluminum oxide, silicon, carbide, boron carbide, cubic boron nitride and manufactured diamond. (Krar and Check, 1997)

**Table 2.2:** Description Type of Abrasives

| Type | Descriptions |
|---|---|
| Aluminum Oxide | It is probably the most important abrasive, since about 75 percent of grinding wheels manufactured are made of this material. It is generally used for high-tensile-strength. |
| Silicon Carbide | It is suited for grinding material that have a low tensile strength (aluminum, brass and bronze) and high density, such as cemented carbides, stone and ceramics. It is also used for cast iron and most nonferrous and nonmetal materials. It is harder and tougher than aluminum oxide. |
| Boron Carbide | It is harder than silicon carbide and next to diamond, it is the hardest material manufactured. Boron carbide is not suitable in grinding wheels and is used only as a loose abrasive and a relatively cheap substitute for diamond dust. |
| Ceramic Aluminum Oxide | Aluminum oxide grains are made from fused aluminum oxide, which is then crushed to the desired particle size. This produces a grain having very few crystal particles. |

Source: Li et al (2002)

## 2.7 GRINDING WHEEL

Grinding wheel (figure 2.4) is the most important products made from abrasives, are composed of abrasive material held together with a suitable bond. The basic functions of grinding wheel in machine shop are generation of cylindrical, flat and curved surface, removal of stock, high finished surfaces, cutting-off operations and sharp edges and points.

For grinding wheels to function properly, they must be hard and tough and the wheel surface must be capable of gradually breaking down to expose new sharp cutting edges to the material being ground. (Krar and Check, 1997)


**Figure 2.4:** Cylindrical Grinding Wheel

Source: Direct Industry (2010)

## 2.8 GRINDING PROCESS

In the grinding process the work piece is brought into contact with a revolving grinding wheel. As the abrasive grains become dull, the pressure and heat created between the wheel and the work piece cause the dull face to break away, leaving new sharp cutting edges. (Krar et al, 1999)

The principal parts of a cylindrical grinder are the base, wheel head, table, headstock and footstock. There are several parameters that involve in cylindrical grinding process.

### 2.8.1 Speed of grinding wheel

Wheel speed is defined as the work moves or rotating with respect to the tool, usually measured in revolution per minute. (Kalpakjian and Schimd, 2006)

### 2.8.2 Speed of work

Work speed is the rotational speed of the spindle and the work piece in revolution per minute (RPM). The spindle speed is equal to the cutting speed divided by the circumference of the work piece where the cut is being made. (Krar and Check, 1997)

### 2.8.3 Feed rate

The speed of the cutting tool’s movement relative to the work piece as the tool makes cut. The feed rate is measured in millimeter per minutes and is the product of the cutting feed and the spindle speed. (Kalpakjian and Schimd, 2006)

### 2.8.4 Depth of cut

The depth of cut may be defined as the depth of the chip taken by the cutting tool and is one-half the total amount removed from the work piece in one cut. (Krar and Check, 1997)

## 2.9 ROUNDNESS MEASURING MACHINE

The basics for a run-out and roundness measuring machine arrived from the development of a roundness measurement method for large rolls rotating on their own bearings in a roll grinding machine. Between mechanical designs and mathematical procedures, the run-out can be eliminated from a measurement. And even more importantly, periodic motion from a bearing clearance and other external factors can be measured and eliminated from the roundness measurement.

The roundness measuring machine includes a base with a high accuracy spindle and a work table on which a work piece to be measured is mounted. Mechanical centering is included. However, roundness is computed regardless of how much the piece is mounted off center.

For measuring roundness of the outside diameter of a work piece there are one or two gauge holders. An optional post is available to hold lever/stylus type gauge(s) to measure the inside diameter of a work piece and/or straightness profile of a work piece vertically. (FMT, 2007)


**Figure 2.5:** Roundness Measuring Instrument

Source: Accretech (2007)

### 2.9.1 Roundness Measuring Machine, RANDCOM-31C Specification

RANDCOM-31C compact practical desktop roundness measuring instrument with analysis functions of a high-end machine and superior cost performance.

**Table 2.3:** Roundness Measuring Machine RANDCOM-31C Specification

| **Specification** | | |
|---|---|---|
| **Measuring system** | **:** | Manual |
| **Measuring range** | **:** | Max. Measuring dia: Φ250mm, Left/Right feed(R-axis): 125mm. Up/Down (Z-axis): 300mm (High-column:500mm), Max.load diameter: Φ400mm, Max.measuring hight: Outer diameter/ID: 520/300mm(High-column:500mm) |
| **Rotation accuracy** | **:** | Radius direction: (0.04+6H/10000μm |
| **Straightness accuracy** | **:** | Up/down direction Z-axis:0.5μm/100mm, 1.5μm/300mm |

**Continuance of Table 2.3**

| | | |
|---|---|---|
| **Parallelism accuracy** | **:** | Z-axis: 3µm/300mm (High-column: 5µm/500mm) |
| **Rotation Speed** | **:** | q-axis: 6/min |
| **Auto stop Accuracy** | **:** | Z-axis/R-axis: ± 5µm |
| **Rotation table** | **:** | Outer diameter: Φ148mm. Load: 25kg, Adjustment range centering/tilting: ±2mm/±1° |
| **Detector: Detection range/Measuring force** | **:** | ±400µm/70mN, Stylus shape: Φ1.6mm carbide ball, Stylus length: L15.5mm |
| **Filter type** | **:** | Digital filter: Gaussian/2RC |
| **Cutoff values** | **:** | Rotation Direction: any value in range15 to 500 peaks /rotation. Rectilinear direction 0.025,0.08, 0.25, 0.8 2.5,8, settable in 0.001mm units. |
| **Display magnification** | **:** | 10-20K (22 steps), auto, measuring magnification |
| **Roundness evolution of profile error** | **:** | MZC, LSC, MIC, MCC, NC, Multi |
| **<u>Measuring items:</u>** | | |
| **Rotation direction** | **:** | Roundness, flatness, flatness(column), parallelism, concentricity, coaxiality, cylindricity, squareness, non-uniformity, diameter, circular parts. |
| **Rectilinear direction** | **:** | cylindricity, diameter deviation |
| **Analysis processing function** | **:** | Centering/tiltring support function, notch function, combination of roundness evluation methods, nominal value collation, cylinder 3D display, real-time display, profile characteristic graph display, Semi-automatic measuring function |
| **Display (Color monitor)** | **:** | 15" LCD |
| **Display items** | **:** | Measuring condition, measuring parameters, printer output condition, profile drawing, comments, error message, etc |
| **Recording System** | **:** | Color printer or laser printer |

Source: QS Metrology (2004)

## 2.10 AISI 1042 CARBON STEEL

AISI 1042 is a Standard grade Carbon Steel. It is composed of (in weight percentage) 0.40-0.47% Carbon (C), 0.60-0.90% Manganese (Mn), 0.04%(max) Phosphorus (P), 0.05%(max) Sulfur (S), and the base metal Iron (Fe). Other designations of AISI 1042 carbon steel include UNS G10420 and AISI 1042.

Steel is the common name for a large family of iron alloys. Steels can either be cast directly to shape, or into ingots which are reheated and hot worked into a wrought shape by forging, extrusion, rolling, or other processes. Wrought steels are the most common engineering material used, and come in a variety of forms with different finishes and properties. Carbon steels alloying elements do not exceed these limits: 1% carbon, 0.6% copper, 1.65% manganese, 0.4% phosphorus, 0.6% silicon, and 0.05% sulfur.

The typical elastic modulus of carbon steels at room temperature (25°C) ranges from 190 to 210 GPa. The typical density of carbon steels is about 7.85 g/cm3. The typical tensile strength varies between 276 and 1882 MPa. The wide range of ultimate tensile strength is largely due to different heat treatment conditions.

## 2.11 BAND SAW

A band saw (figure 2.6) is either a tall machine that sits on the floor, or it's a smaller, shorter machine that sits on top of a bench. It is made up of an outside casing that covers the motor, pulleys, and other inner workings. Band saws are named as such because they have a serrated, metal band that is held in place by two pulleys. The pulleys allow the band (also called the "blade") to move around in a circular motion. The band is what cuts the material feed it, and it is available in different sizes. It is most useful for cutting curved or rounded shapes out of materials. This type of saw has a capacity of handling eight to thirty - six inches of material at a time. The band saw is run by an electric motor, and it can have one or more running speeds.


**Figure 2.6:** Horizontal Band Saw Machine

Source: Everising (2009)

Band saw can cut a variety of materials with a band saw, making it a versatile machine in work shop. However, for every type of material that wants to cut, there is a suitable band saw blade to cut it with. Therefore, the suitable blade needs to change and tune it every time to change materials. By using the proper type of blade, it can cut almost any type of material, including soft wood, hard wood, thin steel, copper, conduit, metals, glass, galvanized pipe, and PVC pipe. Once the proper band saw blade have chosen, and have installed it, then should make sure it is adjusted so it is positioned on the center of the pulleys. The tension of the blade should also be tight enough to keep the blade from slipping. (Sprang, 2002)

## 2.12 TURNINIG WITH LATHE MACHINE

Turning is a form of machining process, a material removal process, which is used to create rotational parts by cutting away unwanted material. The turning process requires a turning machine or lathe machine (figure 2.7), work piece, fixture, and cutting tool. The work piece is a piece of pre-shaped material that is secured to the fixture, which itself is attached to the turning machine, and allowed to rotate at high speeds. The cutter is typically a single-point cutting tool that is also secured in the machine, although some operations make use of multi-point tools. The cutting tool feeds into the rotating work piece and cuts away material in the form of small chips to create the desired shape.


**Figure 2.7:** Lathe Machine

Turning is used to produce rotational, typically axi-symmetric, parts that have many features, such as holes, grooves, threads, tapers, various diameter steps, and even contoured surfaces. Parts that are fabricated completely through turning often include components that are used in limited quantities, perhaps for prototypes, such as custom designed shafts and fasteners. Turning is also commonly used as a secondary process to add or refine features on parts that were manufactured using a different process. Due to the high tolerances and surface finishes that turning can offer, it is ideal for adding precision rotational features to a part whose basic shape has already been formed. (Custompart, 2009)

### 2.12.1 Cutting parameters

In turning, the speed and motion of the cutting tool is specified through several parameters. These parameters are selected for each operation based upon the work piece material, tool material, tool size, and more. (Custompart, 2009)

- Cutting feed - The distance that the cutting tool or work piece advances during one revolution of the spindle, measured in inches per revolution (IPR). In some operations the tool feeds into the work piece and in others the work piece feeds into the tool. For a multi-point tool, the cutting feed is also equal to the feed per tooth, measured in inches per tooth (IPT), and multiplied by the number of teeth on the cutting tool.

- Cutting speed - The speed of the work piece surface relative to the edge of the cutting tool during a cut, measured in surface feet per minute (SFM).

- Spindle speed - The rotational speed of the spindle and the work piece in revolutions per minute (RPM). The spindle speed is equal to the cutting speed divided by the circumference of the work piece where the cut is being made. In order to maintain a constant cutting speed, the spindle speed must vary based on the diameter of the cut. If the spindle speed is held constant, then the cutting speed will vary.

- Feed rate - The speed of the cutting tool's movement relative to the work piece as the tool makes a cut. The feed rate is measured in inches per minute (IPM) and is the product of the cutting feed (IPR) and the spindle speed (RPM).

- Axial depth of cut - The depth of the tool along the axis of the work piece as it makes a cut, as in a facing operation. A large axial depth of cut will require a low feed rate, or else it will result in a high load on the tool and reduce the tool life. Therefore, a feature is typically machined in several passes as the tool moves to the specified axial depth of cut for each pass.

- Radial depth of cut - The depth of the tool along the radius of the work piece as it makes a cut, as in a turning or boring operation. A large radial depth of cut will require a low feed rate, or else it will result in a high load on the tool and reduce the tool life. Therefore, a feature is often machined in several steps as the tool moves over at the radial depth of cut.

### 2.12.2 Facing Operation

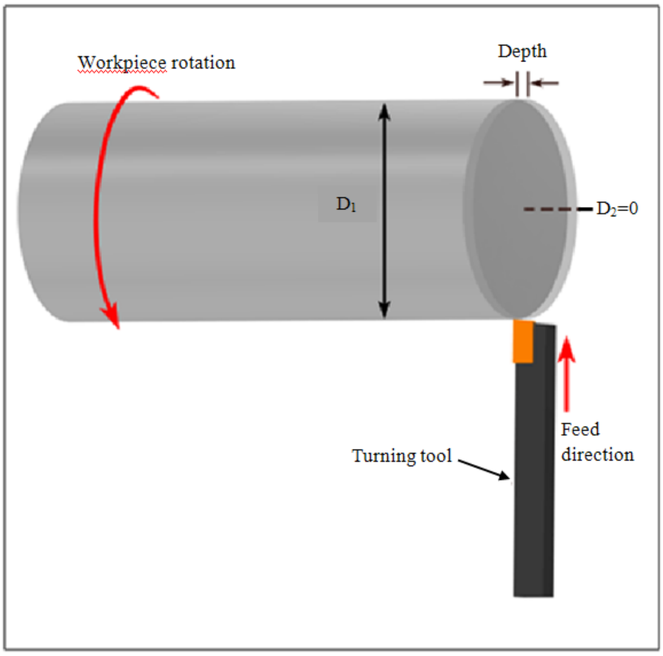


**Figure 2.8:** Facing Process

Source: Custompart (2009)

In facing process (figure 2.8), a single-point turning tool moves radially, along the end of the work piece, removing a thin layer of material to provide a smooth flat surface. The depth of the face, typically very small, may be machined in a single pass or may be reached by machining at a smaller axial depth of cut and making multiple passes. (Custompart, 2009)

## 2.13 STATISTICA SOFTWARE

The STATISTICA line of software provides a comprehensive and integrated set of tools and solutions for (Statsoft, 2010):

i. Data analysis and reporting, data mining and predictive modeling, business intelligence, simple and multivariate QC, process monitoring, analytic optimization, simulation, and for applying a large number of statistical and other analytic techniques to address routine and advanced data analysis needs

ii. Data visualization, graphical data analysis, visual data mining, visual querying, and simple and advanced scientific and business graphing; in fact, STATISTICA has been acknowledged as the "king of data visualization software" (by the editors of " PC Graphics & Video")

iii. Simple and advanced desktop analyses and computing for business, engineering, research institutions, universities, laboratories, and for applications ranging from CRM and predictive modeling to the application of multivariate model-based quality control

iv. Role-based and guided enterprise-wide analytic computing and reporting, using Web-enabled server-based computations managed by a mature, robust, scalable, and open-architected server platform that can take advantage of the most powerful hardware, multi-core servers, and server farms, to perform mission critical analytic tasks (in validated manufacturing environments) that in many cases cannot be accomplished by any other analytic solution platform

v. Quickly deploying enterprise data analysis or predictive modeling solutions, credit scoring solutions, multivariate SPC and advanced process monitoring solution on 32-bit or 64-bit platforms, in various languages, and supported by local offices and training centers world-wide

### 2.13.1 STATISTICA Features and Benefits

The STATISTICA line of software consists of a fully integrated line of analytic, graphics, and data management solutions and libraries, developed and refined over the past 25 years, and validated over decades by thousands of individual users and in enterprise installations worldwide, often for critical data analyses or in mission/business critical applications.

STATISTICA is a carefully planned, brilliantly designed, and meticulously executed line of software solutions that follows industry-standard software rules and interfaces, language standards, accessibility standards, UI recommendations.

STATISTICA solutions were developed to get things done, to provide the fastest return on investment, best value, and uniquely useful and effective analytic, data management, graphics, and presentation tools to create predictable value quickly for you and your organization and applications.

STATISTICA analytic solutions are available (off-the-shelf) for various computing platforms and applications.

All solutions are fully and tightly integrated, and built around the same highly optimized STATISTICA libraries.

STATISTICA Solutions have been in use for decades world-wide and in multiple languages, for diverse applications.

STATISTICA solutions provide an array of unique features that are critical for our customers' successes. Here are some additional key differentiators that set STATISTICA apart from the competition. (Statsoft, 2010)

## 2.14 PREVIOUS REASEARCH

### 2.14.1 Prediction of Surface Roughness And Roundness Error In Cylindrical Grinding

This article writes by C.K. Dhinakarraj and P.Mangaiyarkarasi. This project to assure product quality by predicting the surface finishes parameters in real time. Parameters that measured are speed, depth of cut and feed rate. Analyze surface roughness and roundness.

In experimental procedure, they use full factorial method for design of experiment. They use three parameters with four levels. That means, the job numbers of experiment are sixty four. A silicon carbide grinding wheel A60 L5 V10 (ф350x 125 x 25) and die coat cutting fluid were used for cylindrical grinding operations. The work piece that use is EN8 steel. The values of speed that use are 116rpm, 140rpm, 180rpm and 240rpm. For feed rate are 2.68mm/sec, 3.4mm/sec, 5.6mm/sec and 6.2mm/sec. And for depth of cut are 2µm, 4µm, 6µm and 8µm.

In statistical analysis, analysis of variance or ANOVA was used. Then, artificial neural network was used. Neural networks have been trained to perform complex functions in various fields, including pattern recognition, identification, classification, and speech, vision, and control systems. After that

Conclusions from this article are when feed rate is increased, the arithmetic mean roughness value (Ra) also increased and gives poor finish, the increase in depth of cut during grinding process increases the surface roughness value and roundness error and the increase in spindle speed increases the surface roughness and roundness error.

### 2.14.2 Multi-Parameter Optimization and Control of the Cylindrical Grinding Process

This article writes by G.F. Li, L.S. Wang and L.B. Yang. This paper presents an optimum system for cylindrical plunge grinding process to minimize production time ensuring part quality requirements.

The usual optimization objective in cylindrical in cylindrical plunge grinding is to minimize the production time while satisfying work piece quality constraints. The work piece qualities are usually associated with thermal damage, surface roughness, size tolerance and out-of-roundness. This article had designed a simulating program based on MATLAB software for the whole grinding process. The result of the optimum simulation can be used to control the actual grinding process in the future.

This paper presents an optimum system for cylindrical plunge grinding process to minimize production time while ensuring part quality requirements. The simulation and the experiments proved the exactitude of the optimum models and the feasibility of the optimum strategy. Industrial implementation of this optimal controlling system had reduced grinding time greatly.

### 2.14.3 Improvements In Out-Of-Roundness And Microhardness Of Inner Surfaces By Internal Ball Burnishing Process

The title of this journal is "Improvements In Out-Of-Roundness And Microhardness Of Inner Surfaces By Internal Ball Burnishing Process". This article writes by M.H. El-Axir, O.M. Othman and A.M. Abodiena. This paper presents the investigation of the effect of the stated parameters of internal ball burnishing process on the work material characteristics.

This paper examines the use of the internal ball burnishing process to improve internal surface characteristics such as, surface roundness and surface microhardness for 2014 aluminum alloy using CNC lathe machine. Aluminum alloy 2014 was used as an experimental work material. The main objective of this work is the investigation of the effect of the stated parameters of internal ball burnishing process on the work material characteristics.

The results obtained have shown that burnishing speed has different effect on the two responses studied. An increase in burnishing speed leads to a considerable reduction in out-of-roundness, however, it has no significant effect on surface microhardness.

**Table 2.4:** Previous Research Summary

| Authors (Year) | Title | Description |
|---|---|---|
| C.K. Dhinakarraj, P.Mangaiyarkarasi (2007) | Prediction of Surface Roughness and Roundness Error in Cylindrical Grinding by Artificial Neural Network | This project to assure product quality by predicting the surface finishes parameters in real time. Parameters that measured are speed, depth of cut and feed rate. Analyze surface roughness and roundness. |
| G.F. Li, L.S. Wang, L.B. Yang. (2002) | Multi-parameter optimization and control of the cylindrical grinding process | This paper presents an optimum system for cylindrical plunge grinding process to minimize production time ensuring part quality requirements. |
| M.H. El-Axira, O.M. Othmanb, A.M. Abodienac. (2007) | Improvements in out-of-roundness and microhardness of inner surfaces by internal ball burnishing process | The authors had shown the investigation of the effect of the stated parameters of internal ball burnishing process on the work material characteristics. |

# CHAPTER 3

# METHODOLOGY

## 3.1 INTRODUCTION

This chapter discussed the methodology of the research. Methodology is a way in which all of the techniques, method and procedures adopted to collect data, to analysis data and to carry out research is done. (Nazrin, 2009).

The purpose of the research is to study the optimization of cylindrical grinding parameter for the high product quality subject to roundness constraint. In order to achieve the objective outlined, a systematic approach of methodology is adopted as show in figure 3.1.

This study includes literature review, field work, laboratory work and analysis study. The literature review study included the research about study case. The research are refers to journals, reference books and manual book of the machine. The field work includes work piece preparation and grinding process and laboratory study is measurements of roundness. Analysis done by used Statistica software.

From the experiments, and assessment conducted, analyzing the data for result of research was done. The scope of study is limited to roundness error in cylindrical grinding. Then all the data were analyzing and interpretation, discussion and conclusion can be made.

## 3.2 EXPERIMENTAL DESIGN

In this study, full factorial applied to design the experiment. The reason use full factorial because it responses are measured at all combinations of the experimental factor levels, the combinations of factor levels represent the conditions at which responses will be measured and each experimental condition is a run. The response measurement is an observation. The entire set of runs is the design.

### 3.2.1 Full Factorial Design

The full factorial design are among the most widely DOE used for product, design and process improvement. (Fathul Naim, 2008). The capability to estimate the correlation between two or more factor in one time is the one of the advantages when used full factorial design method.

In this study, three factor experiment design used with three levels. The number of experiment required is $3^3$ equal to 27 experiments. The table of full factorial experiment design is shown in table 3.1.

Three parameters that used are diameter of work piece, speed and depth of cut. The three levels of diameter are 18mm, 20mm and 22mm. The levels for speed are 40rpm, 80rpm and 120rpm. The levels for depth of cut are 5µm, 10µm and 20µm. All parameters filled in table 3.1.

**Table 3.1:** Experiment and Result Table

| **Test No** | **Diameter (mm)** | **Speed (rpm)** | **Depth Of Cut (µm)** | **Roundness, R (µm)** |
|---|---|---|---|---|
| 1 | 18 | 40 | 5 | |
| 2 | 18 | 40 | 10 | |
| 3 | 18 | 40 | 20 | |
| 4 | 18 | 80 | 5 | |
| 5 | 18 | 80 | 10 | |
| 6 | 18 | 80 | 20 | |
| 7 | 18 | 120 | 5 | |
| 8 | 18 | 120 | 10 | |
| 9 | 18 | 120 | 20 | |
| 10 | 20 | 40 | 5 | |
| 11 | 20 | 40 | 10 | |
| 12 | 20 | 40 | 20 | |
| 13 | 20 | 80 | 5 | |
| 14 | 20 | 80 | 10 | |
| 15 | 20 | 80 | 20 | |
| 16 | 20 | 120 | 5 | |
| 17 | 20 | 120 | 10 | |
| 18 | 20 | 120 | 20 | |
| 19 | 22 | 40 | 5 | |
| 20 | 22 | 40 | 10 | |
| 21 | 22 | 40 | 20 | |
| 22 | 22 | 80 | 5 | |
| 23 | 22 | 80 | 10 | |
| 24 | 22 | 80 | 20 | |
| 25 | 22 | 120 | 5 | |
| 26 | 22 | 120 | 10 | |
| 27 | 22 | 120 | 20 | |

## 3.3 WORKPIECE PREPARATION

To do the preparation of work piece, the material type and dimension must be identifying. The material that use as work piece in this research is carbon steel. The diameter of work piece are 18mm, 20mm and 22mm. All length of this work piece is 150mm length.

### 3.3.1 Work piece Cutting Process

The horizontal band saw (Figure 3.1) used to prepare work pieces. The type of band saw that is S-300HB. The specification of this machine as show in table 3.3.


**Figure 3.1**: Material Cutting Process

**Table3.2**: Specification of S-300HB Band Saw Machine

| Specification | | Dimension |
|---|---|---|
| Cross Section | Circle | 300mm |
| | Rectangular | 300x250mm |
| Bundle Cutting | Width | 145 to 230mm |
| | Height | 30 to 130mm |
| Blade Speed | 50Hz<br>60Hz | 20 to 100 m/min (INTERVAL) |
| Blade Size | | 3820x34x1.1 mm |
| Blade Tension | | Hydraulic |

Source: Everising (2009)

The carbon steel AISI1042 25mm diameter enables to be clamp by vise. The material was cut into a 150mm length size by using the horizontal band saw machine. In this process, the cutting speed and feed rate must be set depends on the material. The specifications of AISI1042 show in appendix F.

### 3.3.2 Burr Discard Process

After finish cut the material into its desired length, the next process is discard the burr by using the file as show in figure 3.2. This process must be careful because surface side of material is very sharp.

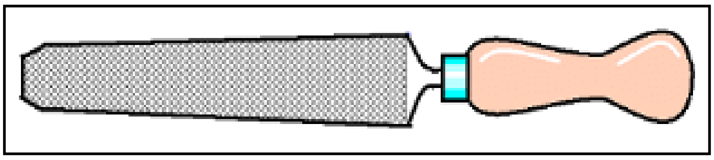

**Figure 3.2**: File

### 3.3.3 Turning Process

After burr discard, the next process is turning process by using lathe machine (figure 3.3). In turning process there are have two processes should be done to work pieces preparation.

The first process is to make work piece diameter into three dimensions there are 18mm, 20mm and 22mm. Three work pieces done for each diameter dimension. The facing process also happens in this process. Facing is important because to make sure work pieces not have rust. The second process in turning is making center drill hole. This is important in cylindrical grinding process.

**Figure 3.3:** Lathe Machine

## 3.4 CYLINDRICAL GRINDING PROCESS

In this grinding process, all parameters of cylindrical grinding constant accept speed, feed rate and depth of cut. The type of cylindrical grinding is Okamoto -OGM 250 EXB and the type of grinding wheel is aluminum oxide.

### 3.4.1 Aluminum Oxide Grinding Wheel

As an angular, durable blasting abrasive, aluminum oxide (or aluminium oxide) can be recycled many times. It is the most widely used abrasive grain in sand blast finishing and surface preparation because of its cost, longevity and hardness. Harder than other commonly used blasting materials, aluminum oxide grit powder penetrates and cuts even the hardest metals and sintered carbide.

Approximately 50% lighter than metallic media, aluminum oxide abrasive grain has twice as many particles per pound. The fast-cutting action minimizes damage to thin materials by eliminating surface stresses caused by heavier, slower cutting media.

Aluminum oxide grit powder has a wide variety of applications, from cleaning engine heads, valves, pistons and turbine blades in the aircraft industry to lettering in monument and marker inscriptions. It is also commonly used for matte finishing, as well as cleaning and preparing parts for metalizing, plating and welding. Aluminum oxide abrasive grain is the best choice for an abrasive sand blasting and polishing grain as well as for preparing a surface for painting.


**Figure 3.4:** Aluminum Oxide Grinding Wheel

## 3.5 ROUNDNESS TEST

After do the cylindrical grinding process, the roundness of work piece $ measured. To measure the roundness of work piece, roundness measuring machine is use. The value of roundness, R filled in table.


**Figure 3.5:** Roundness Measuring Machine

Source: UITM (2010)

## 3.6 ANALYSIS OF RESULT

The experiment data was analyzes using the following statistical tools the present contribution from an analysis of variance (ANOVA) and the correlation between machining parameters and the characteristic of roundness error, R. The statistical method is important indicators in order to show which parameter has an effect and how effective it is on the product quality or process performance. Analysis of variance is an important method used for interpreting experimental data and making essential decisions. Therefore, the experimental data obtained was subjected to analysis of variance.

The experimental data was analyzed using the following statistical tools the percent contribution from an analysis of variance (ANOVA) and the correlation between machining parameters and the characteristic of roundness error (R). When the analysis results are evaluated, the effects of factors will become obvious and which of them can be ignored or must be kept under control. The statistical methods are important indicators in order to show which parameter has an effect and how effective it is on the product quality or process performance. Analysis of variance is an important method used for interpreting experimental data and making essential decisions. This is a statistical decision-making device used to find differences in the average performance of samples. Therefore, the experimental data obtained was subjected to ANOVA and correlation test using mathematical software there is STATISTICA.

ANOVA table must be build to make analysis. From that table, the result of this experiment will conclude.

**Table 3.4:** ANOVA Table

| **Source** | **Sum of Squares, SS** | **Degree of Freedom, DF** | **Mean square, MS** | **F-test** | **Signifi-cance, p** |
|---|---|---|---|---|---|
| Treatment 1 | SST | k-1 | SST / (k-1) | MST/MSE | |
| Treatment 2 | SST | k-1 | SST / (k-1) | MST/MSE | |
| Treatment 3 | SST | k-1 | SST / (k-1) | MST/MSE | |
| Error | SSE | N-k | SSE / (N-k) | | |
| Total | SS | N-1 | | | |

k=3; N=27

# CHAPTER 4

# RESULT AND DISCUSSION

## 4.1 INTRODUCTION

In this section, the results obtained from the experiment are discussed and ANOVA analyses with the help of STATISTICA software. Based on the result of ANOVA analyses, optimal setting of the grinding parameters for roundness is obtained. Then, the conformation experiment is run for verification.

## 4.2 EFFECT OF ROUNDNESS RESULT

### 4.2.1 Roundness Experiment Result

Figure 4.1 show the workpiece after cylindrical grinding process. Three various section on a mild steel workpiece as mentioned in the chapter 3 can see on this figure. Each section show different depth of cut. End workpiece for 20µm depth of cut, middle for 10µm depth of cut and lastly for 5µm depth of cut.

After cylindrical grinding process, the specimen will be test by used roundness measuring machine to measure and record roundness. Figure D-1, D-2 and D-3 in appendix D show the measurement pictures during using the roundness measuring machine.

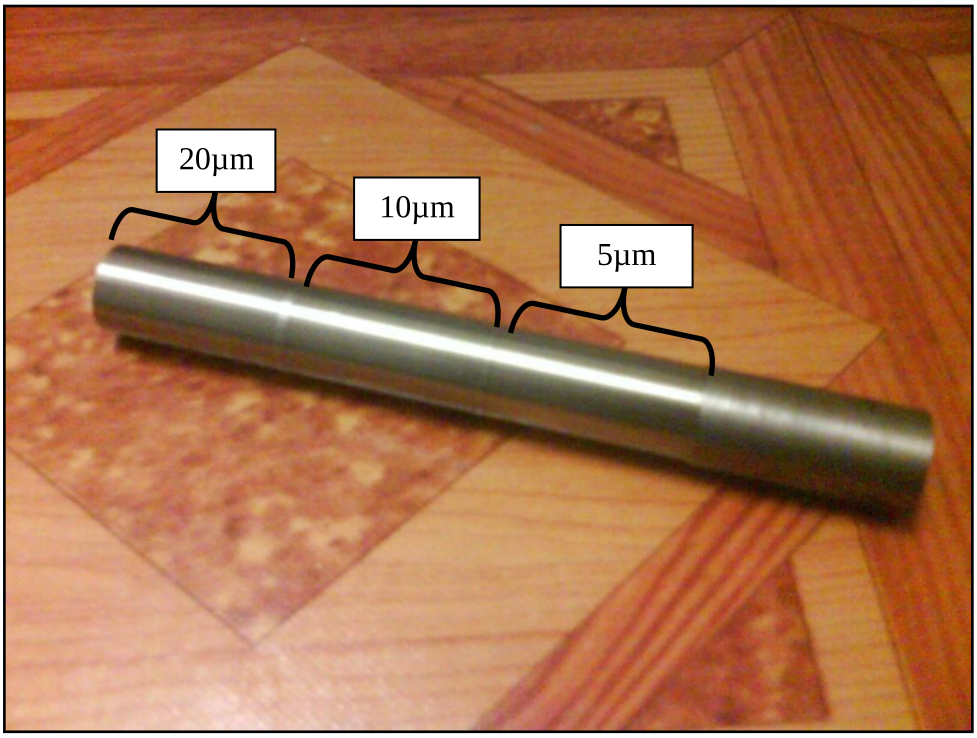


**Figure 4.1:** A Work piece After Grinding Process with Different Depth of Cut

**Figure 4.2:** Three Work pieces After Grinding Process with Different Diameter

**Table 4.1:** Roundness Result

| **Number of Experiment** | **Cutting Parameter Level** | | | **Roundness, R (µm)** |
|---|---|---|---|---|
| | **Work piece Diameter (mm)** | **Cutting Speed (rev/min)** | **Depth of Cut (µm)** | |
| 1 | 18 | 40 | 5 | 15.0 |
| 2 | 18 | 40 | 10 | 4.5 |
| 3 | 18 | 40 | 20 | 3.0 |
| 4 | 18 | 80 | 5 | 25.0 |
| 5 | 18 | 80 | 10 | 18.7 |
| 6 | 18 | 80 | 20 | 4.6 |
| 7 | 18 | 120 | 5 | 11.0 |
| 8 | 18 | 120 | 10 | 4.0 |
| 9 | 18 | 120 | 20 | 1.6 |
| 10 | 20 | 40 | 5 | 20.5 |
| 11 | 20 | 40 | 10 | 3.0 |
| 12 | 20 | 40 | 20 | 2.0 |
| 13 | 20 | 80 | 5 | 34.5 |
| 14 | 20 | 80 | 10 | 13.0 |
| 15 | 20 | 80 | 20 | 10.5 |
| 16 | 20 | 120 | 5 | 14.4 |
| 17 | 20 | 120 | 10 | 1.7 |
| 18 | 20 | 120 | 20 | 2.8 |
| 19 | 22 | 40 | 5 | 25.5 |
| 20 | 22 | 40 | 10 | 26.0 |
| 21 | 22 | 40 | 20 | 27.5 |
| 22 | 22 | 80 | 5 | 48.2 |
| 23 | 22 | 80 | 10 | 33.5 |
| 24 | 22 | 80 | 20 | 31.0 |
| 25 | 22 | 120 | 5 | 20.3 |
| 26 | 22 | 120 | 10 | 5.2 |
| 27 | 22 | 120 | 20 | 4.0 |

Table 4.1 shows the obtained results of the conducted experiment at the Mechanical Engineering Faculty (Universiti Malaysia Pahang) grinding machine laboratory. As mentioned above, the work piece roundness is determined by using the roundness measuring machine at Mechanical Engineering Faculty (Universiti Teknologi Mara, Pulau Pinang) metrology laboratory. Based on these results, analysis will be done by using the STATISTICA software and the analysis of variance (ANOVA) generated by that software.

### 4.2.2 Analysis Result

By using Statistica software, the data checked first before continue with another analysis. This step to make sure that data is valid or not. The graph of observed value against predicted value needs to generate to check the validity of the data. Figure 4.3 the graph of observed value against predicted value.

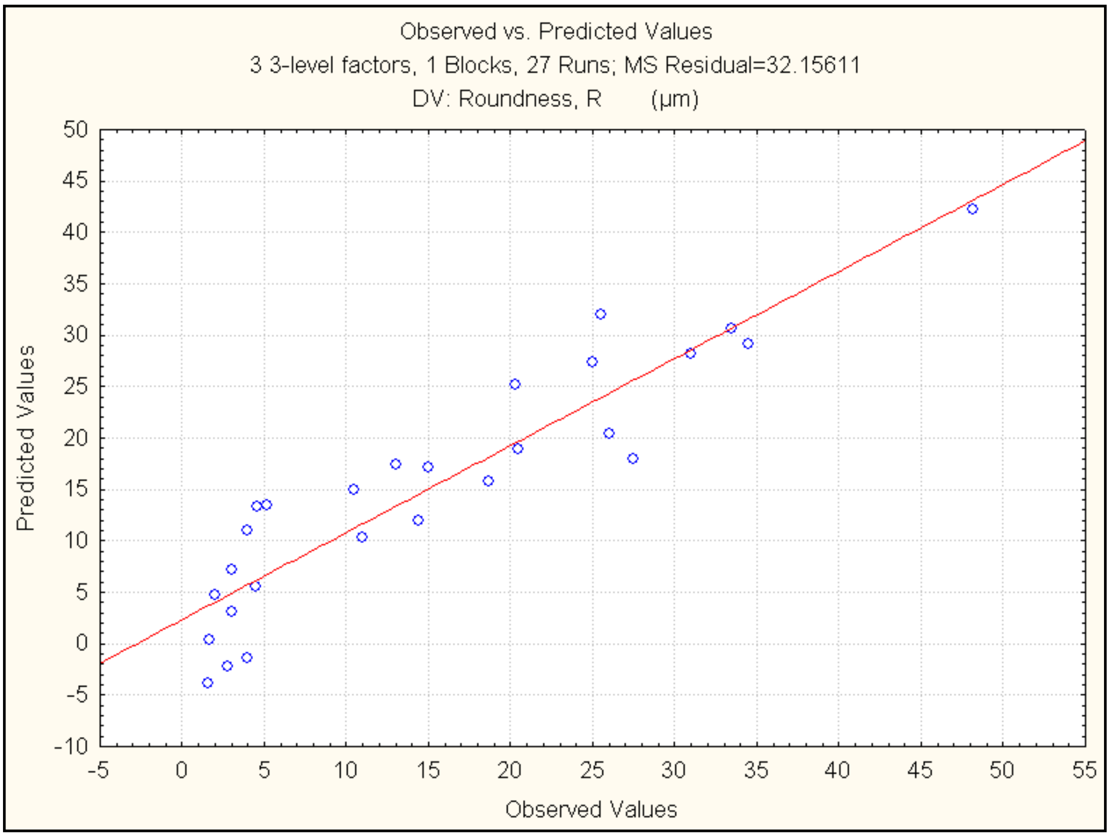


**Figure 4.3:** Graph Observed Against Predicted Value

Based on figure 4.3, the graph shows that the plot of observed value is lies near to the predicted value line. So that, the data can be use for another analysis.

**Table 4.2:** Effect Estimate

| Factor | Effect | Std Error | t(20) | p |
|---|---|---|---|---|
| **Mean/intrc.** | 14.4358 | 1.1014 | 13.1071 | 0.0000 |
| **Work piece Diameter (L)** | 14.8667 | 2.673163 | 5.56145 | 0.000019 |
| **Work piece Diameter (Q)** | -5.7667 | 2.315027 | -2.49097 | 0.021647 |
| **Cutting Speed (L)** | -6.8889 | 2.673163 | -2.57705 | 0.017997 |
| **Cutting Speed (Q)** | 13.6667 | 2.315027 | 5.90346 | 0.000009 |
| **Depth of Cut (L)** | -14.1556 | 2.673163 | -5.29543 | 0.000035 |
| **Depth of Cut (Q)** | -6.9259 | 2.357509 | -2.93782 | 0.008136 |

### 4.2.2.1 Graph Between Cutting Speed Against Work piece Diameter

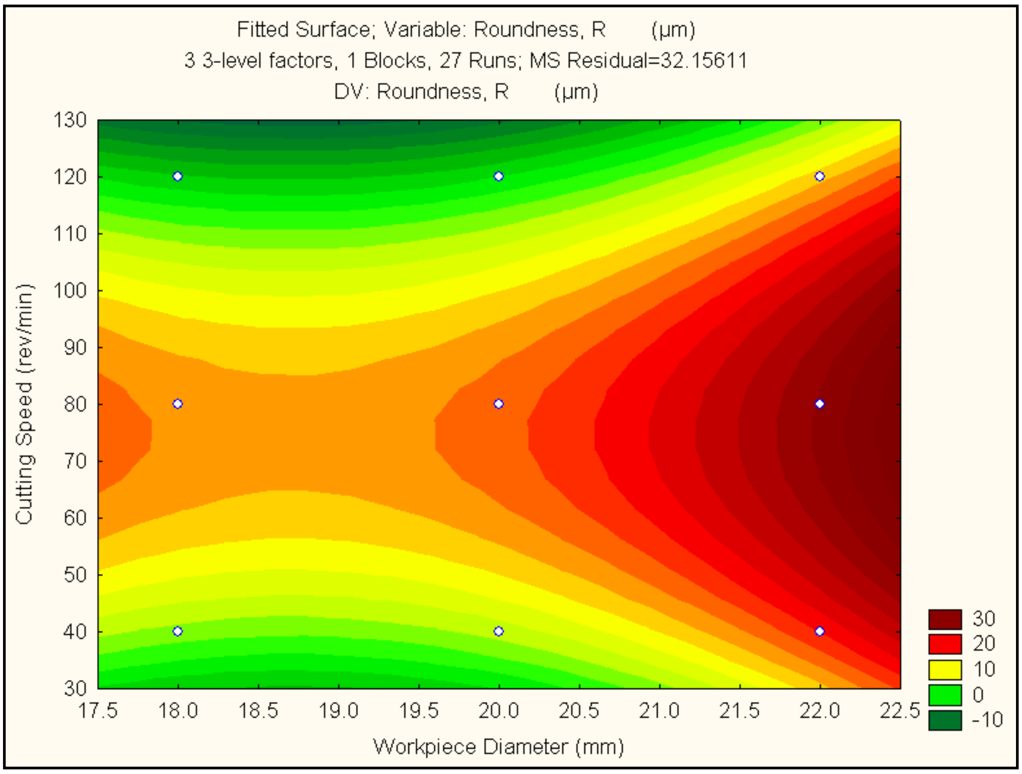


**Figure 4.4a:** Graph 2-Dimension for Cutting Speed against Work piece Diameter

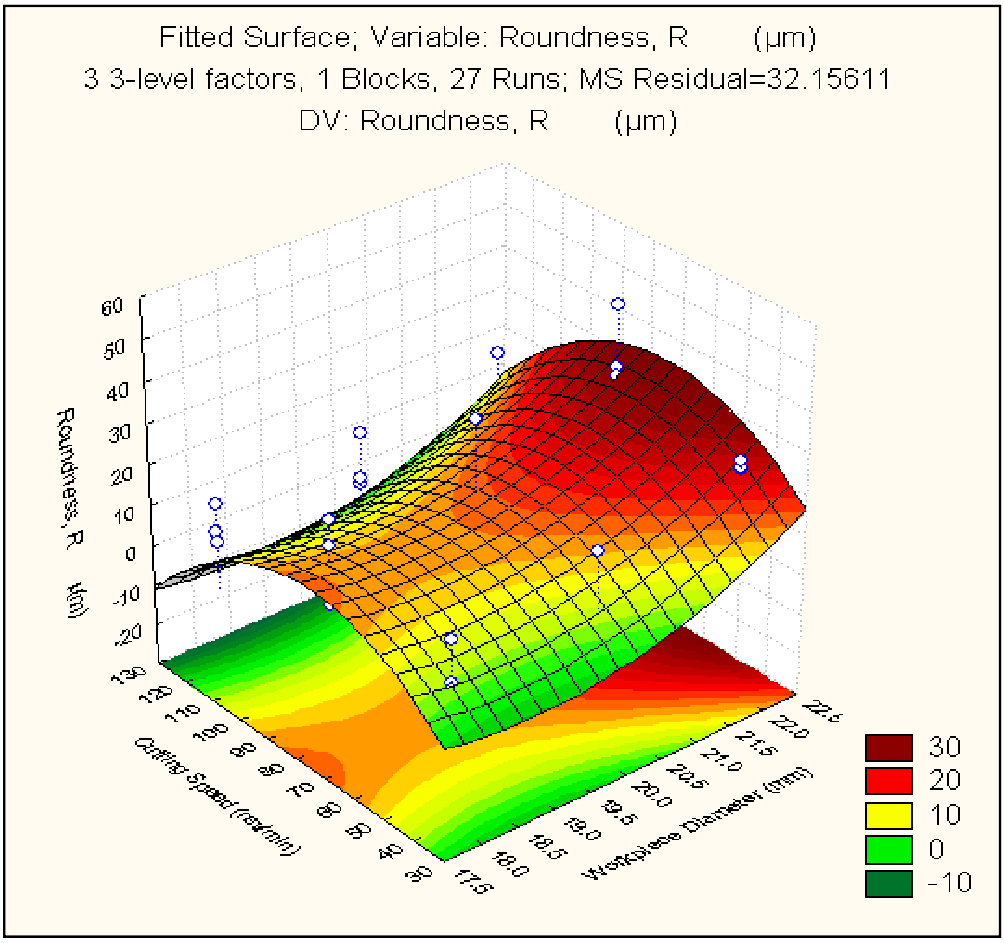


**Figure 4.4b:** Graph 3-Dimension for Cutting Speed against Work piece Diameter

Figure 4.4a and 4.4b shows the graph cutting speed against work piece diameter affected to roundness error. From that figures, the data can concluded that the roundness increase when diameter of work piece increase. Besides that, roundness error higher in middle of cutting speed. But it is effect when diameter is increase. To achieve good roundness error at constant depth of cut, diameter of work piece should be kept at minimum level.

### 4.2.2.2 Graph Between Depth of Cut Against Work piece Diameter

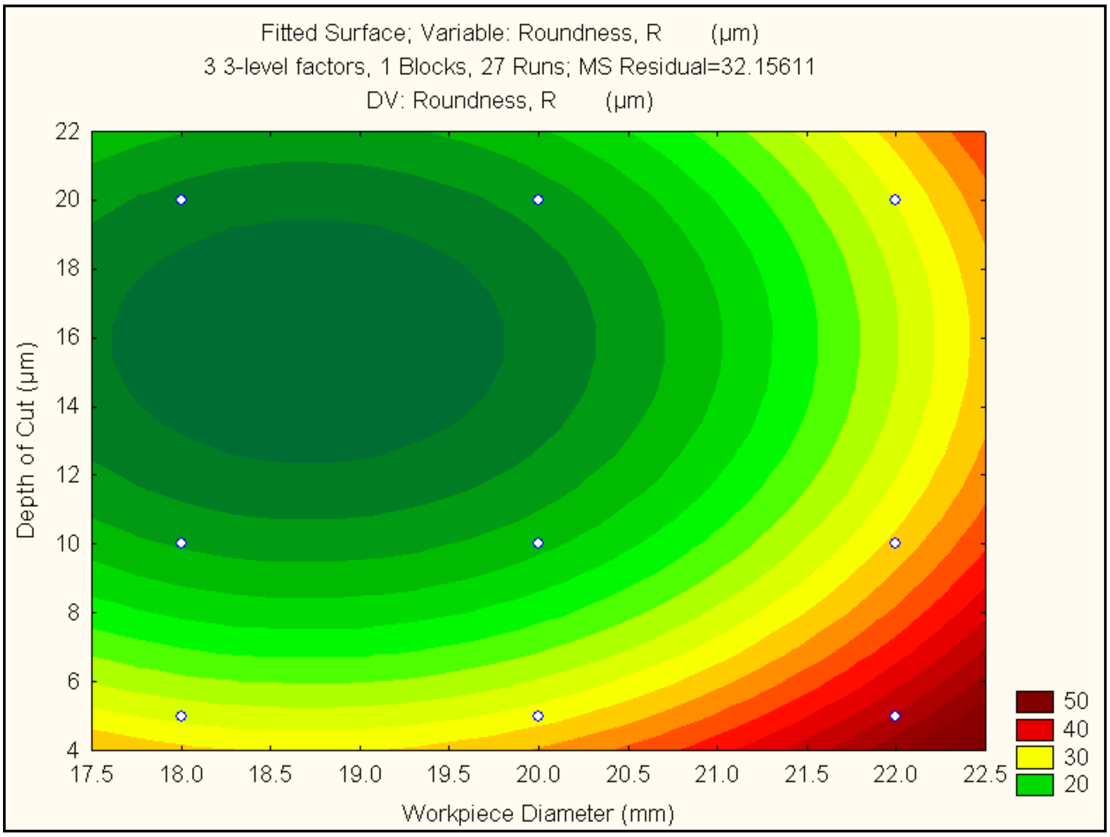


**Figure 4.5a:** Graph 2-Dimension for Depth of Cut against Work piece Diameter

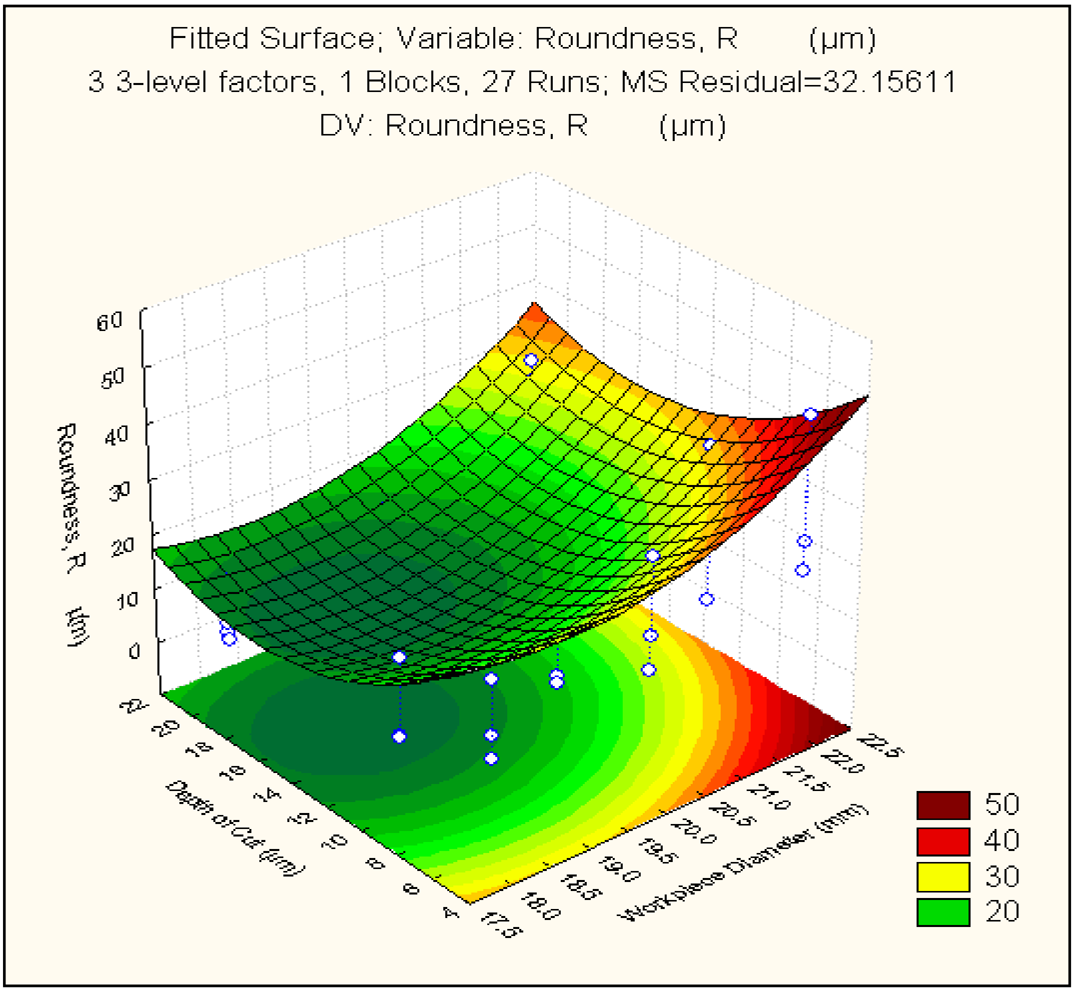


**Figure 4.5b:** Graph 3-Dimension for Depth of Cut against Work piece Diameter

Figure 4.5a and 4.5b shows the graph depth of cut against work piece diameter affected to roundness error. From that figures, the data can concluded that the roundness increase when diameter of work piece increase. Others roundness increase when depth of cut decrease. To achieve good roundness error at constant speed, diameter of work piece should be kept at minimum level and avoid use small value of depth of cut.

#### 4.2.2.3 Graph Between Depth of Cut Against Cutting Speed

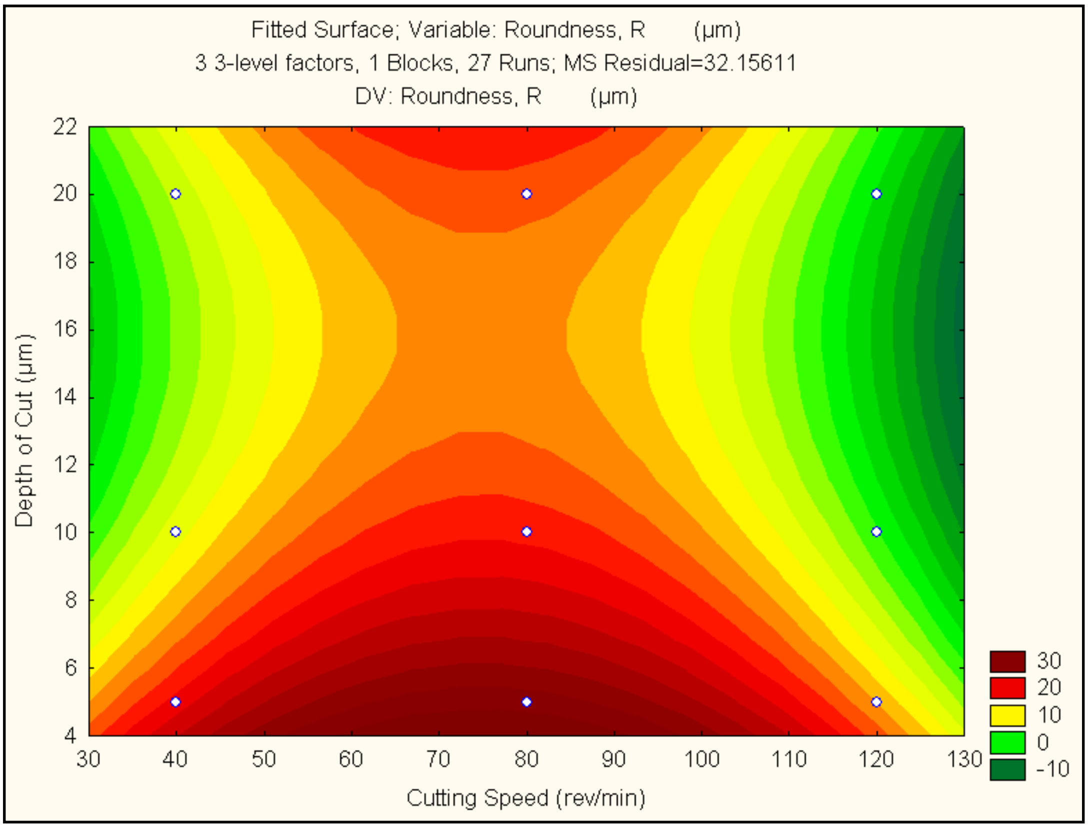


**Figure 4.6a:** Graph 2-Dimension for Depth of Cut against Cutting Speed

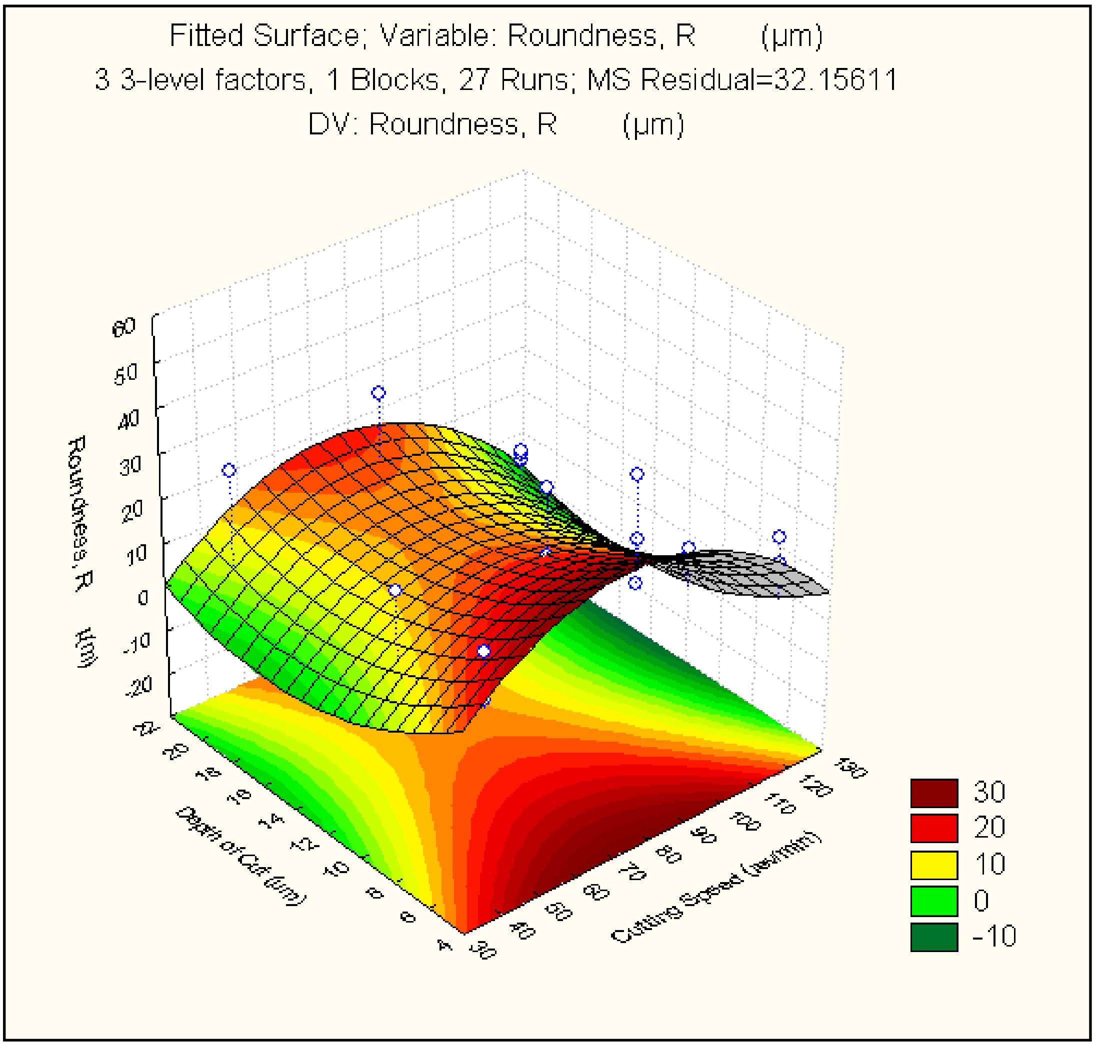


**Figure 4.6b:** Graph 3-Dimension for Depth of Cut against Cutting Speed

Figure 4.6a and 4.6b shows the graph depth of cut against cutting speed affected to roundness error. From that figures, the data can concluded that the roundness increase when cutting speed nearly into range 70-80rev/min of cutting speed. Besides that, roundness error increase when depth of cut decreases. To achieve good roundness error at constant diameter, avoid use range 70-80rev/min of cutting speed and avoid use small value of depth of cut.

**Table 4.3:** Regression Coefficient

| Factor | Regression Coeff. | Std Error | t(20) | p |
|---|---|---|---|---|
| **Mean/intrc.** | 502.2148 | 230.5792 | 2.17806 | 0.041542 |
| **Work piece Diameter (L)** | -53.9500 | 23.1599 | -2.32946 | 0.030427 |
| **Work piece Diameter (Q)** | 1.4417 | 0.5788 | 2.49097 | 0.021647 |
| **Cutting Speed (L)** | 1.2806 | 0.2339 | 5.47476 | 0.000023 |
| **Cutting Speed (Q)** | -0.0085 | 0.0014 | -5.90346 | 0.000009 |
| **Depth of Cut (L)** | -4.4067 | 1.2250 | -3.59729 | 0.001800 |
| **Depth of Cut (Q)** | 0.1385 | 0.0472 | 2.93782 | 0.008136 |

$$\mathbf{Y = B_o + B_1x_1 + B_2x_2 + B_3x_3 + \epsilon}$$

**Equation 4.1:** The General Model Equation For $3^k$ Factorial Design

From equation 4.1, the values of regression coefficient is substitute into that equation. For this experiment analysis:

$\mathbf{x_1}$ for diameter of work piece

$\mathbf{x_2}$ for speed

$\mathbf{x_3}$ for depth of cut

After subtitution, the roundness equations will be get where R for roundness, d for diameter, s for speed and x for depth of cut.

Linear : $\mathbf{R} = 502.2148 - 53.9500\mathbf{d} + 1.2806\mathbf{s} - 4.4067\mathbf{x}$

Quadratic : $\mathbf{R} = 502.2148 + 1.4417\mathbf{d} - 0.0085\mathbf{s} + 0.1385\mathbf{x}$

### 4.2.3 Analysis of Variance (ANOVA)

The experimental data was analyzed using the statistical tools shows the percent contribution from an analysis of variance (ANOVA) and the correlation between machining parameters and the characteristic of roundness error (R). When the analysis result is evaluated, the effect of factors will become obvious and which of them can be ignored or must be kept under control. The statistical methods are important indicators in order to show which parameter has an effect and how effective it is on the product quality or process performance. Analysis of variance is an important method used for interpreting experimental data and making essential decision. This is a statistical decision-making device used to find differences in the average performance of samples. Therefore, the experimental data obtained was subjected to ANOVA and correlation test using Statistica software.

**Table 4.4:** Analysis of Variance (ANOVA)

| | Sum of Squares (SS) | df | Mean Square (MS) | F | Significance (p) |
|---|---|---|---|---|---|
| **Workpiece Diameter** | 1194.107 | 2 | 597.053 | 18.56734 | 0.000028 |
| **Cutting Speed** | 1334.222 | 2 | 667.111 | 20.74601 | 0.000013 |
| **Depth of Cut** | 1026.836 | 2 | 513.418 | 15.96641 | 0.000072 |
| **Error** | 643.122 | 20 | 32.156 | | |
| **Total SS** | 4198.287 | 26 | | | |

$R^2 = 0.84681$

$R^2$ (adj) = 0.80086

From table 4.4, the value of F of cutting speed has higher value and it has 0.000013 significance. The next higher value of F is for work piece diameter which has significance of 0.000028. The last is depth of cut which has significance of 0.000072.

From this analysis, speed influence more in roundness error followed by work piece diameter and depth of cut. It is conclude that speed has more influence in roundness error in this experiment.

In ANOVA analysis, the value of $R^2$ equal to 0.84681, that means the experiments data are accepted because the near to 85%. So, the data that got can use for analysis.

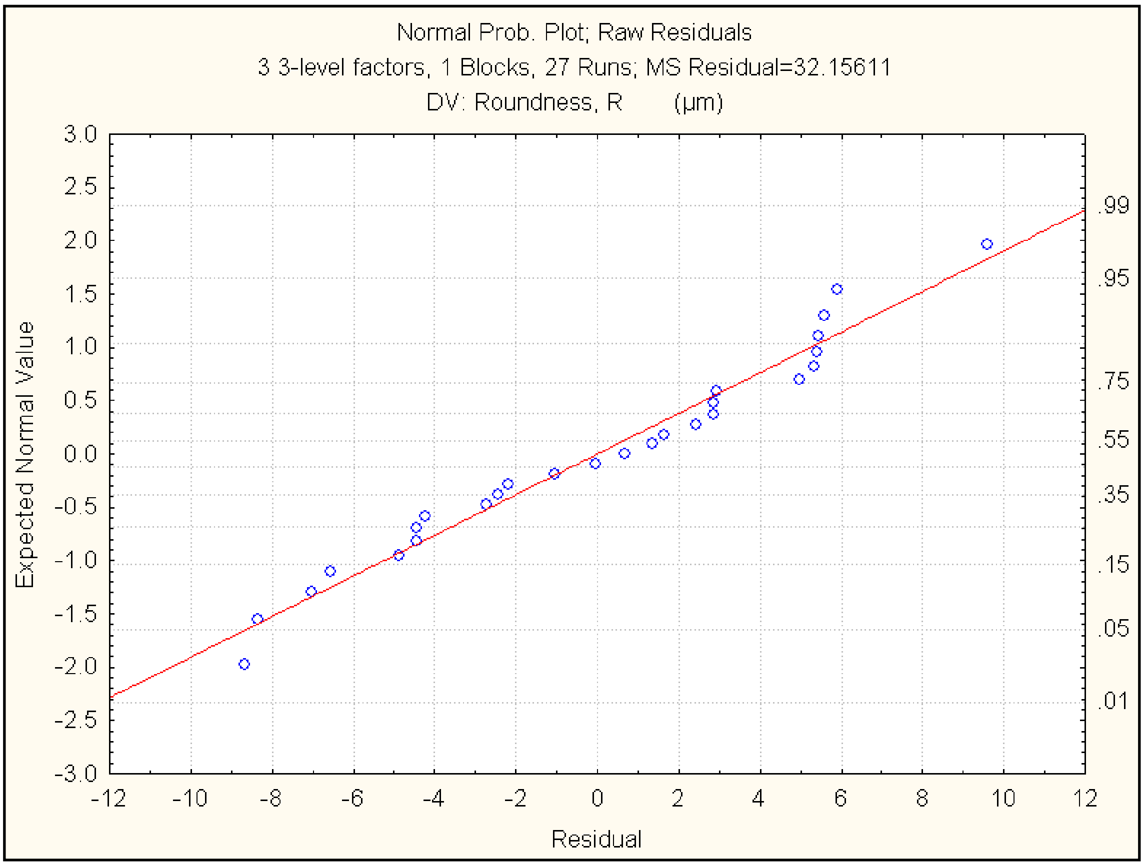


**Figure 4.7:** Graph Residual against Expected Normal

The normal probability plot (figure 4.7) is a common tool to assess how closely a set of observed values (residuals in this case) follows a theoretical distribution. In this plot the actual residual values are plotted along the horizontal x-axis and the vertical y-axis shows the expected normal values for the respective values. Majority values fall onto a straight line. So that the data can be satisfied that the residuals follow the normal distribution.

## 4.3 FACTOR OF ROUNDNESS PHENOMENA OCCUR

Have a few factors that make roundness error occur during conduct cylindrical grinding process. The main factor that influences the surface roundness is vibration. Vibrations are mechanical oscillations, produced by regular or irregular period movements of a member or body about its rest position. Vibration can affect visual perception, muscles, concentration, circulation and the respiratory system.

Another factor is temperature. Temperature is occurring at the wheel and work piece interface. Temperatures occur from friction between wheel and work piece. Temperatures produce heat energy on the work piece. Work piece is expanded when get heat. Materials removing for cylindrical grinding process are not smoothly and it made effect of roundness error on work piece.

Vibration and temperature can be source problems at engineering level because they can result in damage to equipment, loss of control of equipment, and reduction in the efficiency of operation of machines.

# CHAPTER 5

# CONCLUSION

## 5.1 INTRODUCTION

This chapter provides conclusion of finding for this project and summarization by of overall progress taken and discussion of the project. For future reference, some recommendations are enlisted as a topic in this chapter for enhancement of knowledge in continuing this research of chatter vibration.

In order to optimize the cylindrical grinding parameter to yield the lowest roundness error value in the process, a combination of knowledge in cutting tool parameters, variable cutting tool parameters and work piece material is very crucial. The use of Full Factorial Method as the design of experiment (DOE) is very useful in analyzing the effect and the interaction of the factors. An analysis of roundness error value during the process can be very complex if it is involves an interaction.

## 5.2 CONCLUSION

This project is successfully completed and all of the notified objectives already been achieved which are to investigate roundness error that occurrence of cylindrical grinding machining via experimental. The roundness error of work piece after cylindrical grinding machining was successfully obtained by RANDCOM-31C roundness measuring machine and analyze by using ANOVA technique. It obviously showed from the finding that, the most significant factor for the producing roundness error is the speed. It is conclude that speed has more influence in roundness error in this experiment.

When diameter increased, the arithmetic roundness value (R) also increased and gives poor finish. Because of higher diameter make the metal removal is not uniform and it may not remove the material and also due to high vibration of grinding machine which result in the bad quality product (roundness error). The roundness error increased when the value of spindle speed is set nearly to 75rev/min. The increase in depth of cut during grinding process makes increase value of roundness error. Effect of depth of cut is an important aspect on roundness error.

From the plotted graph, it can be concluded that for the most diameter recommended is 18.71mm, the ideal setting of speed is 74.96rev/min and the suitable depth of cut is 15.91µm. By applying these results in AISI1042 steel cylindrical grinding operation, one can even predict and avoid roundness error and thus, elongates the tool lifespan and increased the production rate with less distortion.

## 5.3 RECOMMENDATION

In order to achieve the best result of the roundness error and to achieve the most optimize machining parameter level, some recommendation could be implemented in the future as below;

i. Experiment repetitions are necessary: the data of roundness error should be taken repeatedly in order to gain a more accurate ANOVA table.

ii. Advanced technology provides better: A CNC cylindrical grinding machine are much better for run the experiment instead of a conventional cylindrical grinding machine. The conventional cylindrical grinding machine has less performance in term of poor accuracy and poor stability compared to a CNC cylindrical grinding machine.

iii. Vary cutter tools for each experiment: The wheel that use in the experiment should be do mode of dressing process for each experiment as to maintain a constant performance.

iv. Lastly, performing other method to analyze the experimental data. There should be considered to perform other analysis instead of using the Full Factorial design method. Under the design of experiment (DOE), there are several more method can be used to analyze data obtained from experiment, such as Taguchi design method under the design of experiment (DOE).

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## APPENDIX A

## THE PLANNING OF STUDY

**Table A-1:** Gantt Chart for Final Year Project 1

| Task \ Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Get project title | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Brainstorming | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Identify problem statement | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Determine object. & scopes | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Find journals and articles | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Literature Review | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Methodology | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Survey Equipments | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Slide presentation | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Presentation | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Summit Proposal | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |

**Table A-1:** Gantt Chart for Final Year Project 1

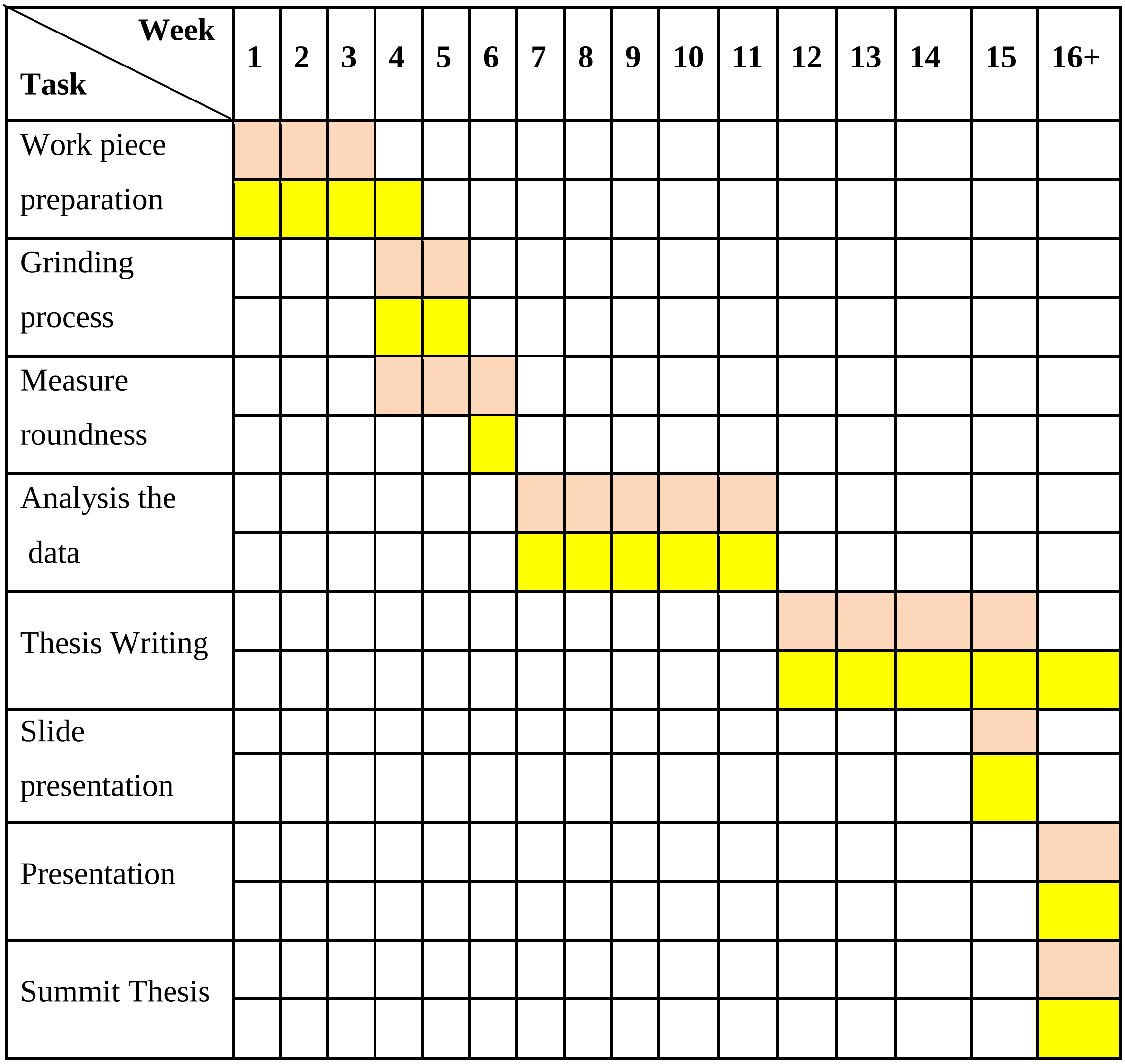
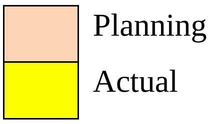



**Table A-2:** Gantt Chart for Final Year Project 2



# APPENDIX B

## WORK PIECE PREPARATION

**Figure B-1:** Raw Material Cutting Process

**Figure B-2:** Turning Process

# APPENDIX C

## CYLINDRICAL GRINDING PROCESS

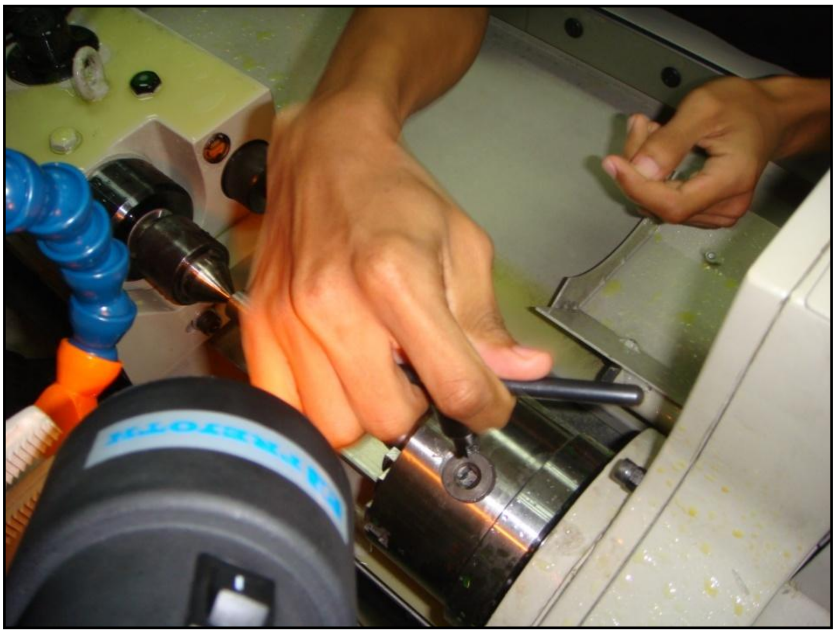


**Figure C-1:** Cylindrical Grinding Setup

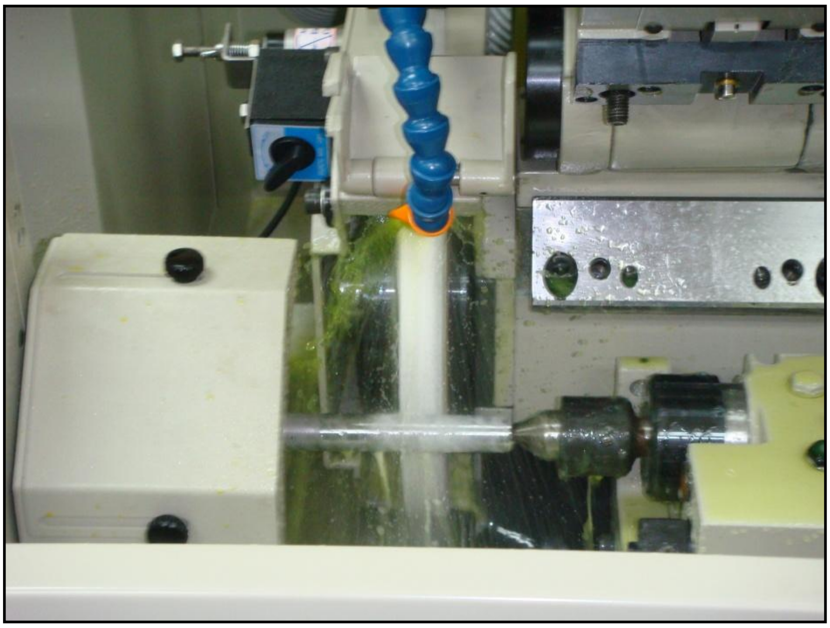


**Figure C-2:** Cylindrical Grinding Process

**APPENDIX D**

**ROUNDNESS MEASURING PROCESS**


**Figure D-1:** Roundness Measuring Machine

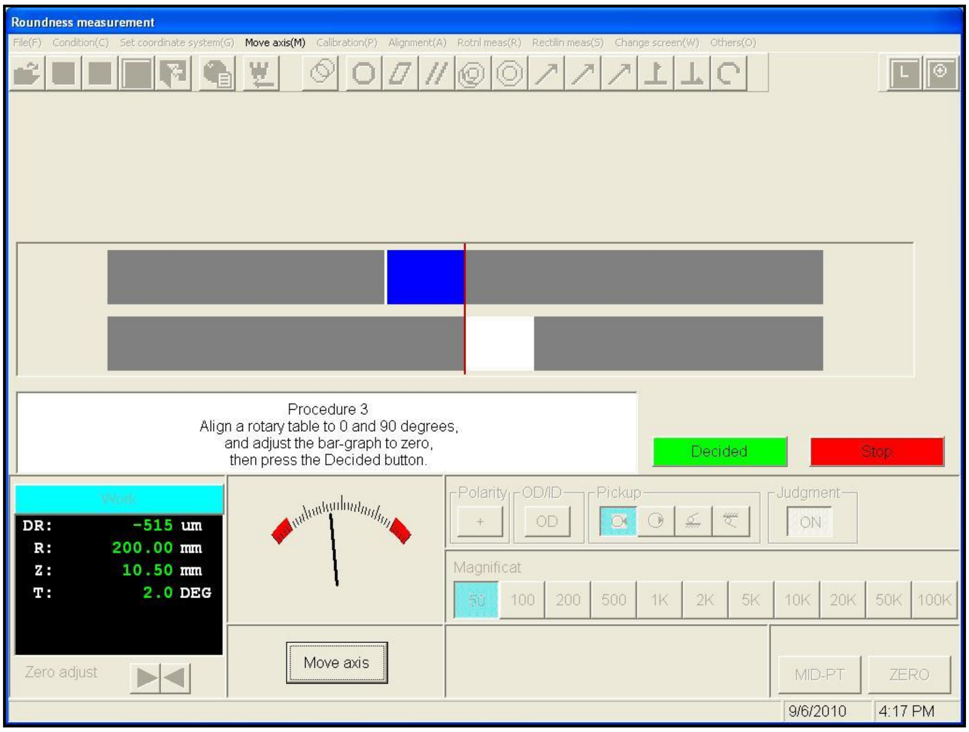



**Figure D-2:** Specimen Centering Process

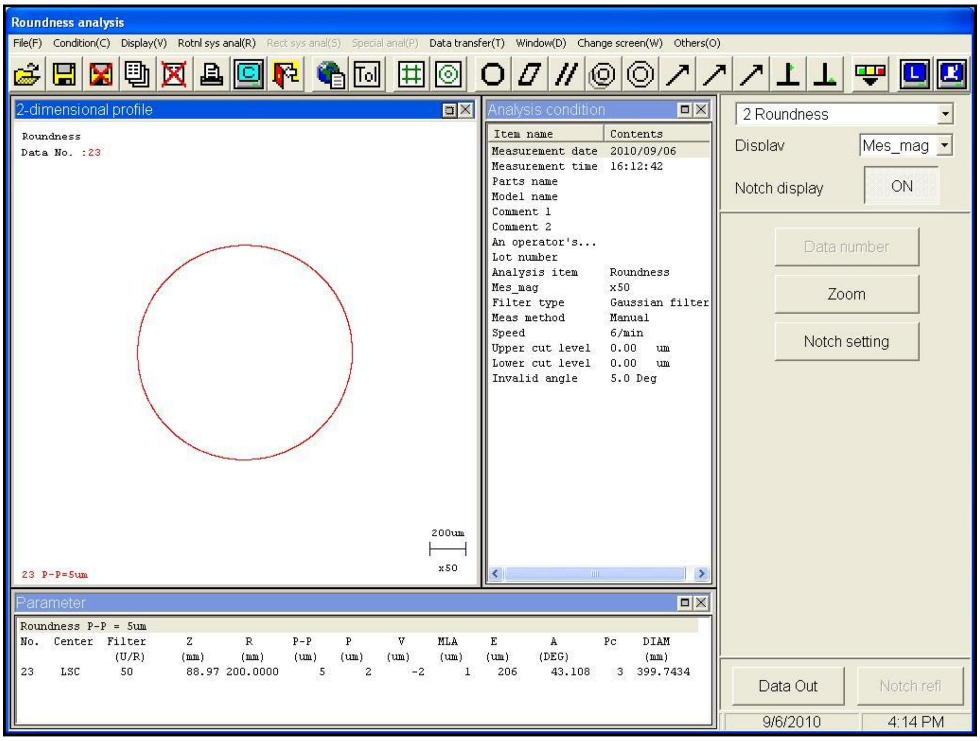



**Figure D-3:** Result of Roundness

# APPENDIX E

## ANALYSIS PROCESS BY USING STATISTICA SOFTWARE

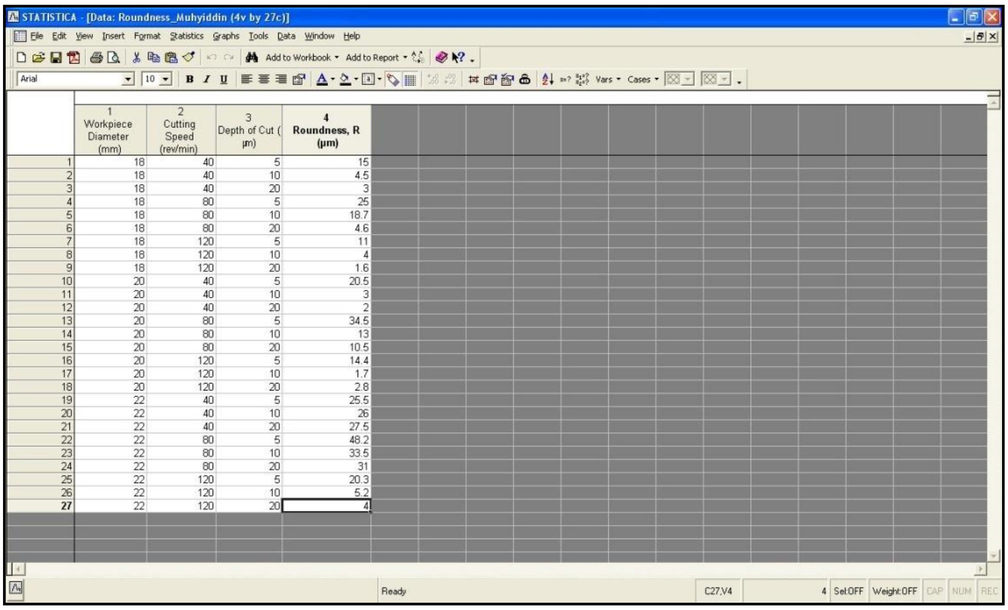



**Figure E-1:** Key-in The Data

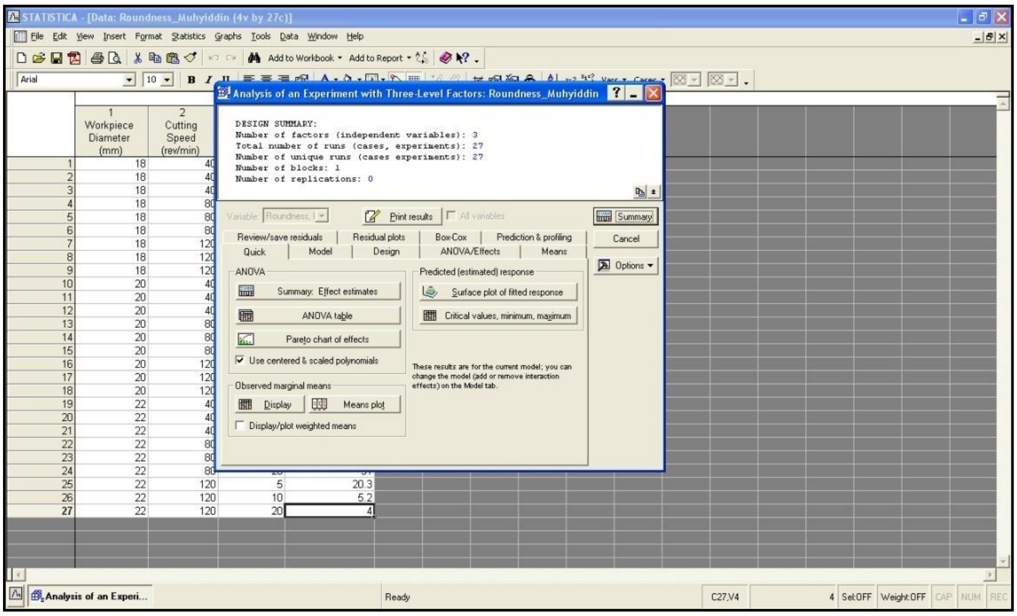



**Figure E-2:** Analysis Process

# APPENDIX F

## PROPERTIES OF AISI 1042

**Table F-1:** AISI1042

| AISI 1042 | |
|---|---|
| **Category** | Steel |
| **Class** | Carbon steel |
| **Type** | Standard |
| **Designations** | **United States**: UNS G10420 |

**Table F-2:** AISI1042 Composition

| Element | Weight % |
|---|---|
| C | 0.40-0.47 |
| Mn | 0.60-0.90 |
| P | 0.04 (max) |
| S | 0.05 (max) |

**Table F-3:** AISI1042 Mechanical Properties

| Properties | | Temp. Conditions (°C) |
|---|---|---|
| Density (×1000 kg/m3) | 7.844 | 25 |
| Poisson's Ratio | 0.27-0.30 | 25 |
| Elastic Modulus (GPa) | 190-210 | 25 |

**Table F-4:** AISI1042 Thermal Properties

| Properties | | Temp. Conditions (°C) |
|---|---|---|
| Thermal Conductivity (W/m-K) | 51.9 | 0 more |
| Specific Heat (J/kg-K) | 486 | 50-100 more |

# APPENDIX G

## CHEMICAL COMPOSITION RESULT

### WAS Sample Testing of different Qualities

#### Chemical Results

Probe Nr. / sample ID :1

Kunde / customer :chandran laa

Kom.-Nr. / commision :10%

Labor Nr. / lab-no. :foundry UMP

PTQ-Nr. / PTQ-no. :

Grundwerkstoff / material :Cu300

Abmessung / dimension :copper ingot

Zusatzwerkstoff / filler metals :no

Wärmebehandlung / heat treatment :no

Schmelze-Nr. / heat-no. :no

Spektralanalyse Foundry-MASTER     Werkstoff / grade :

| | Fe | C | Si | Mn | P | S | Cr | Mo |
|---|---|---|---|---|---|---|---|---|
| 1 | 98,2 | 0,449 | 0,252 | 0,660 | 0,0742 | 0,0211 | 0,0400 | < 0,0050 |
| 2 | 98,2 | 0,464 | 0,261 | 0,658 | 0,0731 | 0,0188 | 0,0426 | < 0,0050 |
| 3 | 98,2 | 0,431 | 0,250 | 0,680 | 0,0762 | 0,0169 | 0,0395 | < 0,0050 |
| Ave | 98,2 | 0,448 | 0,254 | 0,666 | 0,0745 | 0,0189 | 0,0407 | < 0,0050 |

| | Ni | Al | Co | Cu | Nb | Ti | V | W |
|---|---|---|---|---|---|---|---|---|
| 1 | 0,0527 | 0,0023 | 0,0048 | 0,154 | < 0,0020 | < 0,0020 | < 0,0020 | < 0,0150 |
| 2 | 0,0527 | 0,0013 | 0,0048 | 0,150 | < 0,0020 | < 0,0020 | < 0,0020 | < 0,0150 |
| 3 | 0,0593 | < 0,0010 | 0,0051 | 0,159 | < 0,0020 | < 0,0020 | < 0,0020 | < 0,0150 |
| Ave | 0,0549 | 0,0012 | 0,0049 | 0,154 | < 0,0020 | < 0,0020 | < 0,0020 | < 0,0150 |

| | Pb | Sn | B | Ca | Zr | As | Bi |
|---|---|---|---|---|---|---|---|
| 1 | < 0,0250 | 0,0048 | 0,0014 | > 0,0010 | < 0,0020 | < 0,0050 | < 0,0300 |
| 2 | < 0,0250 | 0,0046 | 0,0013 | > 0,0010 | < 0,0020 | < 0,0050 | < 0,0300 |
| 3 | < 0,0250 | 0,0042 | 0,0013 | 0,0008 | 0,0028 | < 0,0050 | < 0,0300 |
| Ave | < 0,0250 | 0,0045 | 0,0014 | > 0,0010 | < 0,0020 | < 0,0050 | < 0,0300 |

| Ort / town | Datum / date | Prüfer / tester | Sachverständiger / engineer |
|---|---|---|---|
| | 18/10/2010 | | |

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47589 Uedem (Germany)
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Web: www.was-ag.com
e-mail: info@was-ag.com

**Figure G-1:** Chemical Composition Result

**APPENDIX H**

**FLOW CHART**

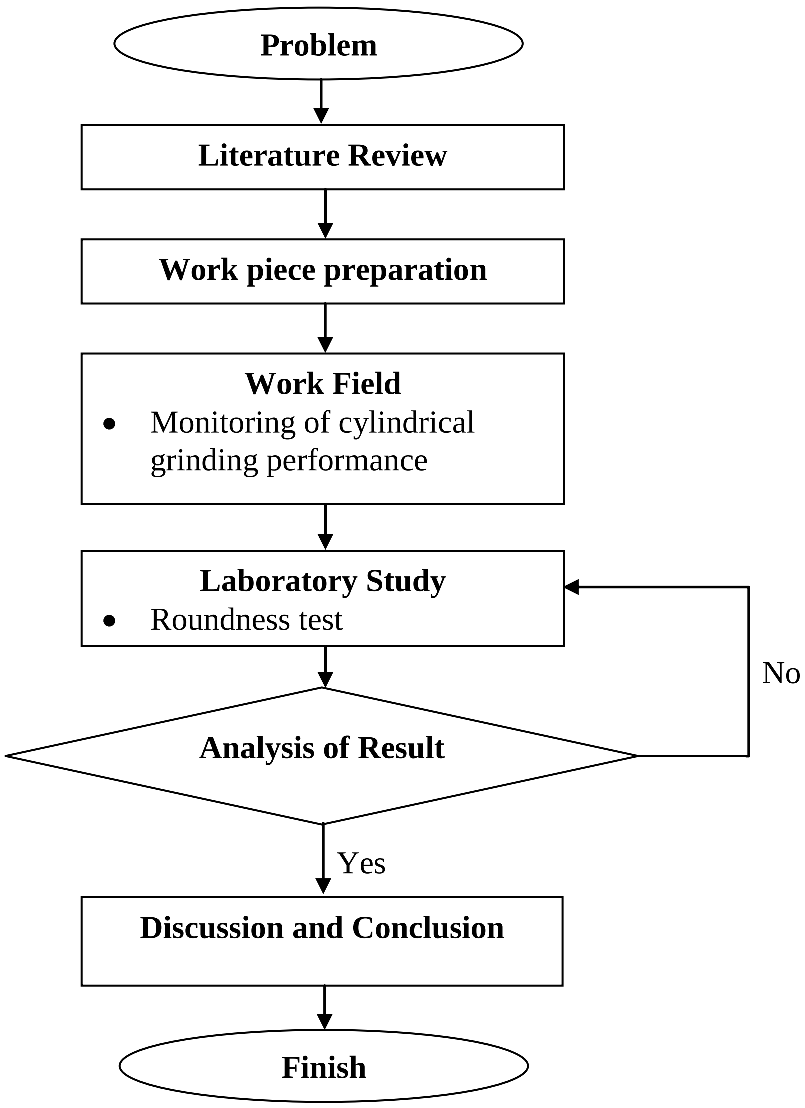


**Figure H-1:** Flowchart of Final Year Project

**UNIVERSITI MALAYSIA PAHANG**

# BORANG PENGESAHAN STATUS TESIS

**JUDUL**: **OPTIMIZATION OF CYLINDRICAL GRINDING PARAMETER FOR THE HIGH PRODUCT QUALITY SUBJECT TO ROUNDNESS CONSTRAINT**

**SESI PENGAJIAN: 2010/2011**

Saya **MOHD MUHYIDDIN BIN IBRAHIM (880210-26-5057)**
(HURUF BESAR)

mengaku membenarkan tesis (Sarjana Muda / ~~Sarjana / Doktor Falsafah~~)* ini disimpan di perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Tesis ini adalah hakmilik Universiti Malaysia Pahang (UMP).
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

| | | |
|---|---|---|
| [ ] | **SULIT** | (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972) |
| [ ] | **TERHAD** | (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi / badan di mana penyelidikan dijalankan) |
| [√] | **TIDAK TERHAD** | |

Disahkan oleh:

| | |
|---|---|
| ___________________________ | ___________________________ |
| (TANDATANGAN PENULIS) | (TANDATANGAN PENYELIA) |
| Alamat Tetap: | |
| **NO. 135, KAMPUNG SURAU** | **EN. KUMARAN A/L KADIRGAMA** |
| **MUKIM SIONG, 09100 BALING** | **(**Nama Penyelia) |
| **KEDAH DARUL AMAN** | |
| Tarikh: 6 DISEMBER 2010 | Tarikh: 6 DISEMBER 2010 |

CATATAN:
* Potong yang tidak berkenaan
** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh tesis ini perlu dikelaskan sebagai SULIT atauTERHAD.

Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara Penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

**UNIVERSITI MALAYSIA PAHANG**

**FACULTY OF MECHANICAL ENGINEERING**

I certify that the project entitled "Optimization of Cylindrical Grinding Parameter for the High Product Quality Subject to Roundness Constraint" is written by Mohd Muhyiddin bin Ibrahim. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

MR HADI BIN ABDUL SALAAM Signature

Examiner