COMPARISON OF THE CUTTING FORCE, POWER, TOOL LIFE AND TORQUE IN THE END MILLING OF MODIFIED AISI P20 TOOL STEEL

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ME06042

A report submitted in partial fulfilment of
The requirements for the award of the degree of
Bachelor of Mechanical Engineering
With Manufacturing Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

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UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

We certify that the project entitled *"Comparison of the cutting force, power, tool life, and torque in the end milling of modified AISI P20 tool steel"* is written by *P.VINOTH A/L S PARAWAKARAN*. We 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. We herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

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Signature	: ……………………………………………
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I declare that this thesis entitled *"Comparison of the cutting force, power, tool life, and torque in the end milling of modified AISI P20 tool steel"* is the result of my own research except as cited in the references. The thesis has not been accepted for my degree and is not concurrently candidature of any other degree.

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ID Number : **ME06042**
Date : ………………………..

This work is dedicated to my beloved ones,

My Father Mr. Parawa Karan

My Mother Mrs. Kamal Thevi

My Sisters Ms Reetha Parawa Karan

And

Allies…

Thank you for the endless support and encouragement.

You all always have a special place in my heart.

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ABSTRACT

The aim of this study is to make comparison of the cutting force, power, torque and tool life in the end milling of modified AISI P20 tool steel with aid of statistical method by using coated carbide cutting tool under various cutting conditions. The first and second order cutting force equations are developed using the response surface methodology (RSM) to study the effect of four input cutting parameters which is cutting speed, feed rate, radial depth and axial depth of cut on cutting force, power, torque and tool life.
In general, the result that been obtained from the mathematical model are in good agreement with that obtained from the experiment data's. It was found that the feed rate, cutting speed, axial depth and radial depth played a major role in determining the cutting tools. The predictive models in this study are believed to produce values of the longitudinal component of the cutting force close to those readings recorded experimentally with a 95% confident interval.

ABSTRAK

Tujuan kertas kerja bagi project ini adalah membincangkan perbandingan antara kuasa potongan, kekuatan, kalungan potongan dan janka hayat peralatan yang dihasilkan dalam operasi hujung kisaran terhadap modifikasi AISI P20 alatan besi.
Persamaan pertama dan kedua dalam sususan peralatan potangan telah dikembangkan dengan menggunakan keadah tindakbalas permukaan yang dipelajari daripada kesan terhadap empat jenis pengeluar pemotongan. Iaitu kelajuan pemotongan, kadar pembekal, kedalaman axial dan radial terhadap kekuatan pemotongan. Kecerunan pemotongan yang berkait dengan parameter pengeluar telah dibentangkan dan model yang dijangkakan.

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LIST OF SYMBOLS

a_e	Effective rake angle	-
Q	Volume that been removed	-
K	Dimension Quantity	-
H	Indention hardness	-
W	loading	-
L	Sliding distance	-
F	cutting tools (response)	-
A, B, C, D and E	constant value	-
V_c	Cutting speed	m/min
f	feed rate	mm/rev
a_a	axial depth	mm
a_r	radial depth	mm

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Machining is very important in the manufacturing process. But now days, many manufacturing companies were often facing problem in setting the machine tools. For that problem, manufacturing engineers and research have been realizing that in order to optimize the economic performance of metal cutting operations, efficient quantitative and predictive model that establish the relationship between a big groups of input independent parameter and output variable are required for the wide spectrum of manufacturing process, cutting tools and engineering materials currently use in the industry. Efforts to further improve and optimize machining time and costs by reliable estimation of performance features such as force, power, tool life, temperature and surface finish is increasing to become important in modern manufacturing industry (V. Karri and H. Talhami, 1995). The aim of the project is to develop the first and second order power, force, tool life and torque model when machining modified AISI P20 tool steel and also to safe the cutting cost and production time.

1.2 PROBLEM STATEMENT

When doing machining process, the tool cutting ability will degrades with time, until in certain time, the tool can no longer cut through the material. Certain conditions affect the tool life, power, force, torque when it was not suitable for the tools. Certain conditions affect the tool life, power, force, and torque when it was suitable for the tools.

So that, we need have a solution in the beginning to solve this type of problem. To solve the problem, cutting tools user need to have a mathematical model that can help them to predict the power, force, tool life and torque by calculation. Therefore the cutting tools users need to have a mathematical model that can help to predict the force, power, and torque and tool life by calculation. From this way, we can prevent the cutting tool from damage at the short period of time. For that, there will be several experiments to gain the need data.

For this project, we need to run 27 experiments with different range of parameters. There will four type of parameters been selected in this experiment. There are cutting speed, the fed rate, radial depth and the axial depth. This project will use coolant and the material hat been use for experiments is modified AISI P20 tool steel. Other than that, the type of cutting tool that been use for this experiments is TiN coated inserts. To run the experiments, we need computer numerical control, and CNC machine. At the end of the experiment, there will be two mathematical models been use. There are the first order and the second order.

1.3 OBJECTIVE

The objective of this study is:

1. To predict the cutting force, power, torque and tool life in the end milling operation of modified AISI P20 tool Steel.

2. To make the comparison about the cutting force, power, tool life and torque in the end milling.

1.4 LIMITATION

The develop models got its own limitation which are the range of cutting speed is between 100 to 180 m/min, the federate between 0.1 to 0.2 mm/rev, the axial depth between 1 to 2mm and the radial depth between 2 to 5mm.

Table 1.1: Parameters range:-

Level	Low	Med	High
coding / Factors	-1	0	1
Cutting speed (m/s)	100	140	180
Feed rate (mm/rev)	0.1	0.2	0.3
Axial depth (mm)	1	1.5	2
Radial depth (mm)	2	3.5	5

1 .5 THESIS OUTLINE

Chapter 1:

- In chapter, we tell about the project mainly. In here, we talk about the problem of the project, the objective of the project, and the project scope.

Chapter 2:

- In this chapter, we talk about the literature review the project. In the literature review, we tell about the wear mechanism, CNC Milling machine, and other topic that related to the project.

Chapter 3:

- Chapter 3 mainly about the project methodology. We will discuss about the project flow chart and the parameter that been use for the project. This is very important because it will show a draft of the experiment.

Chapter 4:

- In this chapter, we will talk about the research result and discussions. In result, we will tell about overall of the experiment result and show the way that the result been gain. Then, we will discuss about that and tell the way to improve it.

Chapter 5:

- Chapter 5 mainly about the conclusion of the project. In here, we will tell about the overall of the project and conclude it.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

There are many type of angle been taken to analyze in wear mechanism in aspect of advance of material, surface engineering and lubricants. Other than that, we also must consider in aspect of design methods and condition monitoring for improving the wear mechanism in cutting tools and the efficiency. As an engineer, we need do more development and challenge in tribology in the wear mechanism field.

As a basic machining process, milling is a one of the widely been used in industry as metal removed process. Milling surface are larger used to mate with other parts in die, aerospace, automotive and machining design as well as in manufacturing in industry. In this research the wear mechanism maps of carbide tools of milling is constructed by many condition of tools material, machined material and machining parameter. In this research, w also discussed about optimizes the machine and choosing the suitable milling parameter of the carbide tools.

From the research, we can obtain various wear rates in carbide tools in milling machine and constructed according the principle and method of wear mechanism. There are three axes been used in the research? There are feed rates and cutting speed and the axial depth. Other region been divided based on the different wear rates and mechanism. There are many type of main wear mechanism been occur in the carbide tools. There type of wear involve is corrosive wear, flank wear, fatigue wear, adhesive wear, abrasive wear and many other. Several wear exists in minor that been called “safety cutting zone” for carbide tools in Al alloys.

Julie Z. Zhang et al (2006) is the studied of surface roughness optimization in the milling process by using the Taguchi design method. The study of the research is about the application of Taguchi design that applied in optimizing surface quality of CNC milling operation. The study also included feed rate, cutting speed and axial depth of cutting control factors. There are analyze been taken out based on signification factors that affect the surface roughness, and the optimal cutting combination.

Julie Z. Zhang et al. (2000) is the research of the optimal cutting condition for face milling by varying cutting parameter through the Taguchi parameter design method. In the 36 experiment that been done, there three main factor been indicated at level two and three about the Taguchi method. The result that obtain are effected the spindle speed and feed rate on the surface were larger than depth of cut for milling operation. The surface finish achievements of the confirmation runs under optimal cutting parameter were able to produce the best surface roughness in milling machine.

K.Kadigama et al. (2008) is the research of the tool life by statistic method in the end-milling operational. The research been done mainly in development of tool life in operating P20 tool steel by using end milling machine. The study been done by using statistical method, and response surface method based on the cutting speed, feed rate, axial dept and radical depth.

As applying roughness surface methodology (RMS) for analysis the parameter of the cutting tools. This methodology had been use for analysis a combination of the design of experiment. The other reason of this methodology is regression analysis and the statistical inferences. By using this roughness methodology, it will also help to identification the factors like tools characteristic and the tools condition wear.

2.2 CUTTING PROCESS

Cutting process is the process that uses to remove material from the surface of a workpiece that use chips. There are three type of cutting operation been use. There are:

- Turning
- Milling
- Drilling

In this projects, the process that been use milling process that the workpiece will move to left and the cutting tools will rotate on the workpiece surface and remove the layer of material.

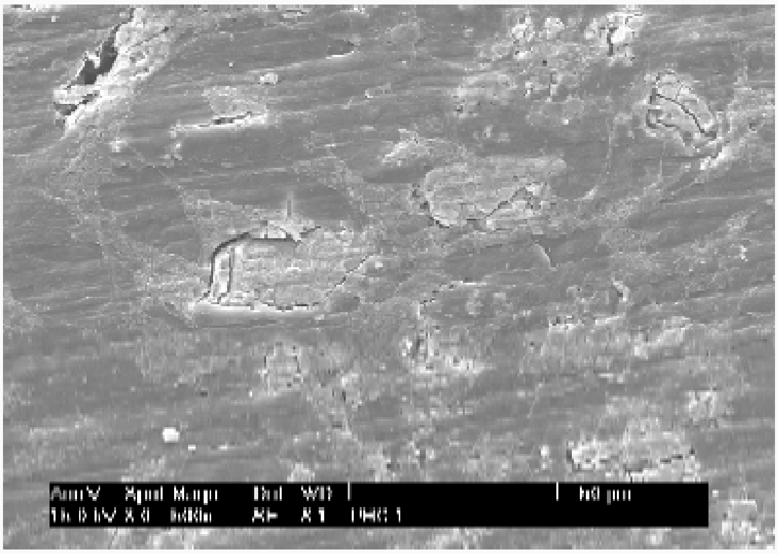


Figure 2.1: Surfaces produced on Aluminum steel after been cut by using milling machine that been scan in electron microscope.

2.2.1 Milling Process

Milling process is a process for producing flat and curved surfaces that using multipoint cutting tools. The machine tools involved is milling machine and milling carbide tools. There are three basic types of milling cutter:

- Plane Milling Cutter
- Face Milling Cutter
- End Milling Cutter.

The plane-milling cutter is used to produce flat surface in manner. The cutting edge may be parallel to or inclined to the axis of the cutter. If the cutting edge is inclined to the axis, this inclination angle referred to as a helix angle. A plane- milling cutter produces a cut of variable undeformed chip thickness (*t*) and the simple orthogonal cutting situation is only a crude approximation because of the variable underformed thickness involved.

The face milling cutter is also used to machine flat surface. But, in these cases, the axis of cutter is perpendicular to the finished surface instead of being parallel to it as in the case of a plane-milling cutter. Also, the undeformed chip thickness (*t*) is constant throughout the cut and corresponds to the feed per tooth, while the depth of cut corresponds to the underformed chip width (*b*). The inclination angle may be 0° or some value up to 45°.

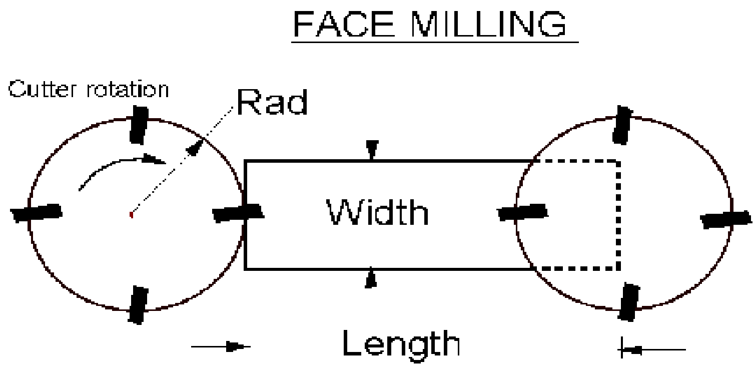


Figure 2.2: Face milling cutter sketch.

An end mill is used to produce slots and surface profiles and operates. It closely resembles a face mill in the manner it is presented to the work but is a very much smaller cutter. As, in the case of the milling cutter axis, a secondary cutting edge perpendicular to the cutting axis, and a nose radius connecting the two. However, the undeformed chip thickness is variable throughout a cut as in the case of the plane milling cutter.

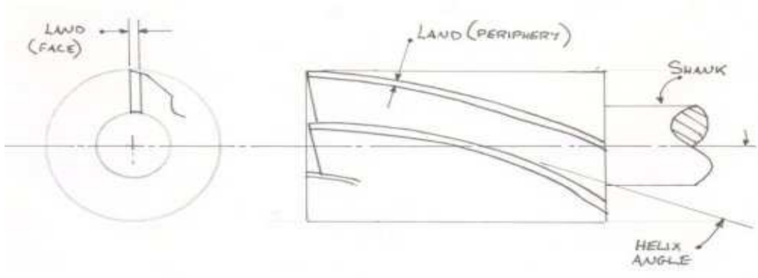


Figure 2.3: End Milling

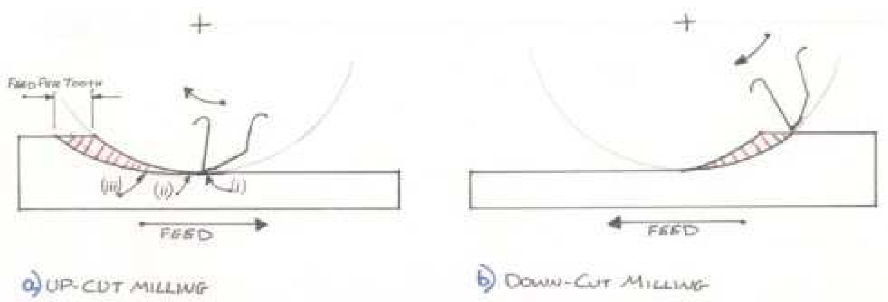


Figure 2.4: (a) up cut of milling, (b) down cut milling

2.3 CUTTING MACHINE

Milling operation is the process done by the Milling machine. CNC milling machine is the main machine that been used in this project. This is the machine that the machine tools that used for shaping of metal and other solid material.

Table 2.1: Table of various type of milling machine operation

Criterion	Example classification scheme	Comments
Control	Manual; Mechanically automated via cams; Digitally automated via NC/CNC	In the CNC era, a very basic distinction is manual versus CNC. Among manual machines, a worthwhile distinction is non-DRO-equipped versus DRO-equipped
Control (specifically among CNC machines)	Number of axes (e.g., 3-axis, 4-axis, or more); Within this scheme, also: - Pallet-changing versus non-pallet-changing - Full-auto tool-changing versus semi-auto or manual tool-changing	
Spindle axis orientation	Vertical versus horizontal; Turret versus non-turret	Among vertical mills, "Bridgeport-style" is a whole class of mills inspired by the Bridgeport original
Purpose	General-purpose versus special-purpose or single-purpose	
Purpose	Toolroom machine versus production machine	Overlaps with above
Purpose	"Plain" versus "universal"	A distinction whose meaning evolved over decades as technology progressed, and overlaps with other purpose classifications above; more historical interest than current
Size	Micro, mini, benchtop, standing on floor, large, very large, gigantic	
Power source	Line-shaft-drive versus individual electric motor drive	Most line-shaft-drive machines, ubiquitous circa 1880-1930, have been scrapped by now
Power source	Hand-crank-power versus electric	Hand-cranked not used in industry but suitable for hobbyist micromills

2.3.1 Milling cutter tools

Milling cutters are generally made of high speed steel or have cemented carbide teeth. It is common practice with large milling cutters to use inserted teeth which may be removed for grinding and replacement. Smaller cutters are frequently equipped with carbide tips that are brazed in place. The normal rake angle is readily computed from the equation 2.1 will give the effective rake angle αe. The helix or inclination angle may be determined by rolling the cutter on sheet of carbon paper.

$$\tan \alpha_v = \frac{\tan \alpha_n}{\cos i}$$

(Eq.2.1)

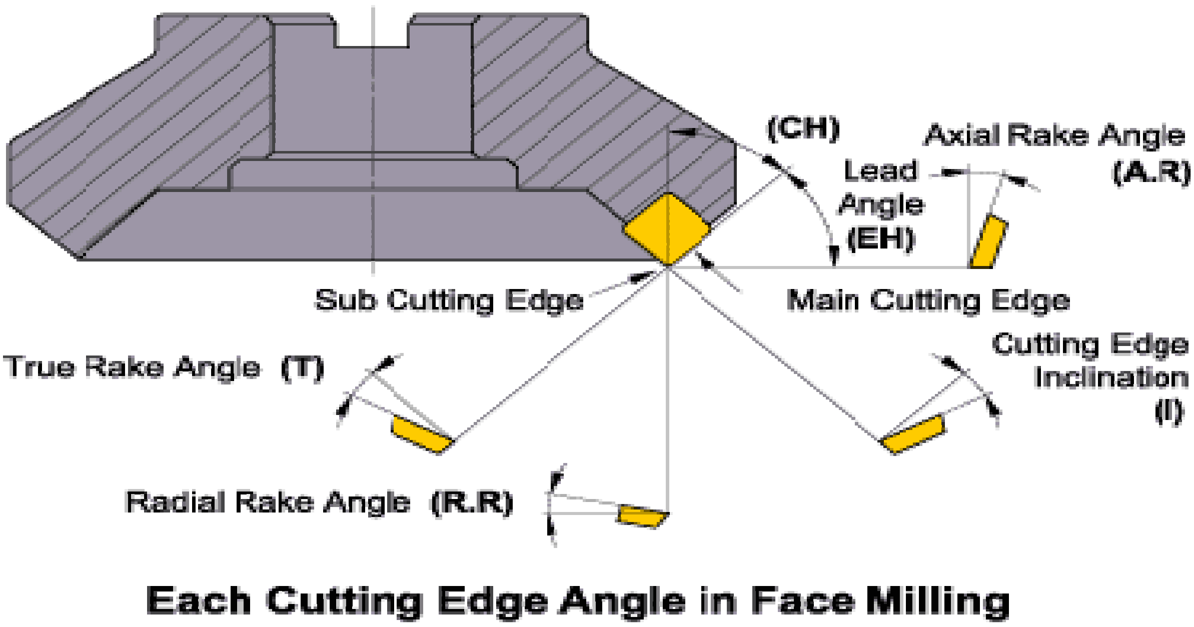


Fig 2.5: Face-milling cutter with inserted lades and show the angles.

2.3.2 Factors in Machining Operations

The operation of removing metal by means of cutting tools using some sort of machine tool in order to obtain a desired shape are called machining. The selection of a machine tool or a particular depends upon many factors, such:

- The shape and size of the product required
- The quantity of material to be removed
- The type operation to be performed
- The number of components required
- The type of material to be handled

2.4 CNC MILLING MACHINE

Computer controlled machine tools (CNC-Computer Numerical Control) operate without requiring human to turn the dials. Since there is no expert running the CNC machine, the differences between an expert and an inexperienced operator must be reduced or eliminated if a CNC machine is to produce acceptable parts. Once the differences are eliminated, the CNC machine can reliably make many copied of the same part with the same accuracy as the expert machinist. The CNC machine however will not get tired and make mistakes. There are no boredom or fatigue penalties.

The machine squareness, adjustment of gibs and the fit of the ways should be common between the manual and CNC methods of machining. Either type of machining requires that the X axis and Y axis are perpendicular to each other and also to the Z axis. The machine slides must be free moving over the length of the travel and cannot bird or flex when cutting or when motion direction changes. Cutting flat surfaces requires linear slides with flat travel ranges. Lubricant applied to ways and lead screws will not measurably affect the differences between the results of an expert and a novice. Lack of lubricant will affect the life of the machine, and may fatigue the machine operator, but will not make a marked difference in results between CNC and manual machining.

There two contributing mechanical factors, which can causes a big difference in the results achieved by an expert and a novice. There are:

- Lead screw nut slop.
- Endplay of the lead screw.

2.4.1 Lead Screw Nut Slop

This is the result of a loose fit between the machine axis lead screw and the table drive nut. Commercial grade V-threads and acme threads have clearances that permit rotation of the screw within the nut. Even a precision ground ball screw will have some small clearance between the nut and the screw. When rotation direction changes, this clearance permits a slight rotation of the lead screw, before the machine slide starts to move in the new direction. Usually this is the main component of backlash because the endplay will remain small on a well-designed and maintained milling machine.

The Nut-clearance backlash can be measured once the endplay has been eliminated. Place an indicator against the end of the machine table, or mount it to the table and contact a moving part of the machine such as the spindle. Of the machine has graduated dials, note the reading when the dial is rotated clockwise to move the indicator dial off zero. Then rotate the handle counter-clockwise until the indicator dial has moved at least 0.001 inch. The nut slop backlash is the change in the hand wheel reading minus 0.001 inch.

The same measurement can be made on a CNC machine by using the incremental jog. The jog machine in a plus direction to move the indicator off zero. The jog in the opposite direction until the indicator moves 0.001 inch. The nut clearance backlash will be equal to distance jogged minus 0.001. If the CNC controllers support backlash compensation, this is the number to use for that parameter. Entering the backlash compensation into a controller will not in any way eliminate backlash, but may make drilled hole locations a bit more accurate.

Adding mechanical backlash control to a milling machine permits the machine to reliably position as good as an expert machinist, turning manual cranks. There are still a few other tricks that the expert machinist uses to make good parts, but much of what at one time was thought of as art is now reduced to practical science with the addition of few anti backlash nuts.

2.4.2 Endplay of the lead screw.

Endplay will occur in lead screw if the lead screw mounts permit motion of the lead screw when direction changes. Typically the ends of lead screws will be machined to precision diameter with shoulders and placed in a sleeve or ball bearing (thrust bearings). If the machine design does not have thrust bearings, or adjustment for endplay, changes in direction will result in rotation of the screw without any corresponding motion of the slide.

This can be easily measured by placing an indicator on the end of the screw. Under cutting loads, during changes in direction of rotation of the lead screw. CNC ready desktop mills from manufacturers such as Taig and Sherine have thrust bearings to prevent endplays.

Endplay can be eliminated for the most part by a slight preloading of the thrust bearings. Take care not to preload the bearings too much as that may cause excessive drag, heating and premature wear of the trust preload the bearings too much as that may cause excessive drag, heating and premature wear of the thrust bearings. Motor shaft bearings should not be used as a substitute for thrust bearings, as they have no method to adjust for endplay.

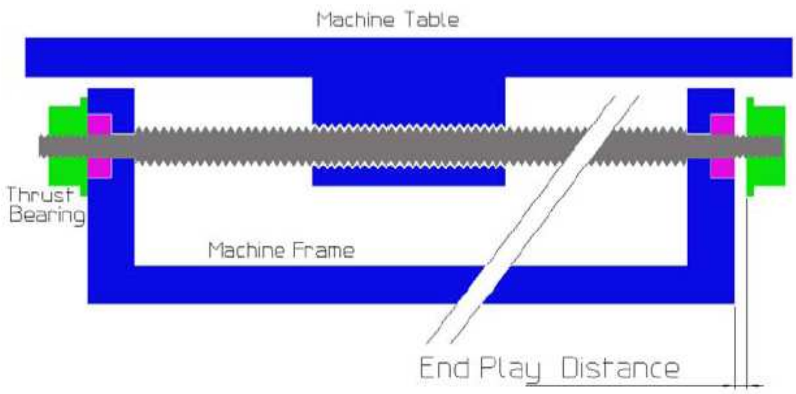


Figure 2.6: Endplay of the lead screw

2.5 WEAR

To understand the degradation process known as wear. The main work is o predict the rate of wear and to reduce wear, still form some of the most problematic challenges facing by the engineers. The understanding of wear often involves detail knowledge of mechanics, physics, and chemistry and material science.

2.5.1 Definition and Development of Wear Studies

The widest definition of wear, which is includes' the loss of material from a surface, transfer of material from one surface to another or movement of material within single surface'. Although a narrower definition of wear has been proposed as 'progressive loss of substance from the operating surface of a body occurring as a result of relative motion at the surface. It is significant to what consider the implied and excluded by this way.

Wear has entered the scientific arena rather more recently. The design and construction of early machine involve large clearance and low speed of operation, resulting gross adhesion or excessive friction could be avoided. Wear cannot be avoided in any manufacturing process that mainly abrasive processing going on.

In the view of highly complex nature of wear process and difficulty of producing realistic model for them, there are many discussion of sliding wear been start in the simple assumption of the relationship between the wear rate and the normal rate.

$$Q = \frac{KW}{H}$$

(Eq 2.2):

Where Q is the volume removed from the surface per unit sliding distance, *W* is the normal load applied to the surface by its counter body and *H* is the indention hardness of the wearing surface. *K* is the dimensionless quantity which usually called the wear coefficient and which provides a valuable means of comparing the severity wear processes. As our understanding of wear process depends, it becomes increasingly important to able to transfer the knowledge into design and operation of machine.

2.5.2 Classifications of Wear Mechanisms/ Models

Wear is not the properties but it is a system response. The wear rate of a material can vary from 10^{-3} to $10^{-10}mm^3/N$ depending on contact condition such as the counterpart material, contact pressure, sliding velocity, contact shape, suspension stiffness, environment and the lubricant.

The wear rate changes through the repeated contact process under constant load and velocity. It generally high in an initial unsteady state and relatively lower in the later steady one are the terms that used to describe wear rate changes resulting from wear due to repeated contact. In steel against steel contact, this changes is caused of the changes that been make in the wear mode. So mechanical wear describes wear governed mainly by the processes of deformation and fracturing. The deformation process has a substantial role in the overall wear ductile materials and fracturing process has a major role in the wear in brittle materials.

Wear modes which is abrasive, adhesive, flow and fatigue wear are more descriptive expression of mechanical wear. In abrasive wear three dimensional wear models of surface scratching by a hard asperity have been proposed and confirmed through quantitative agreements between experimental and theoretically. The wear volumes can expressed in:

$$V = \alpha\beta \frac{WL}{Hv}$$

(Eq.2.3)

Where *V* is the volume of wear, *W* is the loading, *L* is the sliding distance, α is the shape factor of an asperity and β is the degree of wear by abrasive asperity.

If the wear rate is given a specific wear rate, ω_s or a wear coefficient, K. the equation is:

$$Ws = \frac{\alpha\beta}{Hv}$$

(**Eq.2.4)**

2.6 DYNAMOMETER

Certain crystalline materials, notably quartz (SiO_2) and barium titanate ($BatiO_3$), have unit cells with an identifiable dipole. In strong electrical field, all cells tend to align, producing positive and negative ends. If electrodes attached to these ends are subjected to tensile or compressive stresses, they separate or approach each other and voltage change results. Crystals that exhibit such an electromechanical action are referred to as *electromechanical transducers* and called pressure electric devices.

Quartz is the piezoelectric material used in most modern dynamometers. Most force sensors have an elastic element, the deflection of which is a measure of force. With quartz piezoelectric sensors, the deflections involved are of dimensions rather than microns as with strain gages. This provides a transducer of very great stiffness, high natural frequency, low rise time (time for

the output to go from 10 to 90% of the final value), and high time constant (time for a DC signal to decay to 37% of the initial value). Quartz transducer also has a very high resistance (~10^{13} ohms) and useful anisotropic properties. Depending on the orientation of a platelet cut from a single crystal, it may be sensitive to a compressive stress or a shear stress.

This is the type of dynamometer that used in turning, milling, and a variety of other metal cutting studies. These platforms come in a variety of sizes and are sealed against contact of the sensors with cutting fluids. Such a dynamometer would be used in turning studies with tools of moderate size. The tool holder will accommodate tool shanks up to 1 x 1 in (26 x 26 mm) in size. For heavier turning operations, larger platforms with internal water cooling are available as well as tool holders accommodating tool shanks of larger size. This dynamometer also used for variety of milling studies.

2.6.1 Milling Dynamometer

In a plane-milling operation using a helical-milling cutter, three orthogonal components of force must be recorded simultaneously. The dynamometer shown in Figure 2.3 employs four octagonal rings mounted between two plane rigid surfaces oriented as shown in the plane view of Fig 2.3. The axes of rings B and C are in the *y*-direction while rings A and D have their axes in the *x*-direction.

When an arbitrarily vertical load (F_V) is applied it is carried by all four rings, and hence the two vertical measuring gages (T_1 and C_1) of each ring are wired into one eight gage bridge circuit in such a way that all output add. A force in the *x*-direction (F_x) is measured by the gages in the inclined position. A force in the *x*-direction produces no bending in the ring A and D since

their axes are in the direction of the force (a very stiff direction). The gages on rings A and D are used to measure forces in the *y*-direction just as those on rings B and C are used for forces in the *x*-direction.

In designing a dynamometer such like in Fig 2.3, we have need for the stiffness of a ring in the axial direction. From thin ring theory we can obtain an expression for the stiffness (K_a) in the axial direction K, just as we did previously for the radical and tangential directions. The expression for K_a can been found in the thin ring theory.

$$K_a = \frac{Ebt}{40r}$$ **(Eq. 2.5)**

2.7 CUTTING FLUID

There are various type of fluid been used in the cutting machine to prevent the tools to cool and lubricated. The various types are also included oil-water emulsions, plaster, gel and mists. These fluids are made from the petroleum distillates, animal fats, plant oils, and other type of raw ingredients. The types of coolant are:

- Lubricant
- Coolant

Every kind of machining such like turning, milling, grinding and many other can potentially benefit from one kind of cutting fluid or another and depend on the type of work piece been used. Interrupted cuts such as milling with carbide cutters are usually recommended to be used dry due to damage the cutter by thermo shock.

The properties that are sought after in a good cutting fluid are ability to:

- Keep the work piece at the stable temperature.
- Maximize the life of the cutting tip by lubricating the working edge.
- Will ensure a safety for the people who are handing the machine and the environment.
- Prevent rust on the machine parts and cutter.

2.7.1 Lubricant

The lubricant is the substance that been introduced between the two moving surfaces to reduce the friction between them, improving efficiency and reducing wear. They may have also had the function of dissolving or transporting foreign particles and of distributing heat. One of the single largest applications for lubricant in form of motor oil is to protect the internal combustion engines in motor vehicles and powered equipment.

Typically lubricants are containing 90% base oil (petroleum fractions) and less than 10% additives. Vegetable oils or synthetic liquids such as hydrogenate polyolefin, silicone; fluorocarbons and many other are sometimes used as base oils. Additives deliver reduced friction and wear, increased viscosity, improved viscosity index, resistance to corrosion and oxidation, aging or contamination.

Lubricants such as 2-cycle oil are also added to some fuels. Sulfur impurities in fuels also provide some lubrication properties, which have to be taken in account when switching to a low-sulfur diesel; biodiesel is a popular diesel fuel additive providing additional lubricity. Non-liquid lubricants include grease, powders (dry graphite, PTFE, Molybdenum disulfide, tungsten disulfide, etc.), Teflon tape used in plumbing, air cushion and others. Dry lubricants such as graphite, molybdenum disulfide and tungsten disulfide also offer lubrication at temperatures (up to 350 °C) higher than liquid and oil-based lubricants are able to operate. Limited interest has been shown in low friction properties of compacted oxide glaze layers formed at several hundred degrees Celsius in metallic sliding systems, however, practical use is still many years away due to their physically unstable nature.

Function of lubricant:

- Keep moving parts apart
- Reduce friction
- Transfer heat
- Carry away contaminants & debris
- Transmit power
- Protect against wear
- Prevent corrosion

2.7.2 Coolant

Coolant is a fluid that flows through a device in order to prevent its overheating, transferring the heat produced by the device to other device. An ideal coolant has high thermal capacity, low viscosity is low-cost and is chemically inert, neither causing nor promoting corrosion of cooling system.

While the term coolant is commonly used in automotive, residential and commercial temperature-control applications, in industrial processing, heat transfer fluid is one technical term more often used, in high temperature as well as low temperature manufacturing applications. The coolant can either keep its phase or stay liquid or gaseous, or can undergo a phase change, with the latent heat adding to the cooling efficiency. The latter, when used to achieve low temperatures, is more commonly known as refrigerant.

Type of coolant that been use is:

- Oils are used for applications where water is unsuitable. With higher boiling points than water, oils can be raised to considerably higher temperatures (above 100 degrees Celsius) without introducing high pressures within the container or loop system.
- Mineral oils serve as both coolants and lubricants in many mechanical gears. Castor oil is also used. Due to their high boiling points, mineral oils are used in portable electric radiator-style space heaters in residential applications, and in closed-loop systems for industrial process heating and cooling.
- Silicone oils are favored for their wide range of operating temperatures. However their high cost limits their applications.
- Fluorocarbon oils are used for the same reasons.

2.8 MATERIAL PRODUCT

Aluminium Alloy AISI 6061 is a precipitation hardening aluminium alloy, containing magnesium and silicon as its major alloying elements. It has good mechanical properties and exhibits good weld ability. It is one of the most common alloys of aluminium for general purpose use. It is commonly available in pre-tempered grades such as, 6061-O (solutionized), 6061-T6 (solutionized and artificially aged), 6061-T651 (solutionized, stress-relieved stretched and artificially aged).

Aluminum Alloy AISI 6061 is widely used for construction of aircraft structures, such as wings and fuselages, more commonly in homebuilt aircraft than commercial or military aircraft, it also use in yacht construction, including small utility boats and construction of bicycle frames and components

Table 2.2: Composition Data

Aluminum	Balance
Chromium	0.04 - 0.35
Copper	0.15 - 0.4
Iron	0 - 0.7
Magnesium	0.8 - 1.2
Manganese	0.15 max
Other	0.15 max
Remainder Each	0.05 max
Silicon	0.4 - 0.8
Titanium	0.15 max
Zinc	0.25 max

Table 2.3: Aluminum Alloy AISI 6061 speciation

Principal Design Features	Probably the most commonly available, heat treatable aluminium alloy.
Applications	Commonly used in the manufacture of heavy-duty structures requiring good corrosion resistance, truck and marine components, railroad cars, furniture, tank fittings, general structural and high pressure applications, wire products, and in pipelines.
Machinability	Machinability in the harder T 4 and T6 tempers is good. It is notably less easy to machine in the annealed temper.
Forming	Easily cold worked and formed in the annealed condition. Stamping, bending, spinning, deep drawing are all readily accomplished using standard methods.
Welding	The alloy has very good welding characteristics and may be welded by all of the common welding techniques. Gas tungsten arc welding is generally used for thin sections (less than 0.032") and gas metal arc welding is used for heavier sections. Use alloy 4043 filler wire for best results, although a decrease in T 6 properties will result.
Heat treatment	Solution heat treats at 990 F for adequate time to allow for thorough heating and then water quench. Precipitation hardening is done at 320 F for 18 hours and air cool, followed by 350 F for 8 hours and air cooling.
Forging	The alloy is capable of being hot forged at temperatures in the range of 900 F to 750 F.
Hot working	Hot working may be done in the temperature range of 700 F

	to 500 F.
Cold working	Cold working in the O temper condition is readily performed. The alloy is notably less easy to cold form in the T 4 and T 6 tempers.
Annealing	Annealing should be done at 775 F for 2 to 3 hours followed by controlled cooling at 50 f per hour down to 500 F, then air cool.
Aging	The aging precipitation heat treatment is done at 350 F for 8 hours followed by air cooling. This produces the T6 temper.
Tempering	Not applicable.
Hardening	See "Aging".
Other Physical Props	Electrical conductivity 40% of copper.
Other Mechanical Props	Shear strength for O temper is 12 ksi and for T 6 temper it is 30, ksi

2.9 METAL CUTTING PARAMETER

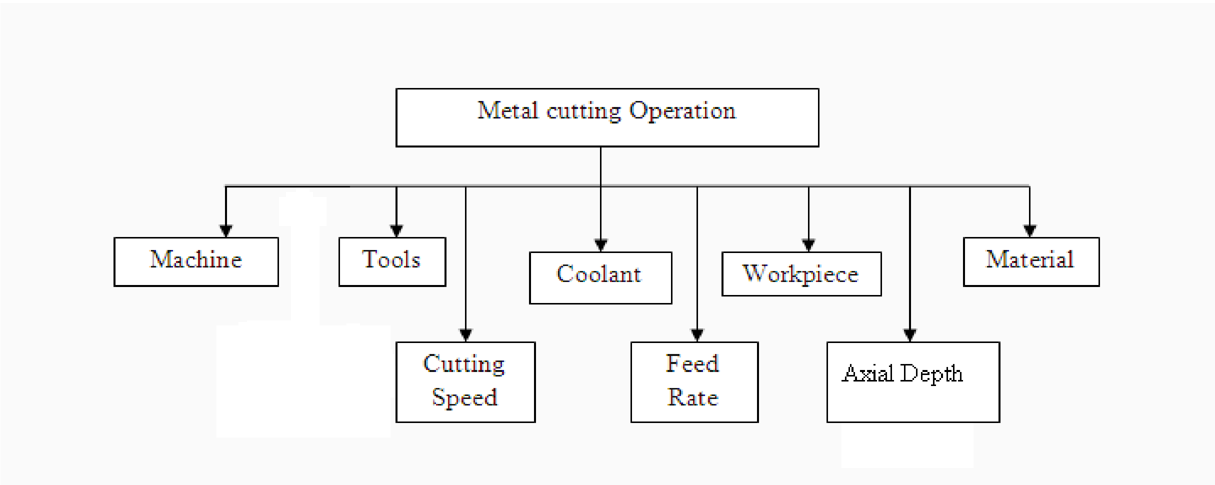


Figure 2.7: The building block illustrates the major factors that affect metal cutting

2.10 RESPONSE SURFACE METHOD (RSM)

Response surface method (RSM) adopts both mathematical and statistical techniques which are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize the response. In most of the RSM problems, the form of the relationship between the response and the independent variables is unknown. Thus the first step in RSM is to find a suitable approximation for the true functional relationship between response of interest ‘y’ and a set of controllable variables {x1, x2 ...xn}. Usually when the response function is not known or non-linear, a second-order model is utilized in the form:

$$y = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n} b_{ii} x_i^2 + \sum \sum_{i<j} b_{ij} x_i x_j + \varepsilon$$

(Eq. 2.6)

Analysis of variance (ANOVA) is used to check the adequacy of the model for the responses in the experimentation. ANOVA calculates the F-ratio, which is the ratio between the regression mean square and the mean square error. If the calculated value of F-ratio is higher than the tabulated value of F-ratio for roughness, then the model is adequate at desired significance level α to represent the relationship between machining response and the machining parameters.

For testing the significance of individual model coefficients, the model is optimized by adding or deleting coefficients through backward elimination, forward addition or stepwise elimination or addition. It involves the determination of P- value or probability of significance that relates the risk of falsely rejecting a given hypothesis. If the P-value is less or equal to the selected α-level, then the effect of the variable is significant. If the P-value is greater than the selected α-value, then it is considered that the variable is not significant. Sometimes the individual variables may not be significant. If the effect of interaction terms is significant, then the effect of each factor is different at different levels of the other factors. In the present study, ANOVA for different response variables is carried out using commercial software Minitab with confidence level set at 95%, i.e., the α-level is set at 0.05.

To have an assessment of pure error and model fitting error, some of the experimental trials are replicated. The adequacy of the models is also investigated by the examination of residuals. The residuals, which are the difference between the respective observed responses and the predicted responses, are examined using the normal probability plots of the residuals and the plots of the residuals versus the predicted response. If the model is adequate, the points on the normal probability plots of the residuals should form a straight line. On the other hand, the plots of the residuals versus the predicted response should be structure less, i.e., they should contain no obvious pattern.

Response surface methods usually involve the following steps:

- The experimenter needs to move from the present operating conditions to the vicinity of the operating conditions where the response is optimum. This is done using the *method of steepest ascent* in the case of maximizing the response. The same method can be used to minimize the response and is then referred to as the *method of steepest descent.*
- Once in the vicinity of the optimum response the experimenter needs to fit a more elaborate model between the response and the factors. Special experiment designs, referred to as *RSM designs*, and are used to accomplish this. The fitted model is used to arrive at the best operating conditions that result in either a maximum or minimum response.
- It is possible that a number of responses may have to be optimized at the same time. For example, an experimenter may want to maximize strength,

while keeping the number of defects to a minimum. The optimum settings for each of the responses in such cases may lead to conflicting settings for the factors. A balanced setting has to be found that gives the most appropriate values for all the responses. **Desirability functions** are useful in these cases.

Uses of RSM

- To determine the factor levels that will simultaneously satisfy a set of desired specifications.
- To determine the optimum combination of factors that yields a desired response and describes the response near the optimum.
- To determine how a specific response is affected by changes in the level of the factors over the specified levels of interest

CHAPTER 3

METHODOLOGY

3.1 Introduction

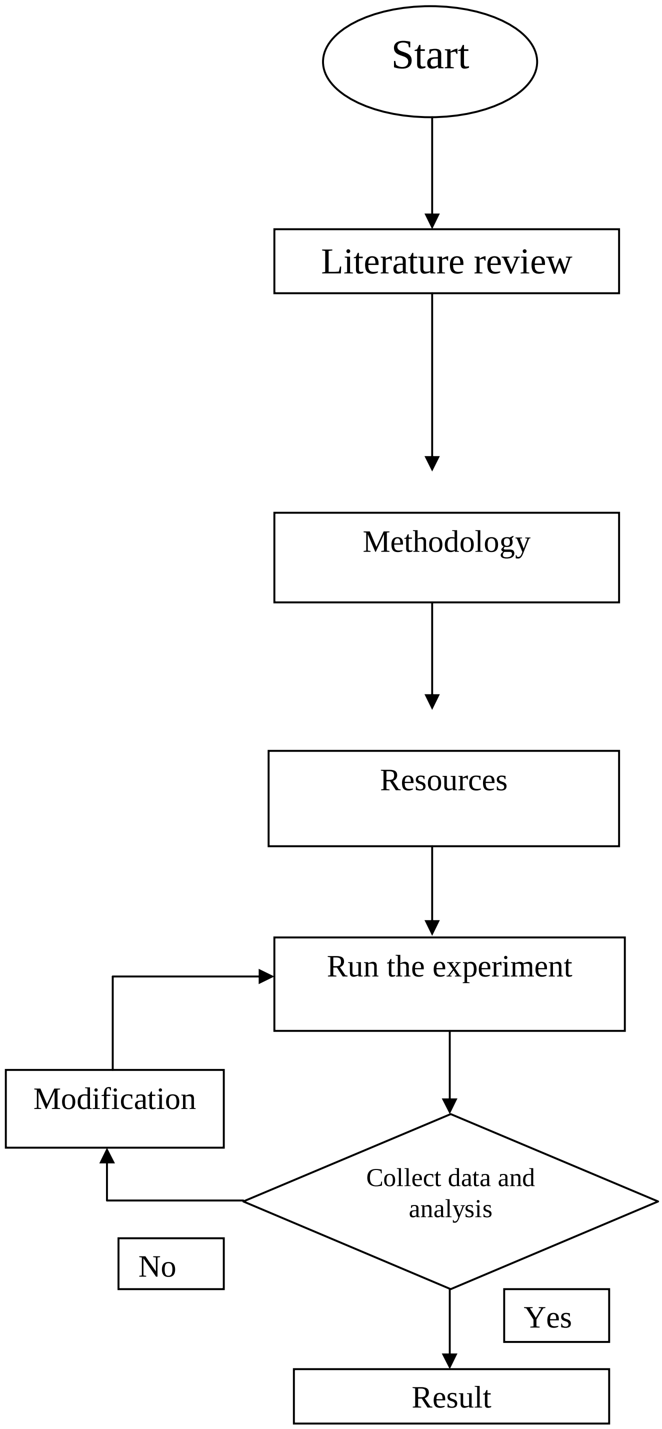
In this chapter, we will explain about the concept and method that been use for this project. From this chapter, we will provide guidelines for generated the result of the project. So, the methodology is the most important element to be considered in order to development of the study running smooth. In that case, the overall of the methodology is the illustrated in the flow chart. The flow chart will show the produced and method that b taken for the experiment.

The design of the methodology is the series step which show the sequence for the experiment to yield an improve understanding of the product or performance.

3.2 Flowchart

The flowchart of the project will described about the element of the work that been done in the project. A good methodology is the described of the research base of the guidelines in the managing the study.

The flowchart that described the elements of the work is show in figure 3.1.



- Show the journal or information about the parameter, cutting process, machine and material that been use.
- Show the method, flowchart, material, and number of factor for the experiment.
- Find the prepare material, cutting tools and software.
- Collect the data from experiment and do analyze of that.
- Generate the result

Figure 3.1: Flowchart

3.1. THE PROCESS STEP DESCRIPTION

The step of the tool life, torque, power, and force of the cutting tools analyze will be based on the literature review. The major step to complete the project will be made based on the step to complete the project will be made based on the effective design of the experiment.

Step 1: Problem Statement.

To implement the experiment in the order to predict the analyze of the cutting force, power, tool life and torque. The implement is based on the CNC Milling machine parameter.

Step 2: Objective of the experiment.

To make the comparison about the cutting force, power, tool life and torque in the CNC Milling process in AISI P20 tool steel.

Step 3: Quality Characteristic and Measurement System.

This experiment will be run at CNC Milling Machine and the measurement will be taken in the Dynometer and the analyze will be make in MINITAB and comparison will be make.

Step 4: The factors that influences the Quality of the Product.

The machining parameter that investigated is:

1. Cutting Speed:

   The speed of the cutter moving on the product surface.
2. Feed Rate:

   The rate of the cutting tool that cut the part in the line at certain feed.
3. Axial Depth:

   The depth of the cutting tool cut of the product in the operation.

4. Radial Depth:

The depth of the cutting tool cut of the product in the operation

The flowchart for the experiment which is the flow of process show in Figure 3.2 and cause effect in the milling process show in Figure 3.3.

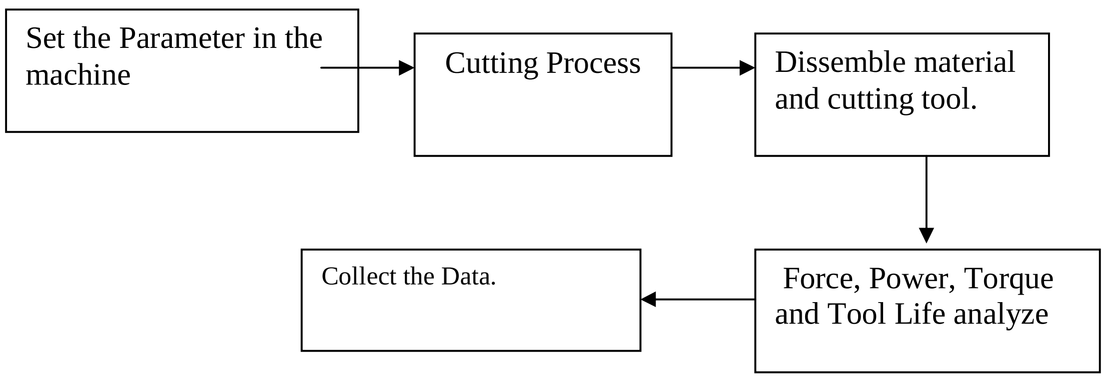


Figure 3.2: the flowchart of the experiment process.

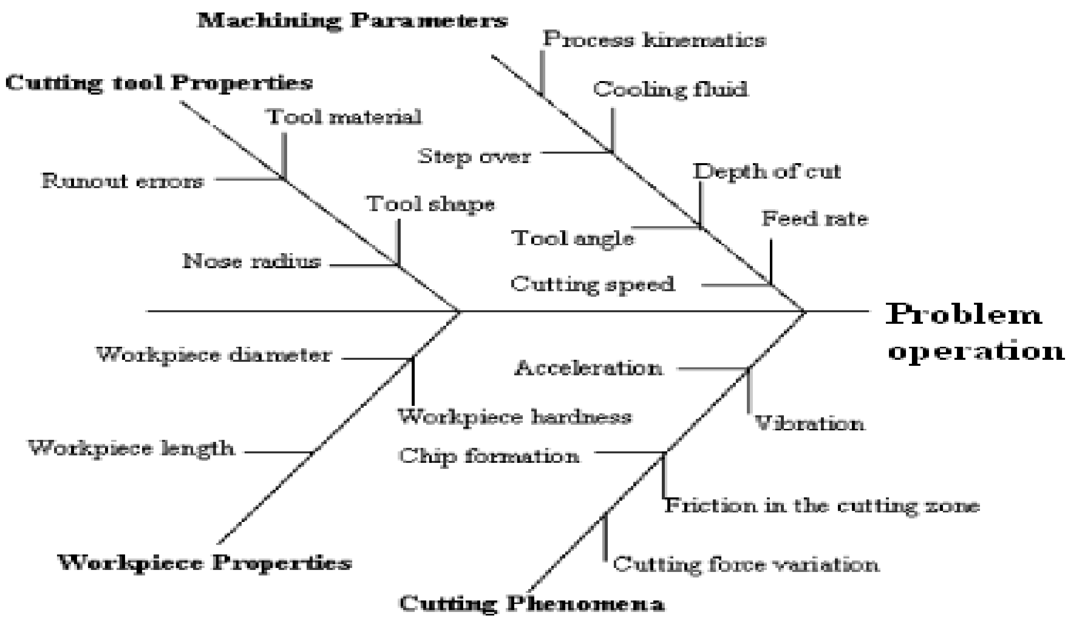


Figure 3.3: Cause effect diagram of the milling process.

Step 6: use software and assign the parameter.

In this step, we need to use the Mintab software and assign the parameter information. Then get the full parameter table.

Table 3.2: the experiment design of milling process

Std Order	Run Order	Pt Type	Blocks	cutting speed (m/min)	feed rate (mm/rev)	axial depth (mm)
14	1	0	1	140	0.15	1.5
8	2	2	1	180	0.15	2
3	3	2	1	100	0.2	1.5
12	4	2	1	140	0.2	2
9	5	2	1	140	0.1	1
1	6	2	1	100	0.1	1.5
10	7	2	1	140	0.2	1
15	8	0	1	140	0.15	1.5
13	9	0	1	140	0.15	1.5
6	10	2	1	180	0.15	1
2	11	2	1	180	0.1	1.5
5	12	2	1	100	0.15	1
11	13	2	1	140	0.1	2
7	14	2	1	100	0.15	2
4	15	2	1	180	0.2	1.5

Step 7: Run the experiment based on the experiment design

Run the experiment based on the parameter that gain. Then, collect the data from the experiment by using Dynosoftware. If the data are not suitable, repeated the step again until u gets the result as u expected.

Step 7: Run the experiment based on the experiment design

Run the experiment based on the parameter that gain. Then, collect the data from the experiment by using Dynosoftware. If the data are not suitable, repeated the step again until u gets the result as u expected.

Step 8: analyze the result from the experiment.

There are several things that need to be analyzed based on the objective of the project. The main factor that needs to discover is:

1. **The main effect**

The main effect is very important to determine the optimum condition of the project because the optimum condition will found when the result of main effect been determine. In this case study, the machining parameter and the level of use is the main effect to produce the optimum results. Other than that, the main effect will play a important role in influencing the result factors.

3.4 Specimen Preparation

The workpiece material that been use for the project is AISI P20 Steel tool in the rectangle bar shape. The dimension of the bar is 10cm of length, 17cm of height and the 2.45cm of thickness. The cutting tool that is coated by chromium-molybdenum alloyed. It considered as high speed steel that used to build mould for plastic injection and zinc die-casting, extrusion dies, blow moulds, forming tools and other structural components.

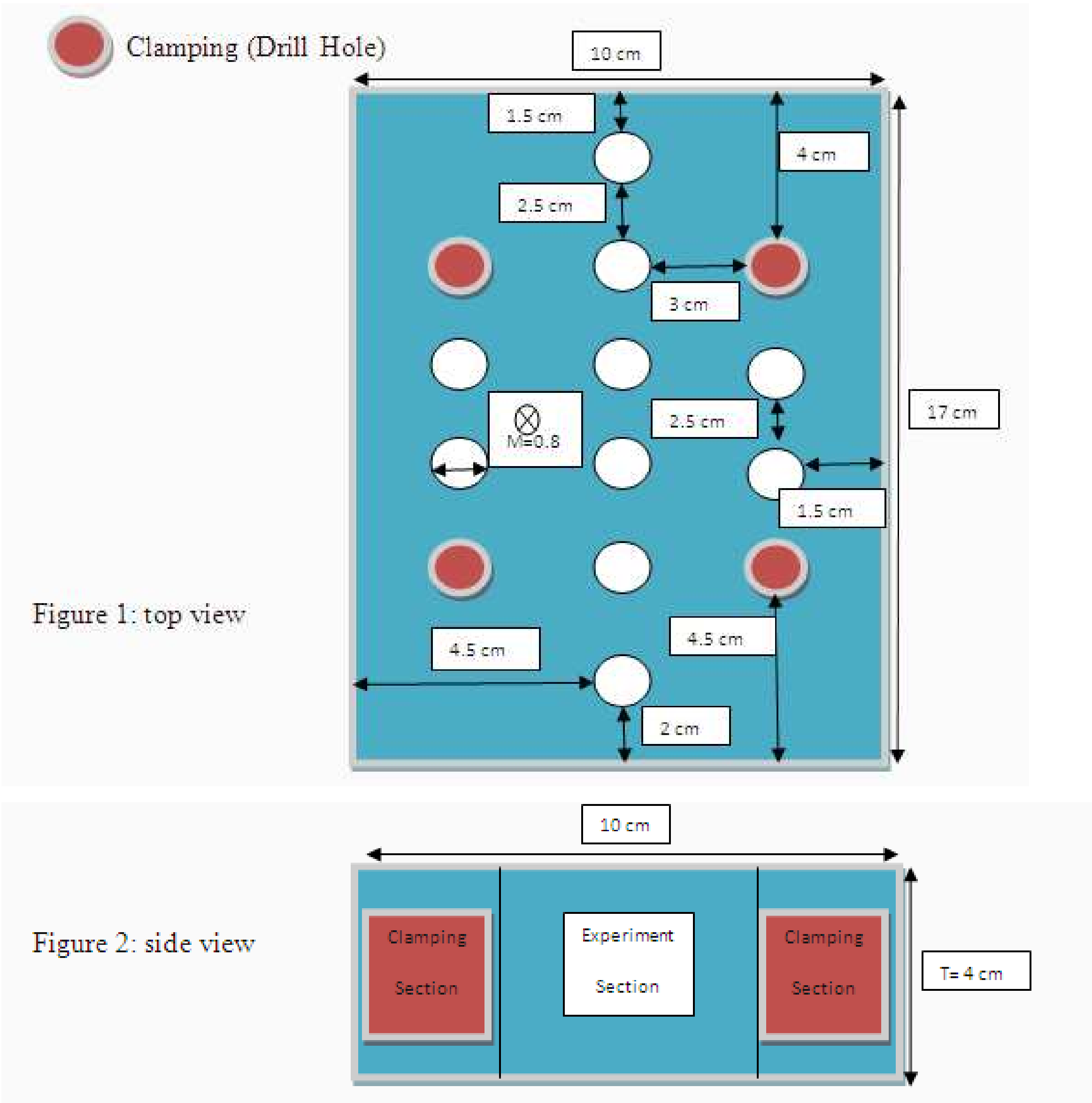


Figure 3.4: Diagram of the workpiece

3.5 CNC Milling Machine

The machine used in study is one of FKM machine. It is a Computer Controlled Machine (CNC) that operates without human help to turn the dials. The machine use to remove the surface of metal by milling process. The model of the machine that use for this project is HAAS VF-6 model.

Figure 3.5: CNC Milling Machine.

CHAPTER 4

RESULT AND ANALYSIS

4.1. INTRODUCTION

In this chapter, the experiment result will be discussed the analysis that done about the development of the cutting tools of CNC Milling Machine by using Aluminum Alloy AISI 6061. The cutting tools that been analysis in this result is cutting force, power, tool life and torque. These results also will discussed about the development of the first and second order model for predicting the cutting tools in end milling operation of modified AISI P20 tool steel.

The cutting tools contours with respect to input parameters are presented and the predictive models analyses are performed with aid of the statistical software package MINITAB. In this study, the cutting tools that been discussed will be developed of first and second predictive models by using four type of variable.

The variable are stand by cutting speed, feed rate, axial depth and radial depth. In order to develop the first and second order of cutting tools models, a design consisting 27 experiment was been conducted. This experiment conducted to measure the cutting force, power, tool life and torque and the cutting speed from the test that been done. After the experiment, the cutting tools values been calculated by the equation that been generated using MINITAB, Box and Behnken.

4.2. Model for Cutting Force, Power, Torque, and Tool Life.

By using the response surface method as the reference, we can investigate the relationship between the four conditions and response that can be related by the linear equation:

$$\ln F = A \ln V_c + B \ln f + C \ln a_a + D \ln a_r + E \qquad \text{(Eq 4.1)}$$

Where, F will be representing the cutting tools (response), A, B, C, D and E is constants. While the V_c is the cutting speed (m/min), f will be the feed rate (mm/rev), a_a is the axial depth (mm) and a_r will be represented the radial depth (mm). By using this equation, the equation 4.2 will be generated by the value of cutting tools. The equation is:

$$y = \beta 0 x_0 + \beta 1 x_1 + \beta 2 x_2 + \beta 3 x_3 + \beta 4 x_4 + \varepsilon \text{ or}$$
$$\hat{y} = y - \varepsilon = \beta 0 x_0 + \beta 1 x_1 + \beta 2 x_2 + \beta 3 x_3 + \beta 4 x_4 \qquad \text{(Eq 4.2)}$$

where y will be representing the cutting tools experiment value and the $\hat{y}$ will be representing the predicted value. For the x_0, x_1, x_2, x_3, x_4 and ε will be dummy variable ($x0$ = 1), stand for cutting speed, feed rate, axial depth of cut, radial depth of the cut and experimental error, respectively β_0, β_1, β_2, β_3 and β_4 are the model parameters.

In most of the cases, the response surface variables demonstrate some curvature in most ranges of the cutting parameter. Other than that, it would also be useful to consider the second

order of study. The second model of study is made to understand the second order affect of each factor separately and the way interaction amongst these factors combined. So that, equation that gain from this model is:

$$\hat{y}'' = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_{11} x_2^1 + \beta_{22} x_2^2 + \beta_{33} x_2^3 + \beta_{44} x_2^4 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{14} x_1 x_4 + \beta_{23} x_2 x_3 + \beta_{24} x_2 x_4 + \beta_{34} x_3 x_4 \quad \text{(Eq 4.3)}$$

4.3 EXPERIMENTAL PROCEDURE

4.3.1 Experimental design for RSM

From the equation (3), the parameter that been appear β_0, β_1, β_2, etc, can be determined using the method of least squares from the calculation of MINITAB. In order to reduce the total number of cutting tests and allows simultaneous variation of the four independent factors, a well designed experimental procedure has to be followed. In machining research, the Box-Behnken design experimental procedure has to be followed. In machining research, the Box–Behnken design has found a broad application compared to other experiment designs used for RSM. Based on the combination of the factorial with the incomplete block designs will be design the Box–Behnken. It does not require a large number of tests as it considers only three levels (−1, 0, 1) of each independent parameter.

Normally, the Box-Behnken is used for the non-sequential experimentation at the time the test is conducted at once. . It allows an efficient evaluation of the parameters in the first and second order models. Using Minitab the cutting conditions of 27 experiments are generated and the experiments are conducted randomly to minimize the chance errors. In order to calculate the experimental error, the 27 experiments consider five times repeating of the central point of the cutting conditions. After a series of preliminary trial tests had been conducted and based on the recommendations given by the tool and work piece manufacturers, the cutting conditions of the main experiments were established. Table 4.1 shows the Conditions of cutting experiments according to Box–Behnken design.

Table 4.1: Condition of cutting experiments according to the Box-Behken design

Number of experiment	Cutting speed (m/s)	Feedrate (mm/rev)	Axial depth (mm)	Radial depth (mm)
2	140	0.15	1	2
7	140	0.2	1	3.5
11	100	0.15	1	3.5
14	180	0.15	1	3.5
19	140	0.1	1	3.5
21	140	0.15	1	5
4	100	0.15	1.5	2
5	140	0.1	1.5	2
6	100	0.2	1.5	3.5
9	140	0.15	1.5	3.5
10	180	0.2	1.5	3.5
12	180	0.15	1.5	2
15	140	0.2	1.5	2
22	140	0.2	1.5	5
24	140	0.15	1.5	3.5
25	180	0.1	1.5	3.5
26	100	0.1	1.5	3.5
8	100	0.15	1.5	5
17	140	0.1	1.5	5
18	180	0.15	1.5	5
22	140	0.15	1.5	3.5
1	140	0.15	2	5
3	140	0.2	2	3.5
13	140	0.1	2	3.5
16	140	0.15	2	2
20	100	0.15	2	3.5
27	180	0.15	2	3.5

4.3.2 Test Work piece, Tool Material and Experimental Setup

The current study is mainly focus on the comparison of cutting tool in the end milling of modified AISI P20 tool steel that coated with carbide inserts. Normally, AISI P20 is a chromium-molybdenum alloyed steel which is considered as a high speed steel used to build moulds for plastic injection and zinc die-casting, extrusion dies, blow moulds, forming tools and other structural components. The modified form of AISI P20 is distinguished from normal P20 steel by the balanced sulfur content (0.015%) which gives the steel better machinability and more uniform hardness in all dimensions. Modified AISI

P20 possesses a tensile strength of 1044MPa at room temperature and a hardness ranging from 280 to 320 HB. The work piece used in this study was pre hardened and tempered to a minimum hardness of 300HB and was provided by ASSAB (Sweden). The approximate chemical analysis is shown in Table 4.2 below.

Table 4.2: Chemical analysis of modified AISI P20 (%)

Composition	Percentage
C	0.38
Si	0.3
Mn	1.5
Cr	1.9
Mo	0.15
S	0.015
Fe	Balance

The cutting tool used in this study is a 0◦ lead-positive end milling cutter of 31.75mm diameter. The end mill can be equipped with two square inserts whose all four edges can be used for cutting. The tool inserts were made by Kennametal and had an ISO catalogue number of SPCB120308 (KC735M). In this study, only one inserts per one experiment was mounted on the cutter. The insert had a square shape, back rake angle of 0◦, clearance angle of 11◦, and nose radius of 0.794mm and had no chip breaker. KC735M inserts are coated with a single layer of TiN. The coating is accomplished using PVD techniques to a maximum of 0.004mm thickness. The 27 experiments were performed in a random manner on HAAS CNC machining centre MX-45 VA and using a standard coolant. Each experiment was stopped after 85mm cutting length. Meanwhile, the data about cutting power component *P*y, was acquired with the aid of a piezoelectric cutting power dynamometer provided by Kistler. Each experiment was repeated three times using a new cutting edge every time to obtain very accurate readings of the cutting power. A cutting pass was conducted in such a way that a shoulder, of depth ranging from 1 to 2 mm, and width of 2 to 5 mm, was produced.

4.4 RESULT AND DISCUSSION

After conducting the first passes which is equal to the 85mm of the 27 cutting experiment, the cutting tools data of comparison will be appear in the format of Box-Behnken data.

From this data, analysis of comparison of cutting force, power, tool life and torque can be discussed. The discussion of the comparison tools will be made based on the table 4.2 that been shown:

Table 4.3: Comparison of data analysis for the cutting power, force, torque and tool life.

Run	Cutting speed(m/s)	Feed rate (mm/rev)	Axial depth (mm)	Radial depth (mm)	Exp. cutting Force (N)	Power calc (W)	Exp. Torque (Nm)	Exp. Tool life (min)
2	140	0.15	1	2	190	342.23	10	8.23
7	140	0.2	1	3.5	240	443.33	13	2.43
11	100	0.15	1	3.5	293.33	316.67	16	17
14	180	0.15	1	3.5	325	510	13	3.94
19	140	0.1	1	3.5	210	256.67	8	16.39
21	140	0.15	1	5	200	525	16	4.33

4	100	0.15	1.5	2	170	400	16	25.1
5	140	0.1	1.5	2	110	233.33	7	39.46
6	100	0.2	1.5	3.5	225	566.67	17	11.48
9	140	0.15	1.5	3.5	340	513.33	14	10.93
10	180	0.2	1.5	3.5	220	879.99	18	1.3
12	180	0.15	1.5	2	145	435	12	7.51
15	140	0.2	1.5	2	200	466.67	13	15.79
22	140	0.2	1.5	5	350	758.33	18	2.02
24 25	140 180	0.15 0.1	1.5 1.5	3.5 3.5	200 190	466.67 390	13 8	11.33 14.17
26	100	0.1	1.5	3.5	340	316.67	14	16.15
8	100	0.15	1.5	5	100	566.67	22	18.7
17	140	0.1	1.5	5	190	490	14	19.43
18	180	0.15	1.5	5	340	720	15	3.46
22	140	0.15	1.5	3.5	350	466.67	18	8.5
1	140	0.15	2	5	146.67	816.67	20	6.88
3	140	0.2	2	3.5	190	816.67	23	3.79
13	140	0.1	2	3.5	200	466.67	13	13.36

16	140	0.15	2	2	130	443.33	11	24.29
20	100	0.15	2	3.5	240	566.67	23	18.7
27	180	0.15	2	3.5	313.33	939.99	16	6.56

From the data analysis, the result that been predict is the tool life will be decrease when the cutting force, power, and torque is increasing. From the table at the run of 7, 6 and 18 shows, that the tool life will be decrease when the cutting force, power and torque is increasing. At that same time there is also some result shows that the tool life will increase when the cutting power, force and torque at run of 19, 24, and 12. This type of result can be appearing because of the changes of cutting speed, feed rate, axial depth and radial depth.

When the value of cutting speed, radial depth and feed rate is large, the result is tool life will be decrease and other cutting tools will be increasing. When the radial depth value is at maximum value and the feed rate at minimum value, the tool life, power, and torque will be increasing but the cutting speed will be decreasing. This can be seen at the run of 8 that the radial depth has achieved at maximum value and the feed rate is at the minimum value.

Other than that, at the maximum value of cutting speed, the cutting force and power will be increasing but the torque and tool life will be decreasing. This result can be show in the experiment run at 14 and 27. By this analysis, there are also result show the increasing of power and torque at maximum value of the axial depth.

4.4.1 Development of first order cutting model

Form the data analysis that been gain, the linear equation that been produced show different type of value for the four type of cutting tool in the changes of four variance.

In the result of power, the linear equation that been produced from the data analysis show that feed rate has the most significant effect of the power. After that, it will be follow by the axial depth, radial depth and cutting speed. This linear equation of the power show that power will increase when the feed rate, axial depth, radial depth increase.

$$\hat{y} = -971.420 + 2.37840x_1 + 2963.87x_2 + 276.017x_3 + 86.4506 \qquad \text{(Eq 4.4)}$$

For the cutting force, the linear equation show force will be at highest value when all condition is increase expected cutting speed. In other hand, the decrease in cutting speed will slightly cause a reduction in cutting speed. The linear equation is:

$$\hat{y} = -177.512 - 0.726x_1 + 1316.29x_2 + 118.610x_3 + 38.87 \qquad \text{(Eq 4.5)}$$

The linear equation that gain for tool life shows that the increase of cutting speed, the feed rate, radial depth and axial depth will decrease the tool life. This equation also tells that the feed rate has the most dominant effect on the tool life. After that it will follow by the cutting speed, radial depth and radial depth. The equation will:

$$\hat{y} = 60.7101 -0.146229x_1 -136.917x_2 + 3.54333x_3 -3.64222x_4 \qquad \text{(Eq 4.6)}$$

The linear equation of the torque will show that the torque value will be increasing at the moment the speed decrease and other variances will increase. The equation also predicted that torque will decrease at the maximum value of cutting speed. The linear equation that gain from the data analysis is:

$$\hat{y} = -1.56481 -0.0542x_1 +63.3333x_2 + 5.0000x_3 +2.0000x_4 \qquad \text{(Eq 4.7)}$$

4.4.2 Development of Second Order Cutting Model

The second order equation was established to describe the effect of the four cutting conditions investigated in this study on the cutting power, torque, tool life and force. The model that been obtained by using Box Behken design from the model of equation, the will be result been produced based on the normal probability plot of the Residual for the cutting. It clearly show that predicted value of increasing or decreasing of the cutting tools very close to the experimental reading.

For the power, the equation show that the power involves is affected significantly by the cutting speed, feed rate. After that, it will follow by the axial depth of cut and lastly will be the radial depth. The equation that been produced is:

$$\hat{y}'' = 2080.01 - 17.2193x_1 - 3099.72x_2 - 945.202x_3 - 113.216x_4 + 0.0357052x^2_1 - 3315.17x^2_2 + 146.298x^2_3 + 2.55148x^2_4 + 29.9988x_1x_2 + 2.24987x_1x_3 + 0.493042x_1x_4 + 1633.40x_2x_3 + 116.633x_2x_4 + 63.5233x_3x_4 \quad \text{(Eq 4.8)}$$

The cutting force will increase with the increasing of the feed rate but decrease if the cutting speed has been reduced. Other than that, the increase of the axial depth of cut will cause a reduction in the cutting force. the linear equation that been produced from this experiment is :

$$\hat{y}'' = 182.562-3.82547x_1 + 1773.99x_2 -44.0012x_3 + 11.6913x_4 + 0.0108850x^2_1 - 7016.80x^2_2 -8.66600x^2_3 -3.72200x^2_4 + 1.66625x_1x_2 -0.0833750x_1x_3 -0.02083x_1x_4 + 700.000x_2x_3+95.5533x_2x_4+27.2233x_3x_4 \quad \text{(Eq 4.9)}$$

The cutting tool life equation shows that reduction when there is increasing in cutting speed and feed rate. It can clearly see in the linear equation of this second model. Other than that this equation also shows that axial depth and radial depth are direct proportional to the cutting tool life. The equation is:

$$\hat{y}'' = 68.4198 - 0.107437x_1 - 351.300x_2 + 34.0150x_3 -14.6219x_4 + 0.000226562x_1^2 + 730.000x_2^2 -7.63500x_3^2 + 1.89056x_4^2 - 1.02500x_1x_2 + 0.0115000x_1x_3 + 0.00979167x_1x_4+43.9000x_2x_3+20.8667x_2x_4-4.50333x_3x_4 \quad \text{(Eq 4.10)}$$

For the value of torque, the value will increase when the cutting speed and feed rate at high value. From this counter plot equation of second model, the result clearly predicted that torque will increase at the increase of the four cutting variance. The equation of the cutting tools is:

$$\hat{y}'' = 17.0116 -0.314583x_1 + 79.1667x_2 -4.00000x_3 + 5.06481x_4 + 0.000885417x^2{}_1 – 633.333x^2{}_2 + 1.66667x^2{}_3 -0.259259x^2{}_4 + 0.875000x_1x_2 -0.0500000x_1x_3- 0.0125000x_1x_4+50.0000x_2x_3-6.66667x_2x_4+1.0000x^3x_4 \quad \text{(Eq 4.11)}$$

From this second order of cutting model, the result show much accurate for the increasing of cutting force, power and torque and decreasing of cutting tool life at the same time. Other than that, tool life is so accurate increase at the minimum value of cutting speed and feed rate. But other cutting tools will increase at the maximum value of the cutting speed and feed rate.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

First and second orders of Mathematic Model were developed to predict the cutting parameter for end-milling of P20 tool steel. The model developed was used to calculate the cutting force, power, tool life and torque based on Response Surface Methodology (RSM).

In general, the result that obtained from the Mathematical Model is in good agreement with that obtained from the experiment data's. It found that the feed rate, axial depth, radial depth and cutting speed have played a major role to comparison of the cutting tools. From the result that been produced, the tool life shows decreasing at the moment the cutting force, power, and torque are increasing. This shows that, tool life always be difference reaction with the other cutting tools (power, force and torque).

In the second order cutting model has proven that the tool life will be strong interaction to the feed rate and the cutting force will be strong interaction to cutting speed. This can see when the feed rate decrease, the tool life value also getting large. Same goes to the cutting speed that get increase at the time the cutting force get increase. For the cutting power, the cutting speed and the feed rate are straight significantly to the cutting power. Form the counter plot of second order, it clearly shown the increasing of the power when the speed and feed rate increase. For torque, the increase of feed rate and decrease of cutting speed will get a large value for torque.

This project will help to make improvement in the cutting tools in future based on the input parameter such like cutting speed, feed rate, axial depth and radial depth.

5.2 RECOMMENDATIONS

Further research should always consider the need for flexibility for variation of parameters in a machining operation, which will make this type of research more adaptable to industry. Comparison which method gives more accurate mathematical model between neural networks (NN), Taguchi method and response surface method (RSM) in term of cutting power result in future study. It may also include comparisons of error in prediction of cutting power by neural network (NN), Taguchi method and response surface method (RSM) and which one has great potential to be employed in predicting optimum cutting parameter without needing extensive iterative cutting trials. The cutting tool used in this study is a 0° lead-positive end milling cutter of 31.75mm diameter. The effects of varying the number of flutes or changing the cutter materials are worth further exploration. Another study that can be further performed on milling process could possibly be a work that studies the affects of different materials on the same types of cutters. Being able to use different materials in milling can be informative about the behaviors of the cutters and differences in ideal cutting parameters across different materials. Aluminum and composite materials can be candidates of material for the next study. Because of their different structures cutting parameters might have different effects on cutting power. The geometries of the end mill will be included as planned factors in future study so as to design the cutter and to decide the optimum cutting conditions under the constraints of the maximum removal rate and the minimum surface roughness.

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APPENDIX A

GANTT CHART OF FYP 1

Task	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14	W 15
Meeting with Supervisor	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Project Planning		■	■												
Defining the Project Information		■	■	■											
Literature Review					■	■	■	■	■	■	■	■	■	■	
Methodology Preparation								■	■	■	■	■			
Draft Preparation											■	■	■		
Submit Project Draft and Report.													■	■	
Presentation Preparation												■	■	■	

GANTT CHART OF FYP 2

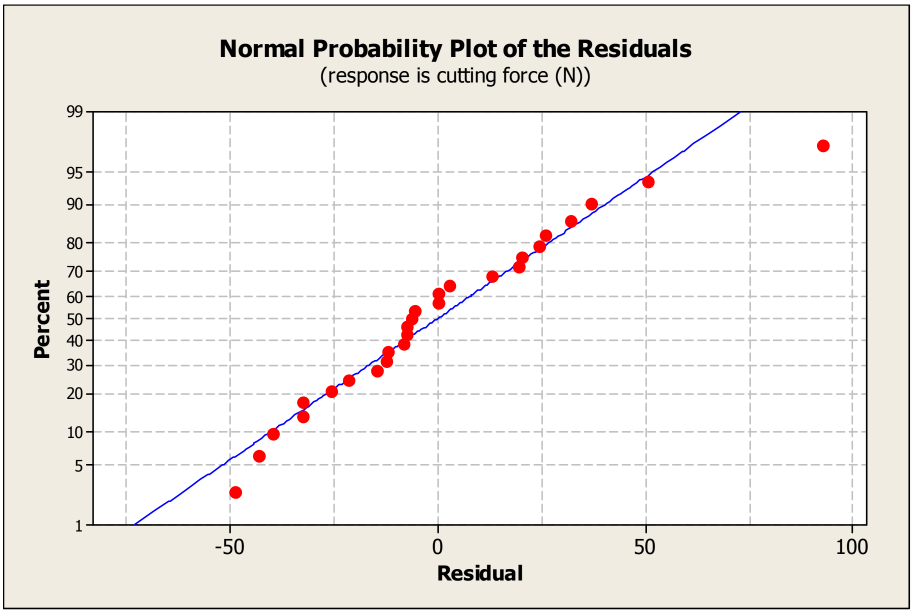
Task	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14	W 15
Literature Review	■	■	■	■	■	■	■	■	■	■	■	■			
Prepare the Samples For Testing	■	■	■	■	■										
Run the Experiment				■	■	■									
Collect the Data and Perform the Analysis							■	■	■	■	■				
Make Result												■	■		
Complete the Full Report												■	■	■	
Presentation 2 Preparation													■	■	
Submit the Final Report													■	■	■

APPENDIX B

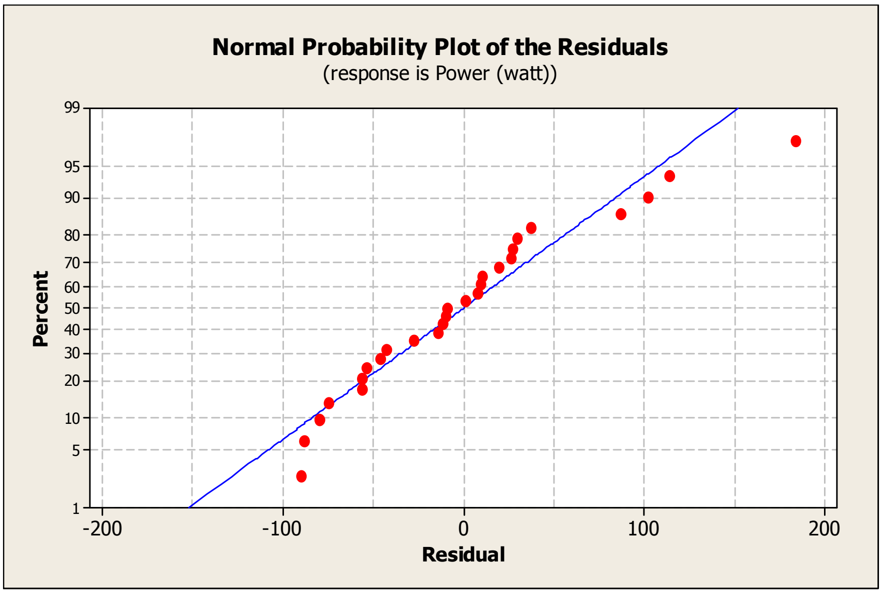
StdOrder	RunOrder	PtType	Blocks	cutting speed (m/min)	feed rate (mm/rev)	axial depth (mm)
14	1	0	1	140	0.15	1.5
8	2	2	1	180	0.15	2
3	3	2	1	100	0.2	1.5
12	4	2	1	140	0.2	2
9	5	2	1	140	0.1	1
1	6	2	1	100	0.1	1.5
10	7	2	1	140	0.2	1
15	8	0	1	140	0.15	1.5
13	9	0	1	140	0.15	1.5
6	10	2	1	180	0.15	1
2	11	2	1	180	0.1	1.5
5	12	2	1	100	0.15	1
11	13	2	1	140	0.1	2
7	14	2	1	100	0.15	2
4	15	2	1	180	0.2	1.5

Figure A: Experiment data collection table

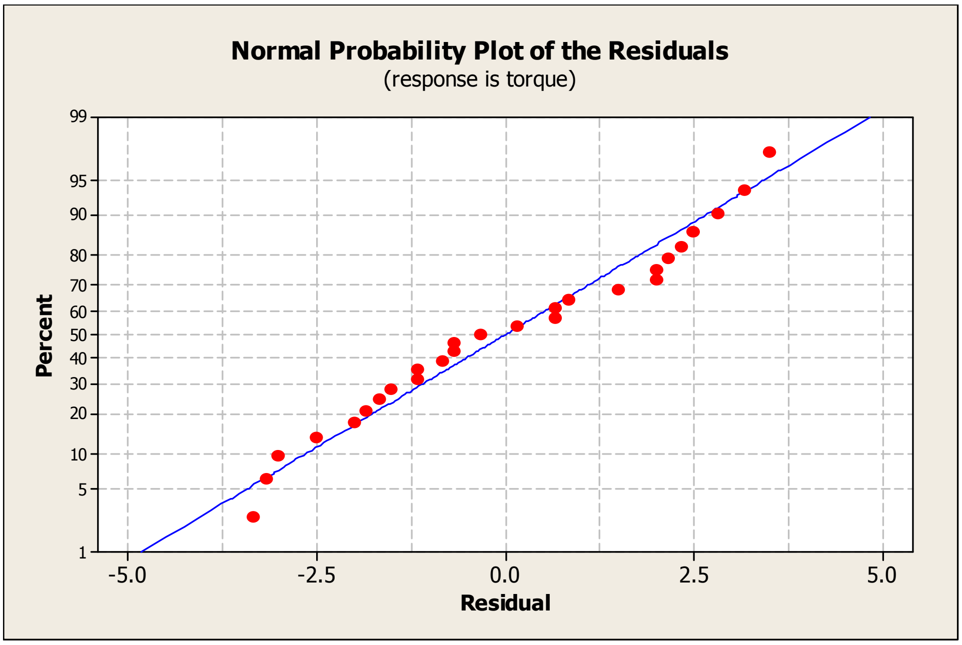
APPENDIX C



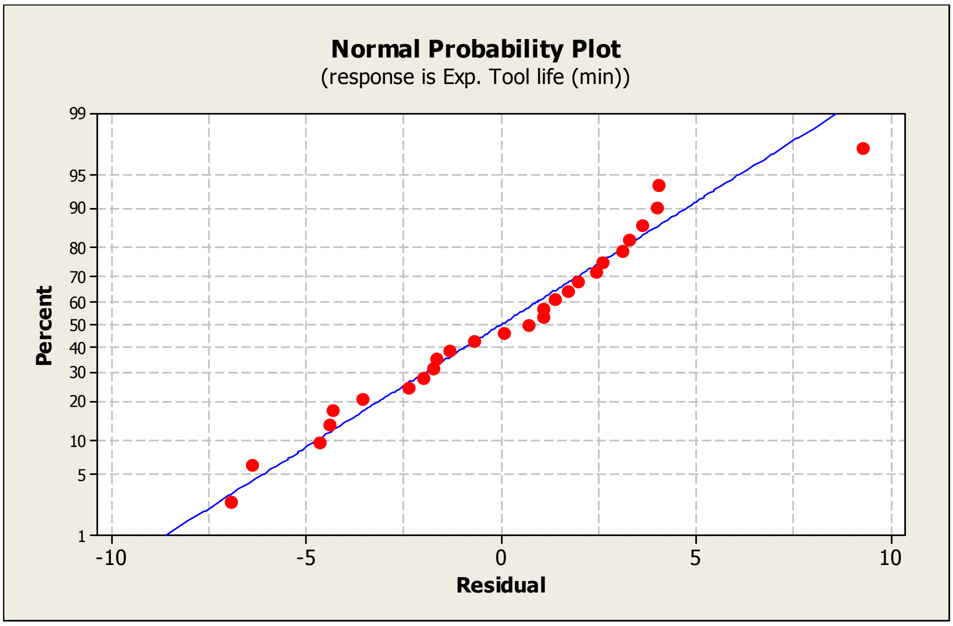
Probability plot of cutting force



Probability plot of cutting power

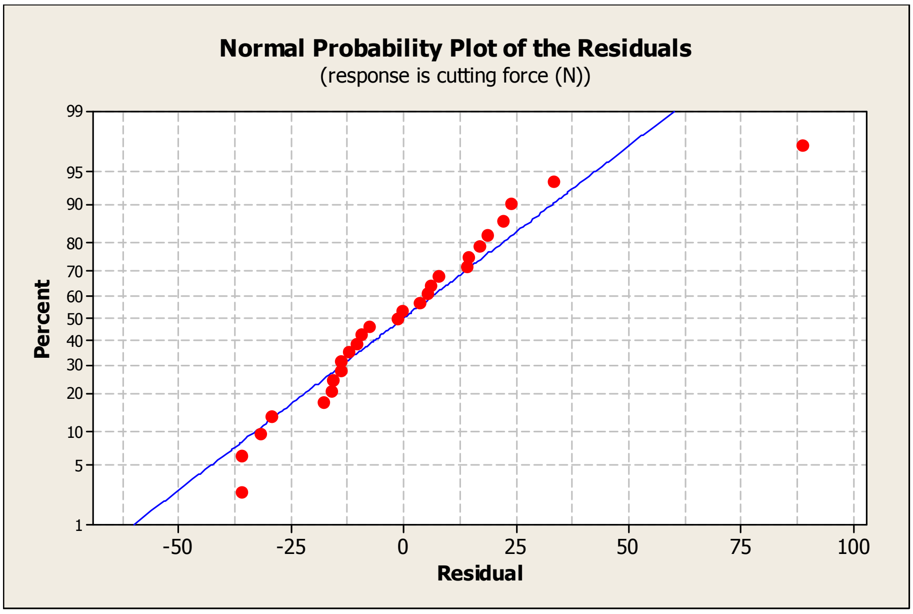


Probability plot of cutting torque

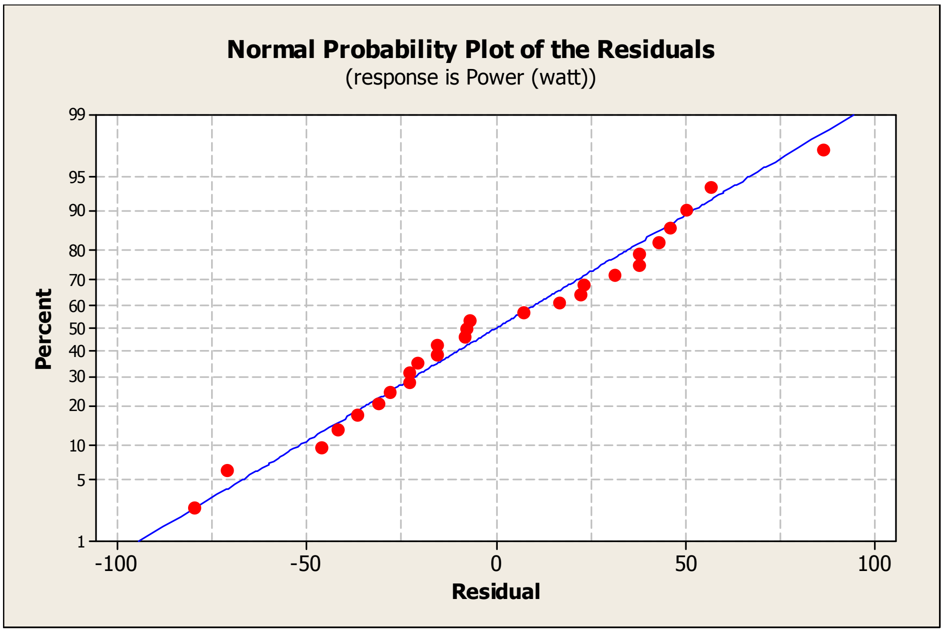


Probability plot of cutting tool life

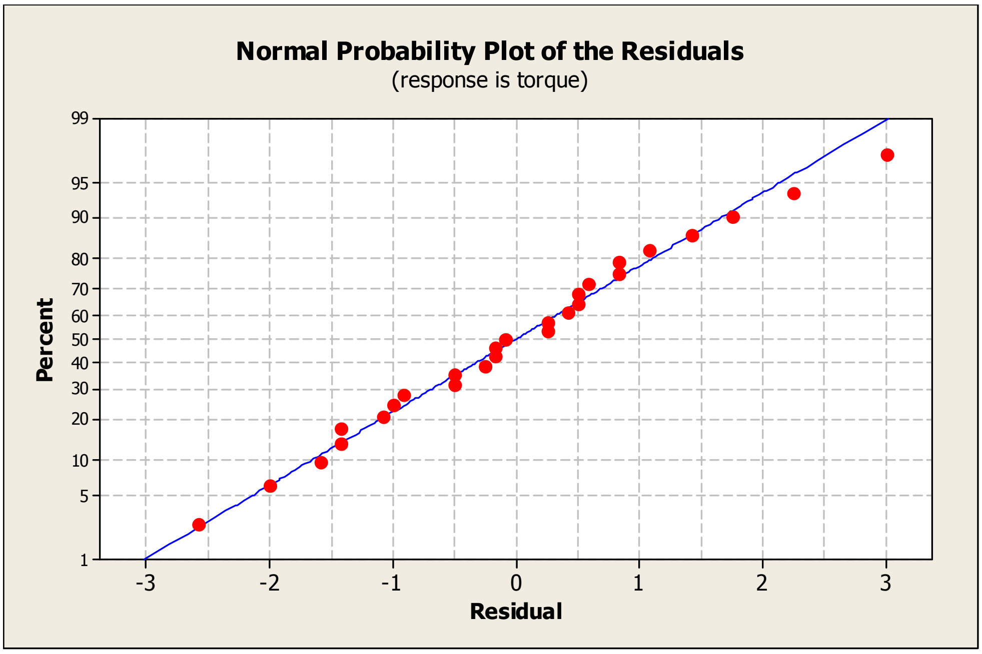
Probability plot of cutting tools of First development



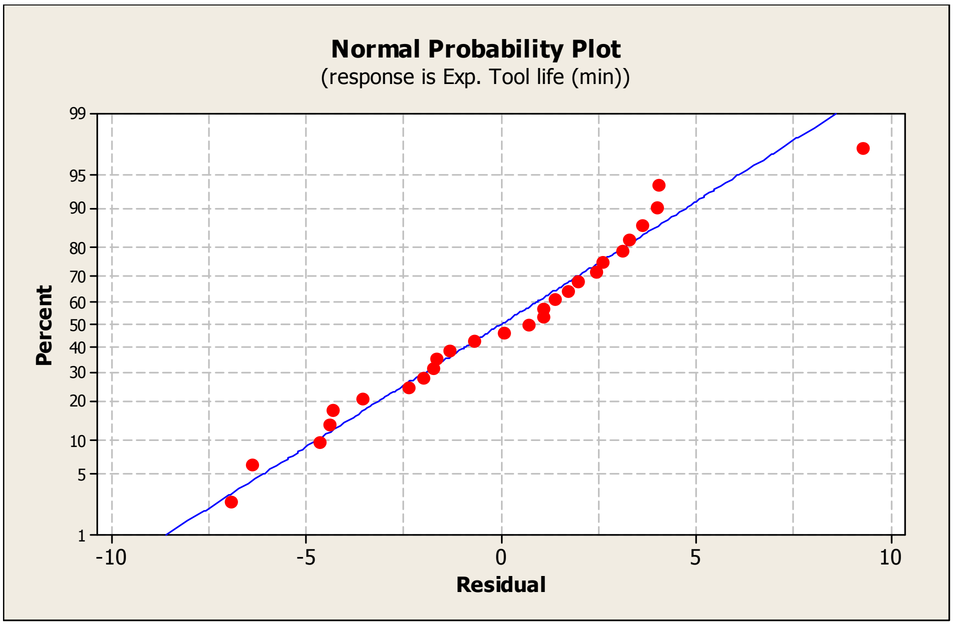
Probability plot of cutting force



Probability plot of cutting power



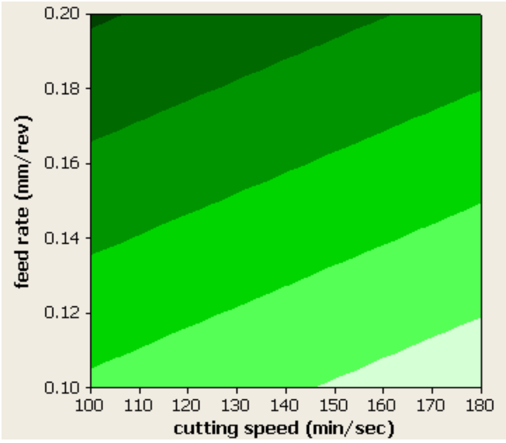
Probability plot of cutting torque



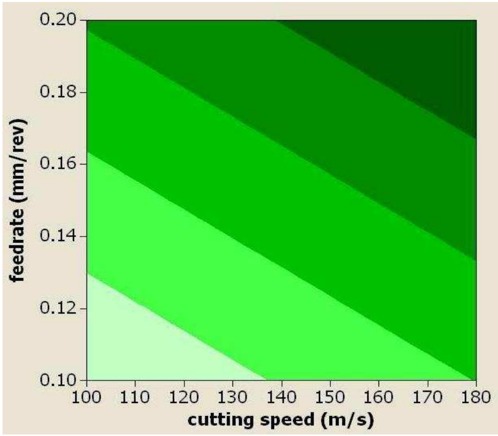
Probability plot of cutting tool life

Probability plot of cutting tools of Second development

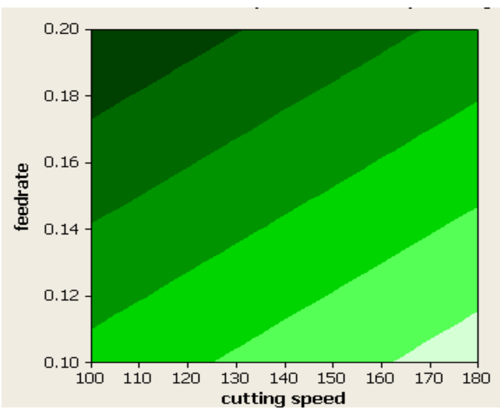
APPENDIX D



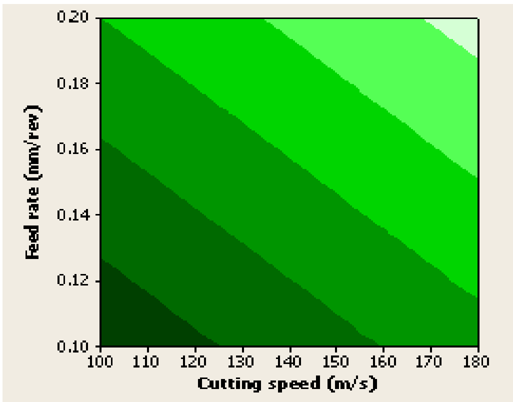
Cutting Force



Cutting Power



Cutting Torque



Cutting Tool Life